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DRAFT COMPREHENSIVE ENVIRONMENTAL EVALUATION (CEE) FOR **ANDRILL**
McMurdo Sound Portfolio

Madrid, 9/20 de junio 2003

ANDRILL - The McMurdo Sound Portfolio

An international research effort with the participation of Germany, Italy, New Zealand, the United Kingdom and the United States of America.

DRAFT COMPREHENSIVE ENVIRONMENTAL EVALUATION (CEE) FOR

ANDRILL

McMurdo Sound Portfolio

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF IMAGES

ACRONYMS

ATCM	Antarctic Treaty Consultative Meeting
ASC	ANDRILL Steering Committee
BrAE	British Antarctic Expedition
CDC	Colliding Detonation drill collar Cutter
CEE	Comprehensive Environmental Evaluation
CEP	Committee for Environmental Protection
CIROS	Cenozoic Investigations in the Western Ross Sea
COMNAP	Council of Managers of National Antarctic Programs
CRP	Cape Roberts Project
DSDP	Deep Sea Drilling Project
DVDP	Dry Valley Drilling Project
EARP	Environmental Assessment and Review Panel
EIA	Environmental Impact Assessment
EPICA	European Project for Ice Coring in Antarctica
HWD	Hot Water Drill
IGNS	Institute of Geological and Nuclear Sciences
IGY	International Geophysical Year
MCM	McMurdo Station
MIS	McMurdo Ice Shelf
MSV	Mackay Sea Valley
MRIS	McMurdo/Ross Ice Shelf
MSSTS	McMurdo Sound Drilling Sediment and Tectonic Studies
NH	New Harbour
ODP	Ocean Drilling Project
RIS	Ross Ice Shelf
ROV	Remotely Operated Vehicle
SB	Scott Base
SLIP	Science and logistics implementation plan.
SMS	Southern McMurdo Ice Shelf
TAM	Trans Antarctic Mountains
UNL	University of Nebraska Lincoln
VLB	Victoria Land Basin
VSP	Vertical Seismic Profiling
VUW	Victoria University of Wellington
WB	Windless Bight

1. NON-TECHNICAL SUMMARY

ANDRILL - McMurdo Sound Portfolio

This draft Comprehensive Environmental Evaluation (CEE) documents the environmental impact assessment of a proposed Antarctic scientific stratigraphic drilling programme, ANDRILL - McMurdo Sound Portfolio. This Draft CEE will be distributed to the Antarctic Treaty Consultative Parties and other relevant agencies and comments made will be incorporated into the Final CEE.

The ANDRILL proposal is an evolution of previous drilling projects carried out in the McMurdo Sound region over the past 30 years. It is a multinational initiative to investigate Antarctica's role in Cenozoic to Recent (65 million years ago to the present) global environmental change, and the implications for future change, through stratigraphic drilling of Antarctica's ice marginal sedimentary basins.

Description of the proposed activities

Four locations are currently being surveyed and evaluated as potential drilling sites: New Harbour, Mackay Sea Valley/Granite Harbour, McMurdo Ice Shelf and Southern McMurdo Ice Shelf. Drilling will take place on sea ice and ice shelf. It is proposed that a specially modified multipurpose drill rig capable of drilling from sea ice and ice shelf platforms in water depths of up to 1000 m and with penetration of up to 1500 m below the seafloor will be developed to achieve the scientific objectives of the project. The scientific targets in the McMurdo portfolio comprise high-quality sedimentary records held within the Victoria Land Basin that range in age from 45 million years to present. The four individual locations have been selected because they are expected to provide direct sedimentary windows into past times of major changes in Antarctic ice cover – e.g. the arrival of Ross Sea sea ice, Ross / McMurdo ice shelves and the East Antarctic Ice Sheet. These past changes provide important analogues against which future changes in response to global warming can be properly modelled and evaluated. Geophysical surveys of potential drill sites began in the austral summer of 2001 and will continue to 2003. Drilling is planned to commence in the 2004/05 austral summer season and will progress through to the 2008 / 09 season. One to two holes will be drilled per season depending on the water depth and depth of sediment core to be extracted.

Description of the support and drill camps

A camp catering for up to 48 personnel will support drilling activities. The camps will be mobilised to the various drilling areas and will be based on the fast ice or the ice shelf. The support camp will consist of approximately 31 modified ISO containers and the drill camp will consist of approximately 19 containers.

The camp will be set up and demobilised on an annual basis. It will be mobilised to the different drilling targets at the beginning of each drill season. This proposal is a logical extension of past drilling projects, which have established that fast sea ice is a suitable surface for transport of equipment and drilling. Once drilling has been completed at New Harbour and Southern McMurdo Ice Shelf the camp will be demobilised and returned to Scott Base for storage. Following the McMurdo Ice Shelf drilling, the camp will either be stored at McMurdo Ice Shelf or returned to Scott Base. The camp will be stored at Cape Roberts following drilling in the Mackay Sea Valley/Granite Harbour.

Environmental Assessment

The environmental impact of this project would most likely be focused on the immediate area of the various drill site camps and the seafloor above the drill holes. Key issues and impacts considered in this Draft CEE include the direct impacts of drilling and support operations such as fuel or other toxic substance spills, pressure control issues, loss of equipment through the sea ice, use of explosives, ground disturbance by vehicles and foot traffic, adverse effects on the local wildlife and on marine ecosystems, effects of hot water drilling, and noise pollution. Indirect and cumulative impacts have also been considered. This Draft

CEE has also addressed monitoring requirements and the clean up and restoration (if required) of each drill site.

Impact Mitigation and Monitoring

Careful planning and operating procedures, including monitoring will be put in place to minimise any impacts at the various drill sites and surrounding areas. Storage and handling of equipment and supplies, especially fuel, and waste management also need to be carried out in ways which minimise impacts. Careful selection of drill sites, camp sites, planning for extreme weather and ice conditions, and use of appropriate best practice pressure control and monitoring systems have all been built into this proposal from the early planning stages. The effects of potential natural hazards such as strong winds, ice movement, and subsea hazards can be mitigated or avoided by such an approach.

A three-year collaborative programme of detailed geophysical surveys (seismic, gravity and magnetic) of prospective drill sites started in the 2001/02 season and will continue through to the 2003/04 season. No potentially hazardous geologic structures have been identified to date. Other subsea hazards, which might lead to a loss of control during drilling operations are not likely to cause problems. This planning, including the operational monitoring, renders the risk of major impacts, such as might be caused by accidental release of harmful or contaminating sedimentary fluids, very low or virtually non-existent.

Information gaps have been identified in this Draft CEE. It is expected that many of these gaps will be filled in the period between circulation of the Draft CEE and production of the Final CEE before the project commences in 2004/05. In particular, fieldwork planned for the 2002/03 and the 2003/04 seasons will obtain data to fill some of these gaps. It is expected that additional knowledge and experience will be gained with each new drill season, and new technology may be developed over the long lifespan of this project to improve both operational potential and environmental performance.

Subsequently, any changes to the Final CEE will go through the New Zealand environmental impact assessment process and documentation produced according to the level of impact of any changes. All changes to the Final CEE will be notified in accordance with Resolution XXI-2 (1997).

Conclusion

Overall this Draft CEE predicts that probable environmental effects of the proposed activity will be minor and short term, and that the more major impacts which are possible can be avoided or mitigated. The level of impact predicted is considered acceptable given the significant scientific advantages of drilling the ANDRILL McMurdo Sound Portfolio.

2. INTRODUCTION

2.1 What is ANDRILL?

ANDRILL is a multinational initiative to investigate Antarctica's role in Cenozoic-Recent (65 million years ago to the present) global environmental change through the recovery of stratigraphic records from around the Antarctic margin. The Antarctic cryosphere (ice sheets, ice shelves, and sea ice) is a complex system which plays a critical role in Earth's past, present and future climate, yet it is currently poorly understood. The ANDRILL project was initially conceived and promoted by scientists who led the successful Cape Roberts Project (CRP) and other interested parties. Following completion of the operational phase of the CRP in January 2000, and driven by an appreciation that critical questions regarding the behaviours of Antarctic ice cover history could only be fully addressed through drilling a series of targeted sites, one page proposals were solicited and submitted to the interim ANDRILL Planning Committee, and considered at a meeting in Brisbane, April 2000.

The result is ANDRILL McMurdo Sound Portfolio, an 8 to 9 year plan spanning from 2001 to 2010 that is focused on survey, geophysical and drilling investigations of the McMurdo Sound region of the Ross Sea (Figure 1). The plan involves a four to five year drilling programme with up to 8 individual holes being drilled at four different locations.

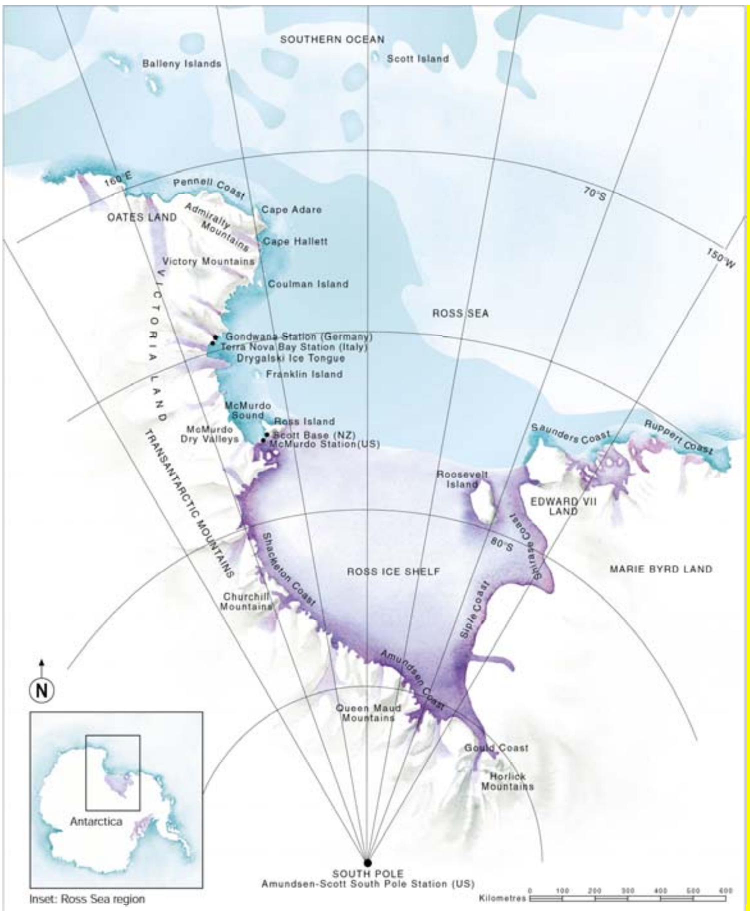

Figure 1 Map of Ross Sea region with inset of Antarctica (Waterhouse 2001)**.**

The drilling areas are:

- New Harbour (NH)
- McMurdo Ice Shelf (MIS)
- Southern McMurdo Ice Shelf / Black Island and Brown Peninsula (SMIS)
- Mackay Sea Valley / Granite Harbour (MSV)

The ANDRILL McMurdo Sound Portfolio is set up using a three-phase approach involving geophysical surveys, stratigraphic drilling and climate and glacial modelling. The phases of data collection and analysis are planned as follows:

1. Phase I - Three seasons of geophysical surveys (2001-2004) to document basin extent, architecture and to correlate target drilling areas to known drillcores. A three year geophysical survey program including gravity and magnetic surveys and seismic acquisition from the sea ice and ice shelf is already underway through collaborative efforts of all ANDRILL member nations. An important goal of this phase is to select the most suitable sites for drilling and to assess any potential drilling hazards (e.g. gas accumulations or fault planes). Additionally, a programme of oceanographic measurements and seafloor sediment sampling is underway, which will provide critical drill string and sea riser design constraints.
2. Phase II - Four seasons of drilling (2004-2009) in different locations in McMurdo Sound (Figure 10) to recover target strata to address key objectives and questions - different targets overlap several objectives. Geological targets in these four areas focus on several key time intervals that have not yet been recovered from the Antarctic region.
3. Phase III - Includes four years of data analysis and integration into glaciological, climate and oceanographic models (2006-2010) to determine global links and the role of Antarctic cryosphere in global environmental change.

This Draft CEE covers activities associated directly with the drilling programme (Phase II, 2004-2009). The geophysical surveys are being addressed through a separate Environmental Impact Assessment (EIA) process.

The management structure for ANDRILL is set out in Appendix I.

2.2 The CEE process

2.2.1 What is a CEE and why is it needed?

This Draft CEE follows the requirements in Annex I, Article 3 of the Protocol on Environmental Protection to the Antarctic Treaty. Annex I provides for different impact categories (less than, equal to and more than minor or transitory) and establishes a basic principle to conduct an EIA for planned activities. The proposed activity needs to be preceded by a Comprehensive Environmental Evaluation (CEE), if the predicted impacts are to be more than minor or transitory. The ANDRILL Steering Committee (ASC) commitment to environmental issues and management has been shown in their request for a CEE level EIA. A precedent was also set with the CRP, for which a CEE was prepared in January 1994. Given that ANDRILL is proposed to be carried out over a number of sites and over a longer time frame than CRP, a CEE is an appropriate EIA level for this activity.

This Draft CEE has been prepared as part of the environmental impact assessment process required under the Antarctica (Environmental Protection) Act 1994, which implements the Protocol in to New Zealand law. Antarctica New Zealand, as the project manager, has responsibility for ensuring compliance of all project activities with the CEE. This will include the implementation of specific measures, and monitoring and auditing to minimise the environmental impacts of the project within the limits predicted in the CEE.

2.2.2 Process for preparing the Draft CEE

Antarctica New Zealand, as the project manager, has prepared this Draft CEE for consideration at the June 2003 Antarctic Treaty Consultative Meeting (ATCM). The document's approach has drawn largely on the *Final CEE for Antarctic Stratigraphic Drilling East of Cape Roberts in Southwest Ross Sea, Antarctica* (Keys, 1994), and subsequent CEEs prepared for the ATCM including the *CEE for the European Project for Ice Coring in Antarctica* (EPICA) (Oerter 2000), and the *Final Environmental Impact Statement for the Modernization of the Amundsen-Scott South Pole Station, Antarctica* (NSF 1998). Information within this Draft CEE has come from a variety of sources including workshop proceedings, reports, project plans and published articles.

The process for the preparation of the Draft CEE has run parallel to detailed planning for the ANDRILL project. At this stage the timeline assumes a first drilling objective undertaken in the 2004/05 austral season.

2002	*January*	Commence process for drafting CEE.
	October - December	Further fieldwork/site assessments carried out if required.
2003	*January*	Complete Draft CEE
	22 January	Circulate Draft CEE to Antarctic Treaty Parties and chair of Committee for Environmental Protection (CEP)
	January - May	CEP intersessional contact group established (refer Annex 4, CEP II Final Report). Report compiled.
	7 May	Deadline for comments on Draft CEE.
	9 - 20 June	Draft CEE considered by CEP/ATCM
	October - December	Further fieldwork/site assessments carried out if required.
2004	*January - February*	Further fieldwork/site assessments carried out if required.
	February - June	Final CEE prepared taking into account comments and results of any fieldwork.
	20 June	Final CEE circulated to Parties.

Copies of the Draft CEE will be circulated for comment within New Zealand and overseas and made publicly available on Antarctica New Zealand's website. Specifically, input from the Antarctic Treaty Parties, New Zealand Environmental Assessment and Review Panel (EARP), the Pollution Prevention and Safety Panel of the Ocean Drilling Program, non-governmental organisations and other experts and interested parties will be sought on the Draft CEE. An intersessional contact group of the CEP may also be convened to consider the CEE. Comments received on the Draft CEE will be taken into account in preparing the final document, which will be reviewed by EARP and circulated accordingly. After the CEE has been finalised, a decision will need to be taken as to whether or not to proceed with the proposal. The Protocol stipulates that the examination of a CEE will take no longer than 15 months or the proposed activity may proceed. The Final CEE will be prepared by June 2004 and will include comments made to the Draft CEE.

It has been recognised that the long duration of the proposed ANDRILL project immediately sets new challenges for the writing of the Draft CEE. At this early stage in planning there are several uncertainties in the proposal. Options are given where known. It is expected that many of these information gaps will be filled within the 18 month timeframe between the writing of the Draft CEE and producing the Final CEE mid-2004.

It is also expected that for many aspects several options or alternatives will be given rather than a single solution as it is expected that more knowledge will be gained with each new drill season, and that new technology may be developed over the long lifespan of this project. Any changes to the activities proposed in the CEE would only be carried out with the approval of EARP, and would be notified to the Antarctic Treaty Consultative Parties (ATCPs) in accordance with Resolution XXI-2 (1997).

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3. DESCRIPTION OF PROPOSED ACTIVITES

This section will discuss the purpose and need of the proposed activity, focusing on the scientific justification, the generic scientific themes and objectives and the scientific reasons behind selecting McMurdo Sound as location for this project.

2.1 Purpose and Need

3.1.1 Scientific justification

There is now widespread appreciation, from the study of sedimentary archives, that Earth's climate during much of the Cenozoic Era (the last 65 million years) has experienced dramatic and continuous changes. Evolving from relatively warm, ice-free "greenhouse" conditions, the planet has progressively cooled during the last 50 million years to its present "icehouse" state with continental ice sheets on the polar regions of both hemispheres (Figure 2).

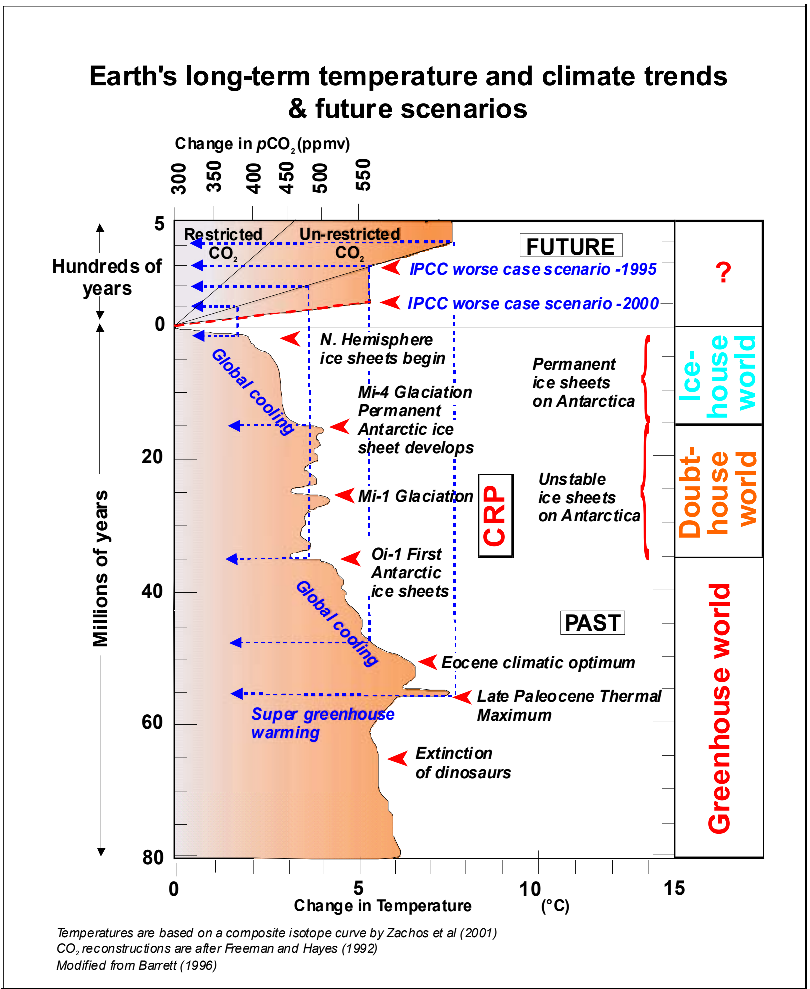


Figure 2 **Earth's temperature during the last 65 million years based on reconstructions from deep-marine oxygen isotope records.** Note general cooling trend from 50 million years. Also note the abrupt "climatic threshold events". For example Oi-1 at 33 million years ago when abrupt global cooling led to the first sheets developing in Antarctica. Future atmospheric temperature scenarios are based on IPCC greenhouse trace gas projections are shown at top of diagram. Given the worst case scenario, planetary temperatures could increase in 100-200 years to a level, where according to our knowledge of previous Antarctic glaciations, ice cover on Antarctica could not be sustained. [Temperatures are based on a composite isotope curve by Zachos 2001. CO² reconstructions are after Freeman and Hayes 1992. Temperature curve is a composite of and Miller et al. 1991. Modified from Barrett 1996].

One of the most perplexing questions involves the nature of the long-term cooling and evolution of the Antarctic cryosphere. The presence of an ice sheet on Antarctica over the last 35 million years has played a fundamental, yet poorly understood role, in global environmental change. It acts as an enormous heat sink steepening the latitudinal thermal gradient of the Southern Hemisphere and enhancing the vigour of both atmospheric and oceanic circulation. Periodic and abrupt variations in its size have caused, and will continue to cause, dramatic changes and feedbacks in Earth's climate through rapid modulation of deep-ocean circulation, the distribution of atmospheric and ocean temperatures, and its effects on global sea level. Response of Antarctic ice sheets to projected "super-greenhouse warming" of up to 6°C by the end of the century (Houghton et al., 2001) is not known, and the models on which predictions are based, need to be constrained by geological data. Furthermore recent research has identified abrupt changes in the pre-historic past from sectoral collapse of ice sheets and ice shelves (Houghton et al, 2001).

A further complexity is recorded by oceanic sediments and terrestrial ice cores that show rhythmic climate cycles driven by variations in Earth's orbital geometry on timescales of 10^4-10^6 years, and higher frequency cycles of less certain origin with durations $10^{1-}10^3$ years. Such variability has been linked with changes in Antarctic ice volume. Longer-term trends (>10^6 years) in the mean climate state, such as those illustrated in Figure 2, onto which these higher frequency changes are often superimposed, are considered to reflect influences on Earth's major boundary conditions, such as the ocean floor bathymetry and gateways (Lawver and Gahagan, 1998) and the concentration of atmospheric carbon dioxide (Pearson and Palmer, 2000). As a consequence of these ever changing tectonic boundary conditions on gradual variations in mean climate-state, the sensitivity of the system to orbital forcing can increase significantly and lead to unusually rapid or extreme climatic changes.

Our understanding of Antarctica's role in the climate system is limited by a lack of physical evidence of past climate and ice sheet behaviour from the Antarctic continental margin. Acquiring this understanding calls for this knowledge not only from recent times, but also for times as long as 40 million years ago, when global temperatures were last similar to those expected by the end of this century. The themes and objectives outlined in this Draft CEE are all designed to obtain and analyse high-resolution climatic archives from sediment cores and will contribute direct evidence of past change, critical calibration for climate and ice sheet stability models, and new knowledge of Antarctic climate *drivers* and the environmental *consequences* for Ross Sea, Southern Ocean and Southwest Pacific.

Drilling of shallow-marine sedimentary basins on the continental edge of Antarctica by ANDRILL is motivated by the need for fundamental knowledge in the following specific areas:

1. Progressive, long-term cooling of the polar regions leading to the inception and maintenance of ice sheets on Antarctica.
2. The series of abrupt steps in the evolution of the Antarctic cryosphere.
3. The poleward transfer of heat during periods of extreme global warmth that have punctuated the overall cooling trend.
4. Orbital and sub-orbital modulation and the role of Antarctic ice volume fluctuations on global sea-level and the oceanic thermohaline "conveyor".
5. Abrupt transitions and climatic surprises when thresholds in the climate system were exceeded.

3.1.1.1. Generic Science Themes and Objectives

The McMurdo Sound Portfolio of drilling will address and contribute to four generic themes and specific objectives therein.

Theme 1: Development of the Antarctic cryosphere and extreme climates

<u>Glacial transitions</u>

- Late Eocene-Oligocene Oi-1 glaciation
- Oligocene-Miocene Mi-1 glaciation
- Middle-Late Miocene climatic deterioration (Mi4-Mi-6 glaciation)
- Late Pliocene global climatic deterioration
- Mid-Pleistocene climatic transition (MIS 22)

<u>Periods of climatic warmth</u>

- Late Paleocene thermal maximum
- Late Eocene climatic optimum
- Late Oligocene warming?
- Middle Miocene climatic amelioration
- Middle Pliocene warming
- Extreme Quaternary interglacial warmth (e.g. MIS 11)
- Mid-Holocene climatic optimum

Theme 2: Behaviour of the Antarctic cryosphere

- Orbital and sub-orbital climatic variability, and the role of Antarctic ice cover on global sea-level and oceanic circulation
- Stability of ice sheets and ice shelves at orbital timescales
- Stability of ice sheets and ice shelves during at sub-orbital time scales
- Calibration of the ocean sediment proxies by correlation with direct records (e.g. calibration of ice volume and sea-level)
- Interhemispheric comparisons
- Understanding ice sheet “amplification” of the global climate signal (what intervals of past climate were more sensitive to orbital influences and why?)
- Antarctica’s contribution to Quaternary glacial-interglacial climate cycles
- The role of Ross sea ice and the Ross Ice Shelf on bottom water production
- Rapid climate surprises and extreme events (e.g. D-O climate fluctuations, Younger Dryas and Antarctic Cold Reversal)

Theme 3: Origins and adaptations of polar biota

- Mode and timing of evolution of the polar and sea-ice biota
- Biotic response to warm, cold and extreme environments and events

Theme 4: West Antarctic Rift (WAR) evolution and uplift of the Transantarctic Mountains (TAM)

- Timing of WAR inception, TAM uplift and evolution of the Victoria Land Basin (VLB).
- Implications for global plate reconstructions
- Temporal and Spatial flexural response of the WAR crust to TAM uplift and volcanic loading.
- Long term volcanic history and processes

A number of countries have expressed interest in participating in circum-Antarctic margin drilling. Proposed target areas for ANDRILL after the McMurdo Portfolio include the eastern

Ross Sea, Weddell Sea, Palmer Basin, McMurdo Sound, Terra Nova Bay, Beaver Lake, Prydz Bay, Lutzow-Holm Bay and Wilkes Land. Logistical considerations, the extent of knowledge of the region, a proven chronological framework, and the level of international interest indicated that McMurdo Sound should be the first region for further Antarctic drilling under the ANDRILL programme.

3.2 Locations

3.2.1 Why drill in McMurdo Sound?

- The area is underlain by the Victoria Land Basin (VLB) – a sedimentary 'tape recorder' of ice, climate and tectonic history for most of the last 50 Ma.
- The sediments record the paleoclimatic history of the Ross Sea region, which, like the Weddell Sea, is a major producer of Antarctic Bottom water. Ross Ice Shelf / Ross sea ice / Ross Sea polynya are all critical to the formation of deep water and pump to the deep ocean conveyor system.
- It is uniquely located to the East Antarctic Ice Sheet and next to the giant Ross Ice Shelf, both of which have oscillated across the Ross Sea through Cenozoic time. It is also adjacent to a major intracontinental rift shoulder (Transantarctic Mountains), which allow for an assessment of the role of tectonics in climate and ice sheet development (Figure 3).

Figure 3 **The East and West Antarctic ice sheets dominate Antarctica's landscape. The two ice sheets are separated by the Transantarctic Mountains and the Ross and Ronne-Filchner ice shelves (Waterhouse, 2001).**

- The area has experienced many volcanic eruptions over the last 25 Ma, contributing primary tephras to basin sediments, and providing opportunity for high-precision geochronology.
- The area has the best understood marginal sedimentary basin in Antarctica through years of previous work on integrating seismic and drillhole data (DVDP, MSSTS, CIROS, CRP; Figure 4).

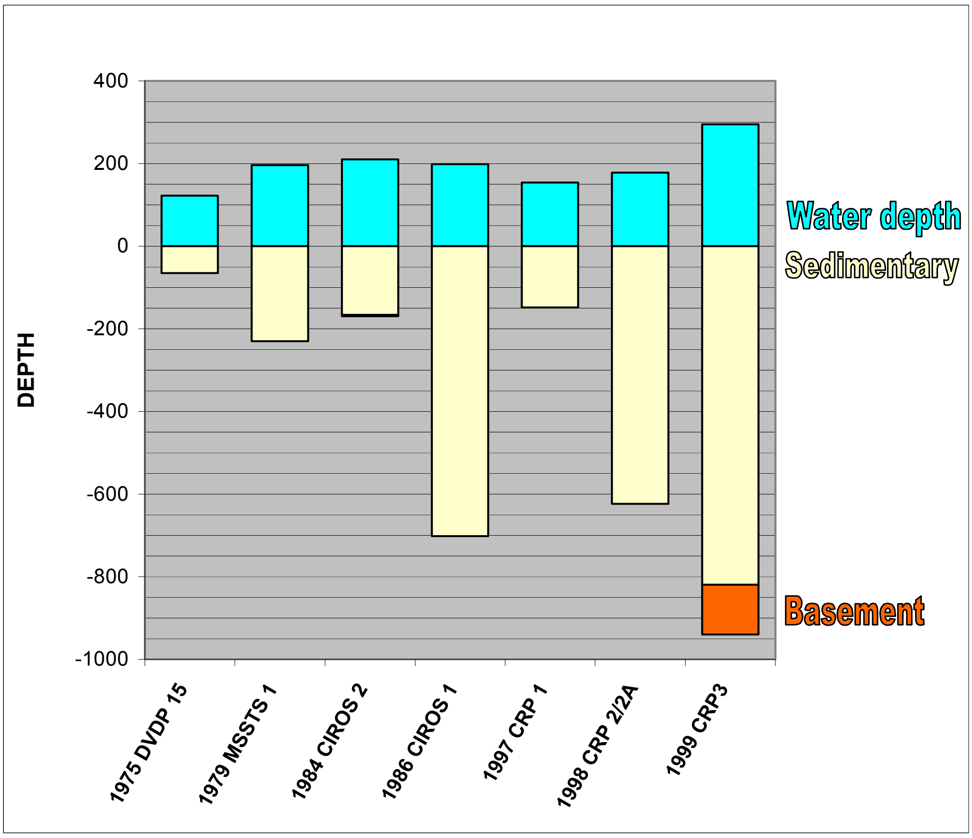


Figure 4 **Sea ice platform Drill Sites in south-western Ross Sea showing water depth, drilled depth. The percentage of core recovery was as follows – DVDP 52%, MSSTS 1 44%, CIROS 2 67%, CIROS 1 98%, CRP 1 86%, CRP 2/2A 95% and CRP 3 98% (Pyne, 2001).**

The McMurdo Sound Region has been chosen because there is a proven chronological framework from past drilling in this area and an ease of logistic support. Most areas of interest within the McMurdo Sound Region are within one hour by helicopter and two days by ground vehicle from Scott Base (New Zealand) and McMurdo Station (US), making the area well located for logistical support.

The McMurdo Sound Portfolio target areas were selected based on scientific, technological and logistical considerations. Four target areas have been identified for drilling, each with up to 2 drill sites. The areas are New Harbour (NH), McMurdo Ice Shelf (MIS) Southern McMurdo Ice Shelf (SMIS) and Mackay Sea Valley (MSV) in Granite Harbour.

3.2.2 Drill sites

The drill site locations within each target area have been selected but are subject to change because geophysical and other site survey data are still being collected. The locations for drill sites in the four areas of McMurdo Sound are restricted by several criteria:

- The sites must be able to potentially answer the scientific questions posed.
- The NH and MSV sites must lie in the fast ice zone so that the fast ice would be of adequate thickness and integrity to support the drilling rig.
- The NH and MSV drill holes must be drilled from fast sea ice, in water depths within a range of 50 to 1000 m to accommodate a 5 percent maximum horizontal shift of the sea ice platform during drill operations.
- None of the drill sites can lie above basement faults, which complicate the stratigraphic sequences and complicate the scientific interpretation.
- None of the drill sites can lie above closed sedimentary structures for safety reasons. Because faults are common, and possibly hidden beneath the basin flanks, efforts should be made to drill into sedimentary sections that open updip onto the sea floor.
- Holes should not be drilled below seismic imaging as a safety issue.

These criteria play an important role in determining that the project will be technically feasible, and environmentally sound and safe. Application of these criteria to drill site selection represents a major part of planning and environmental assessment process. Seismic data are an essential tool in using these criteria to select drill sites. Seismic surveys have been carried out in the McMurdo Sound region since the International Geophysical Year (IGY) for the investigation of ice thickness and subsurface geology. A three-year collaborative programme of geophysical surveys is currently underway in the McMurdo Sound area for ANDRILL (Appendix II).

Specific drilling objectives of each of the McMurdo Sound Region drill sites.

The specific drilling objectives for each of the drilling sites are summarised in Table 1.

Table 1 Specific drilling objectives of each drilling site.

	Specific drilling objective
New Harbour	Muliti-proxy, high resolution records will be recorded of: • the Middle-Late Neogene East Antarctic Ice Sheet • Miocene glacial-sea-ice dynamics • Late Miocene cooling • mid-Pliocene climatic optimum (~ Ma) • pre-Neogene "greenhouse" to "ice house" transition
Windless Bight/ McMurdo Ice Shelf	Muliti-proxy, high resolution records will be recorded of: • Ross / McMurdo Ice Shelf development and during the last 5 Ma • Role on the production and modulation of Antractic bottom water to the oceanic conveyor. • Response of the ice shelf to climatic extremes, such as past periods of known global warmth, and climate variations. • Relationship to atmospheric ice core records and Ross Sea sea-ice dynamics. • Reference record of Quaternary environmental change in Ross Sea for correlation with other less complete records.
Southern McMurdo Ice Shelf/ Black Island & Brown Peninsula	Muliti-proxy, high resolution records will be recorded of: • Pre-Neogene climates and "greenhouse" to "ice house" transition. • Eocene-Pliocene climatic transitions and climate optima • Volcanic history of the WAR • Pre-Quarternary Ross/McMurdo Ice Shelf dynamics and modulation of Antarctic bottom water • Inception of the WAR and uplift of the TAM
MacKay Sea Valley/ Granite Harbour	Muliti-proxy, high resolution records will be recorded of: • 15000 year to present record of western Ross Sea, sea-ice dynamics and glacial history • Integration with ice core records and implications for Holocene climate variability • Early-Middle Miocene glacial-sea-ice dynamics • Early-Middle Neogene East Antarctic Ice Sheet history

The locations of three of the proposed ANDRILL drill locations (New Harbour, McMurdo Ice Shelf (only one hole shown) and Southern McMurdo Ice Shelf) and anticipated stratigraphic interval penetrated are shown in Figure 5.

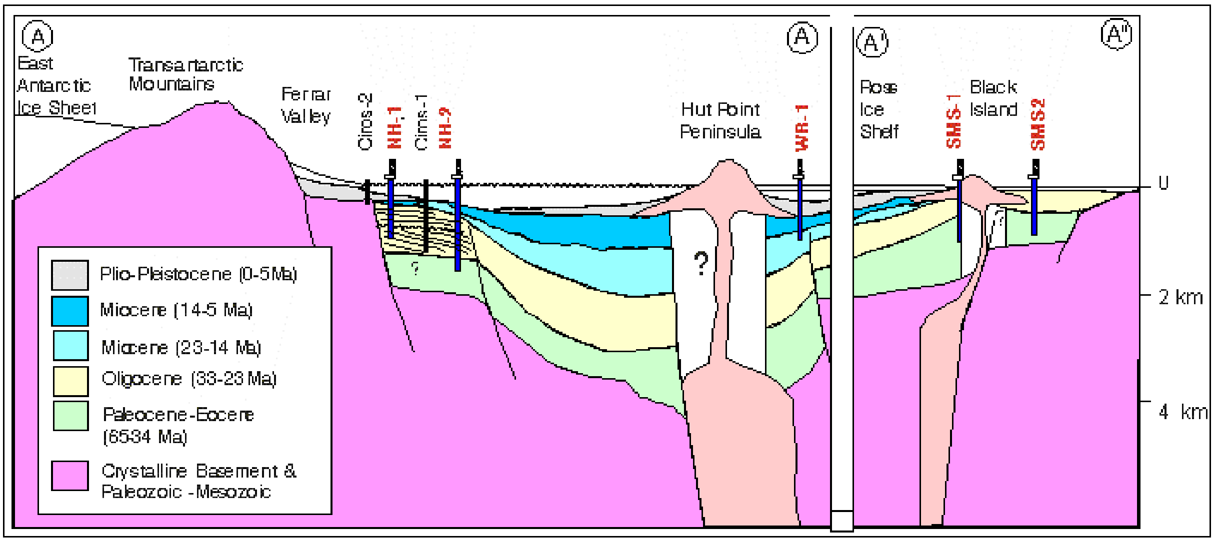


Figure 5 **Schematic x-section based on previous drill hole and seismic data. (After Naish et al., 2001).**

New Harbour (NH)

The primary objective at sites NH-1 and NH-2 are to recover middle to late Neogene (10 -2 my) strata from within submarine valleys. Middle Neogene age strata have not thus far been recovered in McMurdo Sound. The sites are located in the track of potential outlet glaciers and should record East Antarctic Ice Sheet history following the warm climatic optimum in the middle Miocene to the formation of the current ice sheet configuration. NH-2 is positioned to allow recovery of pre glacial Paleogene strata by deep drilling (> 800m).

Neogene strata from New Harbour will allow direct comparison of East Antarctic records with West Antarctic and Ross Ice Shelf records from the MIS and SMIS targets. In particular it is hoped that a continuous multi-proxy record of the middle Pliocene climatic optimum will be recovered and evaluated. Additionally this hole should fill important gaps in the Neogene basin record both in terms of biostratigraphy and cyclostratigraphy. Southern Hemisphere comparisons will be made between the New Harbour cores, the deep ocean ODP 181 record of eastern New Zealand, Chilean records and the shallow-marine Wanganui Basin Record (New Zealand).

The drill sites at New Harbour, will be easily drilled with current technology.

Site Investigations

CIROS -1 and MSSTS-1 were drilled offshore in the region. CIROS-2 and DVDP 9-11 were drilled in the mouths of the Ferrar and Taylor valleys respectively. Poor quality low-resolution marine seismic was shot in the 70-80s. More recently, Italian and US marine seismic data was collected east of New Harbour in the vicinity of CIROS-1 and MSSTS-1. In 2001, two seismic lines (10km) were shot along the seaward extension of the Taylor and Ferrar Valley axes. Combined with gravity data, they indicate a deep flat lying sequence extending both temporally and spatially from the CIROS-1 and MSSTS-1 sites. These flat lying strata a cross cut and overlain by a complex series of valleys (sometimes fault abounded) and valley fill sediments recording a more recent history. The larger valleys with simple subhorizontal stratal fill are to be targeted for drilling. Further seismic data collection is planned to confirm exact site locations. Site visits were conducted in December 2002 (see Section 2.4.11).

McMurdo Ice Shelf (MIS)

Loading of the crust by volcanoes of the Ross Island Massif has provided c. 1.5 km scale flexural moat basin at the juncture of the MIS and Ross Ice Shelf system that has accumulated sediment since the beginning of loading ~5 my ago. The target for this ANDRILL site is a body of sedimentary strata around 1200 m thick deposited in a crustal depression behind Ross Island (Fig. 1). It is proposed that 1 hole of between 1000-1300 m and possibly a 2nd hole to from the ice shelf in 800 m of water in this key location beneath the northwestern corner of the Ross Ice Shelf where it flows into the McMurdo Ice Shelf (MIS). During the Last Glacial Maximum 20,000 years ago the ice was much thicker and more extensive. At other times the site very likely lay beneath open water. The drill hole proposed here will provide a record of these changes to the ice cover and consequent variations in the extent of the ice shelf and its effect on ocean circulation over the last 5 million years or so.

The primary goal is to better understand the behaviour of the Ross Ice Shelf, which covers an area of 560,000 square km, and the waters beneath. This will contribute to a better understanding of ice shelf stability and of the production of saline Antarctic bottom water in Ross Embayment. Through comparison with southern ocean sediment records it will be possible to assess its role in modulating the global oceanic conveyor belt. We expect the Windless Bight strata to have recorded variations in the extent and character of the ice shelf that follow the major glacial-interglacial cycles of the Quaternary polar ice sheets. However we are also likely to find abrupt climatic “surprises”, major changes in years or decades, comparable with those described from polar ice cores (Alley et al., 2001).

The RIS is currently considered to be stable, pinned to the east by Roosevelt Island and to the west by Ross Island, despite the calving of a 40-km-wide strip across its northern margin over the last 2 years (www.natice.noaa.gov - see press release of May 11, 2002). However, the recent iceberg calving events, together with progressive collapse of ice shelves on the Antarctic Peninsula over the last decade, has heightened awareness of potential ice shelf vulnerability, particularly as global atmospheric temperatures continue to rise. Of critical interest is the behaviour of the Ross-MicMurdo Ice Shelf during past interglacial warm extremes (e.g. 400,000 years ago).

The uppermost c. 500 m of the sedimentary succession is expected to be fine-grained muds with occasional glacigene sediment and layers of volcanic ash. Underlying strata may become progressively more glacigene in character as they were deposited at a time when the depression was shallower and the ice shelf may have been grounded. The composition and abundance of biogenic sediment, chiefly diatoms, will help identify variation in ice shelf cover and open marine conditions and estimation of marine paleotemperatures; key input to guide glacial and climate models.

The MIS cores will provide a more or less continuous record of multiple paleoenvironmental and paleoclimatic tracers during the Quaternary and possibly older times at this most southerly coastal high latitude location. We expect these to be sensitive to the presence or absence of an ice shelf and/or sea-ice, and to record the influence of a number of globally significant transitions and climatic events. These include:

- The mid-Pliocene warm period and partial collapse of the Antarctic ice sheets around 3 million years ago (what was the pattern of ice shelf or sea ice behaviour through this period?)
- The late Pliocene climatic cooling from 2.7-2.2 million years ago (what was the relative influence of the Ross Ice Shelf/East and West Antarctic Ice Sheets during this period)

- The mid-Pleistocene transition from climate cycles with a period of 40 k.y. to the 100k.y. cycles the Earth currently experiences, centred on marine Isotope Stage (mIS) 25-19 between 900,000 to 700,000 years ago,
- The mIS Stage 11 super-interglacial 400,000 years ago (when global sea-levels were inferred to be 20m higher than today)

This study will also address the following fundamental questions that surround Antarctica's influence on global climate:

- When did the current RIS develop?
- What is the frequency and timing of prior ice shelf cover?
- What global conditions result in the loss of the ice shelf?
- What is the role of large ice shelves on climate change through the production of bottom water, albedo effects, and ocean-atmosphere heat exchange?
- What was the interplay between the Antarctic and Northern Hemisphere cryospheres with respect to temperature, bottom water circulation, and sea-level?
- Can we provide constraints for marine oxygen isotope proxies?

<u>Site investigations</u>
Seismic surveys show a simple geometry to the sedimentary basin beneath the MIS/WB. The first seismic survey imaged only the edge of the basin, but revealed the presence of a thick sedimentary sequence. Further seismic surveys (Bannister and Naish, 2001; and Horgan et al., in press) was carried out across the middle of the basin between Scott Base and White Island and along the axis in 2001-2002, and confirmed sedimentary strata to a depth of at least 1200 m below the sea floor.

Today, sediment accumulation beneath the MIS is limited by the permanent ice shelf above. However, biogenic and subordinate terrigenous suspended sediment is carried in from the open Ross Sea to the east and north. Following completion of the seismic surveys, water column measurements of current speed and direction, along with suspended sediment load and sea floor samples, will be taken in early 2003 through holes in the ice shelf at the proposed drill site and nearby locations. These will allow us to document the local water column properties and sea floor conditions both for designing the drilling system to withstand the currents and also for understanding the present day depositional environment. It will also allow us to estimate present day rates of deposition of the sediment and its source.

Southern McMurdo Ice Shelf (SMIS)

Like beneath the MIS, the volcanoes of Southern McMurdo Sound have also provided flexural moat basins that have accumulated sediment beneath the McMurdo Ice Shelf. Volcanic activity in this region has persisted since early Miocene times and hence flexural basins should record and older and longer history of the McMurdo Ice Shelf. Additional motivation for drilling this region stems from the occurrence of middle Eocene sedimentary erratics that reflect warm, pre-glacial conditions in Antarctica (Levy and Harwood 2000a, b). A study of the moraine sequences that bear these erratics demonstrates a glacial history for this region that indicates less erosion than further north in the McMurdo Sound region and a local source for the Eocene erratics (Wilson, 2000). Pre-Neogene. Initial seismic survey data indicate pre-Neogene strata that underlies the flexural basins and volcanic massifs themselves. These pre-Neogene strata are likely to have been the source for the glacial erratics now deposited between Black Island and Mount Discovery.

Drilling beneath the Southern McMurdo Ice Shelf has several important objectives. Strata that fill flexural moat basins will record Neogene history of the MIS and Antarctic bottom water modulation that extends back in time from the MIS targets closer to Ross Island. Strata that underlie the flexural moat basins will provide a record of the Paleogene preglacial-glacial transition from Eocene-Oligocene strata and an early unroofing history of the Transantarctic mountains. Drillholes beneath the SMIS are well located to provide a subcontinuous record of volcanism in Southern McMurdo Sound, which in turn will provide important age control for stratigraphic sequences recovered from the region.

Site Investigations

In 2002, two intersecting seismic lines (10km) were shot from the ice shelf between Black Island and Mount Discovery. Combined with gravity data, they indicate a 500m water column underlain by a >1km thick sedimentary sequence. The upper part of the sedimentary record comprise strata infilling moat basins along unconformities that dip in towards the volcanic massifs. Strata underlying the basal flexural unconformity dip more steeply but are relatively unbroken except for possible faulting towards Minna Bluff. Additional volcanic material is indicated on the sea floor between Black Island and Minna Bluff. Further seismic data collection is planned to confirm exact site locations. Hot water drilling and sub-ice hydrodynamic measurements and sub-ice shelf floor piston coring is also planned. Site visits were conducted in December 2002 (see Section 2.4.11).

Mackay Sea Valley, Granite Harbour (MSV)

It is proposed that two holes will be drilled in this area, coring up to 500 m beneath the sea floor.

The scientific goal of the proposed drilling in Mackay Sea Valley is to extract high-resolution (decadalmillennial) multi-proxy records of environmental, glacial, biological and climatic change for the last 5-10,000 years since the ice last retreated from MSV. MSV is believed to have eroded beneath Granite Harbour and out to the Western Ross Sea by previous expansion of the Mackay Glacier, a major outlet of the East Antarctic Ice Sheet (Barrett et al, 1995). Following erosion, sediment has accumulated in the valley, at least in the Quaternary and possibly earlier in the Cenozoic. Quaternary and older geological successions have been a recent focus for providing high resolution records of past environmental changes on which to base future predictions, and to assist in deciphering natural variability from anthropogenic changes (Leventer et al., 1993; Shevenell et al., 1996; Berkman et al., 1998; Ingolfsson et al., 1998). Coring will also target the Miocene sequence that underlies the Late-Pleistocene, Holocene record.

With core sites in both inner and outer basins, it should be possible to resolve records for Mackay Glacier retreat history, sea-ice dynamics of western McMurdo Sound and fluctuations in the Ross Sea Polynya. Proxy records of sea-ice variability and deep water production from sediment flux/diatom productivity and geochemical markers should elucidate Ross Sea modulation of the oceanic conveyor from Ross Ice Shelf super cooling of water masses and sea-ice induced brine production. The relationship between the Granite Harbour glacimarine record and the coastal climate record from the adjacent Wilson Piedmont Glacier along with the more distant records from Taylor and Siple domes will improve understanding of high-resolution (decadal-centennial scale) responses to climate in this part of the Antarctic. There is considerable interest from New Zealand and the CRP community to extend the Granite Harbour holes beneath the uniformity that is thought to represent the first Holocene sediments and sample the underlying Quaternary sediment, which seismic data indicate is between 100 and 200 m thick.

<u>Site Investigations</u>

Shallow cores and seabed sampling, limited moderate resolution seismic surveying, palaeobathymetric mapping, Remote Operated Vehicles (ROV) and hydrodynamic measurements have all been undertaken in this area in the past. High-resolution air gun seismic surveys that were planned for 2001/02 season were postponed due to thick sea-ice conditions and will now take place in 2003/04.

3.3 Duration

Drilling is intended to be conducted each spring/summer from 2004 to 2008. Table 2 shows the current survey and drilling timeline for the McMurdo Sound Portfolio of ANDRILL. A floating contingency year has been added (in the table below it is in the 2008/09 season but can be moved if needed in another season). If it is used then the entire programme will be pushed back a year.

Table 2 Survey and drilling timetable

Season	Activity Description	Pressure Points	Contingency options
2002/03	**Geophysical and Site Surveys** • Multipurpose drill rig construction begins • Camp containers refurbished		
2003/04	**Geophysical and Site Surveys** • Drill rig construction continues and rig transported to Scott Base • Test drill rig at Scott Base / McMurdo Ice Shelf • Camp containers refurbished		
2004/05	• Mobilise drill rig and support camp to New Harbour **Drill New Harbour (1 and 2)** • Mobilise camp to SB • Prepare McMurdo Ice Shelf site	• May not be possible to drill two holes in New Harbour and move the rig back to Scott Base in the same year. • Sea ice route and sites must be suitable.	**Drill New Harbour (1)** 1. Mobilise to Scott Base. OR 2. Mobilise to Marble Point and store.
2005/06	• Mobilise drill rig and support camp to McMurdo Ice Shelf **Drill McMurdo Ice Shelf** • Storage at McMurdo Ice Shelf or Scott Base • Prepare SMS site	• Site must be suitable.	*Contingency year 2005/06* **Drill New Harbour (2)** • Mobilise to McMurdo Ice Shelf *(programme goes back a year)*
2006/07	• Mobilise drill rig and support camp to SMS **Drill Southern McMurdo Ice Shelf** • Storage and maintenance of rig at Scott Base		
2007/08	• Mobilise drill rig and support camp to MSV **Drill Mackay Sea Valley** • Store at Cape Roberts	• May not be possible to mobilise from Scott Base to Mackay Sea Valley and drill Mackay Sea Valley in one season. • Sea ice route and sites must be suitable.	• Mobilise to New Harbour **Drill New Harbour (2)** • Mobilise to Marble Point and store.
2008/09	**Contingency Drill or Pack up** • Drill (if timeline has slipped) • Rig and other equipment removed to Scott Base • Demobilise		• Mobilise to Mackay Sea Valley **Drill Mackay Sea Valley**.
2009/10	**Further pack up and site cleanup**		

The timeline recognises some logistical constraints and the delay of one season's activity is forecast as a contingency. Natural conditions such as sea ice stability could also influence the order of drilling activity through the programme.

Within each season, activities are expected to take place between October and February. Programme constraints to drilling operations include the need to be off the "fast-ice" of NH and MSV by late November, flight operations in and out of Antarctica from early October to late February each year, and the ship cargo for heavy equipment and re-supply, arriving once a year in January or February. At present a small window of flights to and from Antarctica is also available in August each year. This may be utilised to allow a set-up phase between August and October. A drilling operation which operates continuously 24 hours a day is considered to be the most desirable to take the best advantage of potentially short drilling seasons (especially on sea ice). In addition, the drilling of sedimentary sequences can have particular problems including drill hole stability, which can be best overcome by operating with continuous drilling and circulation. For these reasons 24 hour drilling within the seasonal constraints is preferred.

3.4 Nature and Intensity of the proposed activity

3.4.1 Overview

The scientific objectives of ANDRILL necessitate the recovery of high quality sediment and rock core from a variety of areas in the McMurdo Sound Region. Drilling is the only realistic method to achieve this. The specific scientific objectives, which include drill targets, depths and continuous core lengths, define the capability required of the drilling operation and the size and scope of the total field operation. The areas of operation, distance from logistic support centres, nature of the drill platform (sea ice or ice shelf), ambient environment (cold temperatures and wind), and the seasonal drilling window (spring and summer) define the support needed for a successful drilling operation.

The proposed drilling objectives under consideration for the McMurdo Sound Portfolio number 8 holes, which will require varied drilling equipment and strategies. The targets will all be accessible by ice surface mobilised drilling systems and a camp such as that developed for the CRP. The drilling platform will very between sites, including coastal fast sea ice and ice shelf. Most of the targets have several common requirements including drilling through hundreds of metres of water (up to 1000m) and to depths of 1500m or greater below the sea floor (Table 3; Figure 6).

Table 3 Summary of the technical specifications of McMurdo Portfolio drill sites

	New Harbour	McMurdo Ice Shelf (WB)	Southern McMurdo Ice Shelf	MacKay Sea Valley
Platform	Sea Ice	Shelf Ice	Shelf Ice	Sea Ice
No. of drill holes	2	2	2	2
Target 1	164.10 E 77.32 S	167.144 E 77.904 S	165.933 E 78.315 S	163.027 E 76.917 S
Target 2	164.20 E 77.35 S	167.333 E 77.843 S	165.878 E 78.261 S	162.888 E 76.985 S
Water depth	150 – 250 m	800 – 1000 m	300 – 1000 m	800 – 1000 m
Coring depth	500 - 1200 m	1000 – 1500 m	500 – 1000 m	200 – 300 m (<=500 m core)
Drilling techniques	Rotary coring	Soft sediment coring / rotary diamond coring	Soft sediment coring / rotary diamond coring	Soft sediment coring / rotary diamond coring
Target age	Eocene - Pliocene (58-5 Mya)	Pliocene - Pleistocene (5-0 Mya)	Palaeogene (67-24 Mya)	Pre-Quatenary & Quatenary

LOCATION 4	LOCATION 1	LOCATION 2	LOCATION 3
MACKAY SEA VALLEY 2 holes	**NEW HARBOUR** 2 holes	**MCMURDO ICE SHELF** 2 holes	**SOUTHERN MCMURDO ICE SHELF** 2 holes

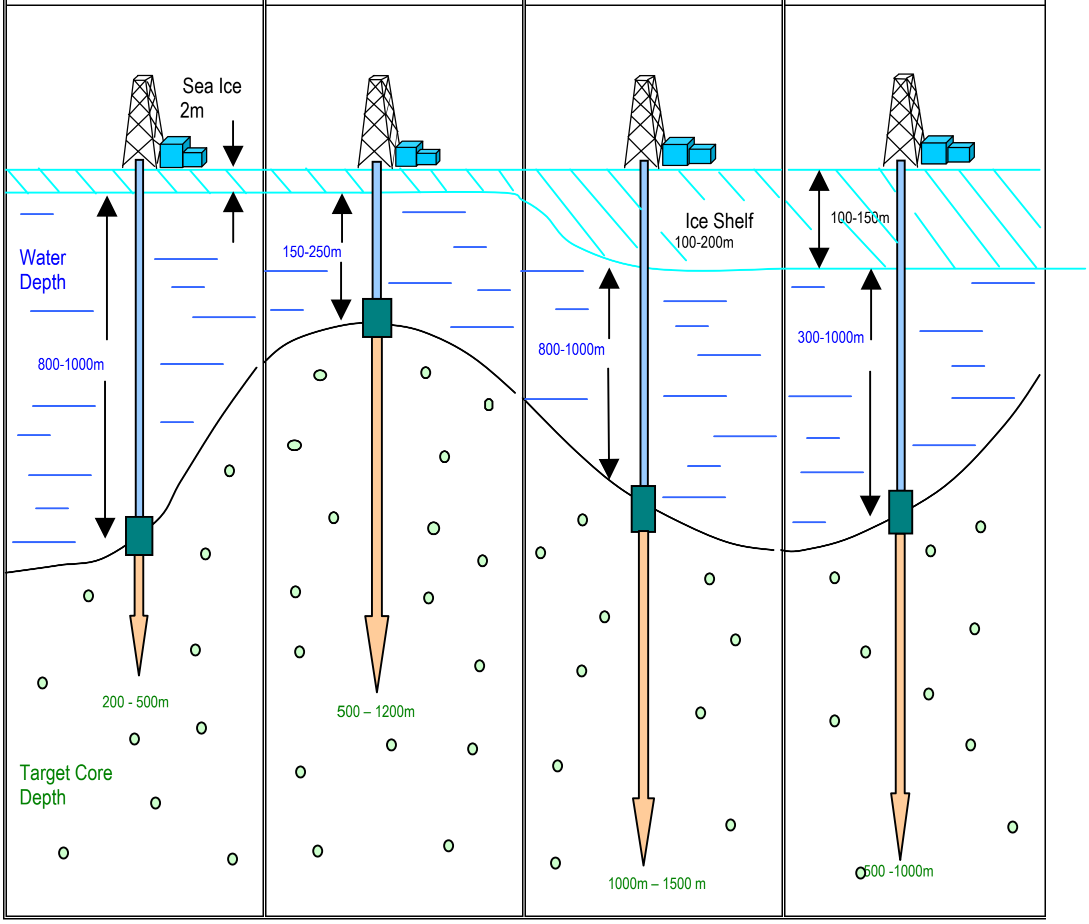


Figure 6 The four locations with sea ice / ice shelf thickness, water depths and core depths.

3.4.2 Drilling Activities

3.4.2.1. Main steps in the drilling operation

This section introduces the drilling operation envisioned for ANDRILL and describes a generalised drilling process. Table 4 summarises the general drilling process.

Table 4 Description of the general drilling process.

1. Mobilisation and set up (Figure 9; Figure 11). The mobilisation and set up of the drilling systems (including running generators, hot water drilling access holes through the ice shelf) and support camps will vary to some extent depending on the type of platform to be drilled from. Most of the component parts of the system are individual sledge-able units and can be mobilised by heavy surface plant (bulldozers etc).
2. Drill fluid circulation: Water supply Of primary importance to the drilling operation will be the access to a water supply for the production of drill fluids to drill non-frozen rocks and sediments. On both the sea ice and ice shelf sea water is readily available once access holes for the drill strings have been made.
3. Deploying sea riser and anchoring into sea floor At all sites the first drill string to be deployed is the sea riser casing that 'connects' the drill rig to the sea floor. By anchoring the sea riser to the sea floor, the riser if kept from buckling in the currents within the water column.
4. Soft sediment coring Soft sediment sampling will be required for all sites. Both specific soft sediment tooling and rotary coring tools will be necessary. This will require changes in the installation procedure of the sea riser at the sea floor to complement soft sediment coring to ensure undisturbed cores are recovered prior to sea riser anchoring.
7. Downhole logging Once the core is removed, downhole logging instruments are lowered into the open hole measurements prior to casing off and cementing.
8. Recovery of casing, sea riser At the completion of coring and logging the drill strings and casing are progressively removed. The uncemented casing is normally severed from the cement either with cutting tools driven by the drill rod or small explosive cutting charges and recovered for reuse.
9. Dismantling and Remobilisation. Following each drilling season, the camp and rig will be dismantled and prepared for transport and storage. The equipment is relocated and reassembled at the start of the following season.

3.4.2.2. Drilling Platforms

The ANDRILL McMurdo Sound Portfolio identifies two generic types of drilling operations:

- Drilling from the annual sea ice platform in water depths up to 1000 m, in near shore and offshore drill sites, into unfrozen sea floor sedimentary strata to depths of up to a further 1200 m (requiring up to 2200 m of drill string). This operation is closest to the original CRP capability but will require development for drilling in deeper water and the recovery of younger (unconsolidated) strata.
- Ice shelf-based drilling operations where both the floating ice shelf and the water column beneath must be penetrated to recover up to 1500 m of core from strata beneath the sea floor. The combined ice shelf and water column could also reach 1200 m.

Therefore the total drill string will need to be capable of reaching 2700 m.

Sea ice platforms (NH and MSV)

Annual sea ice poses the highest potential risk for a drilling platform because of the difficulty in predicting winter sea ice formation, growth to a safe operating thickness and stability during the operating period. There is a higher risk in not being able to drill in any particular season on sea ice than for ice shelf platforms. In McMurdo Sound the large area (approx. 2500 km^2) of fairly stable fast ice that develops in winter and spring most years, fills harbours and fringes the coast is probably unique in Antarctica. Offshore sites pose a higher risk than near-shore and harbour sites, in which the ice forms earlier and normally reaches a greater thickness.

The sea ice operating season is short, usually from mid September, when the ice has reached sufficient thickness, to early December, when cracks reactivate and shore transitions become difficult to cross with melt pools and active ice thinning near shore. Mobilisation and drilling operations must all fall within the sea ice stability "window".

The drilling projects at both NH and MSV require stable fast sea ice. The thickness of ice required for drilling is dependent on ice strength (and temperature) and the loading of the drill site equipment. At this time the precise drill loadings are not known but it is clear that the system should be designed to minimise and distribute weight. The CRP experience has shown that the sea ice minimum thickness for early spring (late August) operating routes should be at least 1.2 m. Ice thickness at the drill site should be 1.7 to 1.8 m by early October and the start of drilling.

Buoyancy systems can be accommodated relatively simply as the holes which can be drilled through sea ice allow equipment up to 1.0 m diameter to be deployed into the water column. Under-ice air bag flotation was required for the CRP under the drill rig to minimise sea ice deflection on ice 1.8 to 2 m thick. The ANDRILL rig will be heavier and increased under-ice flotation is required. Previous drilling at CIROS-1 on 1.8 m thick ice depressed the ice under the drill rig by a maximum of 130 mm. This was well within the strength limits of the ice and the surface was not depressed below sea level. Early season ice thickness measurements would be an essential prerequisite for a final operational decision on whether drilling should be carried out in a particular season.

Sea ice is subject to tidal movement and lateral movement causing offset of the drill string in the water column over time. Localised loading of the ice platform is a significant issue to drill site operations.

Water supply for drilling and camp support is underfoot at sea ice camps, and disposal of non-contaminating wastes (drilling cutting sediments) is easy.

Ice Shelf Platform (SMIS and MIS)

Drilling from the McMurdo Ice Shelf will require the development and integration of ice drilling technology to make a hole for the riser to pass through to the sea floor. Hot water drilling techniques are commonly used to make access holes through Antarctic ice shelves (e.g. the Australian Amery Ice Shelf Interaction Research - AMISOR).

The ice shelf will provide a predictable platform for drilling operations that is accessible for a longer period of the year than the sea ice. The thicker ice will directly support drilling equipment loads including drill strings/casings. Making holes through to the seawater column requires hot-water drilling techniques and holes will be maintained to supply seawater for drill fluids and conversion to fresh water. The drill rig and drill strings used in sea ice deployments will also be used for the ice shelf drilling. Some consideration, including ice shelf thermal modelling and the development of technology will be required to ensure that the drill strings can be recovered from the ice shelf holes after drilling.

3.4.2.3. Hot Water Drill

Critical to the success of the project from the ice shelf platforms is a reliable drilling system for making 25-30 cm diameter holes through the thick ice of the Ross Ice Shelf to deploy the sea riser and drill string to the sea floor. Hot water drills (HWD) provide a very quick method for making deep access holes in to the ice, and have been in use for over 20 years in Antractica.

Hot water drilling techniques will be used to make the initial access holes and then periodic reaming and continuous circulation of heated water will keep the holes open for sea water recovery. Hot water drilling techniques are described in more detail in Appendix IV but are described briefly below in the context of the general drilling (and support camp) operations.

Basic hot water drilling equipment consists of the following components:

- an initial surface water supply (melted snow on site);
- boilers to heat the water for drilling (and start up water supply);
- a high pressure pump suitable for heated water;
- submersible pump for water recirculation;
- thermoplastic hose with jetting nozel and winch.

Both the drill site and the support camp need continuous sea water access for water supply. Separate HWD systems will be needed at the camp and drill site locations at the ice shelf locations as even though the camps and the drill sites may be in close proximity, the two operations will be different and spatially separated. Some of the HWD systems components may be mobile and could be shared. The HWD equipment for both operations will be housed in ISO containers.

At the drill site the HWD systems will be integrated with the drill fluid systems to provide an ice drilling and hole reaming capability for the sea riser deployment and operation, a source of sea water for drill fluids, and water heating for drill fluid production. Should reverse osmosis (RO) be the preferred option for fresh water production at the camp, then an open access hole will be required for sea water for the RO process and for the disposal of heated brine formed during the fresh water production process. Treated grey water may also be disposed of through this hole.

The Alfred Wegener Institute have provided a HWD system for site survey operations to be conducted in January 2003. This HWD system was developed for making holes through ice shelves up to 600 m thick in the mid 1990's (Nixdorf et al., 1994). Once set up, the drill is capable of making an access hole through the 100 - 200 m thick shelf ice in McMurdo Ice Shelf in less than 24 hours. The hot water drilling operation will require the burning of 2500 litres of fuel for formation of the access hole through the ice shelf. This will involve emission of CO_2 and water vapour and small quantities of related gases.

Chemicals

The hot water drilling process will require the pre-heating of the system with a non-freezing fluid prior to melting snow to start drilling. During the pre-heating phase, fluid will be circulated in a closed loop and water will be melted and heated from snow via a heat exchanger system. The preheat fluid will be recovered from the system for reuse and replaced with hot water so that drilling can begin. A small residue of the preheat fluid may mix with the hot water that is re-circulated from the ice shelf hole (cavity).

To minimise the effect of any small loss of preheat fluid it has been proposed that a food grade antifreeze (propylene glycol) that has a low health risk and a slight flammability rating will be used. It is estimated that 200-400 litres of glycol will be used. It will be recovered and drummed.

The propylene glycol will be transported to the site in the containers it is provided in from the manufacturer. Secondary protection in the form of over-pack drums will be used if necessary. The chemicals will be stored in polyethylene, stainless steel or other non-corroding storage units. The glycol can be reused over several seasons but will eventually be drummed and shipped home eventually. The hot water drill system will be cleaned by flushing and the flushing fluid will be recovered on completion. Compressed air will be on-site and will be an alternative cleaning system.

3.4.2.4. Multipurpose Drill Rig

A new multipurpose rig and deep water sea riser for both sea ice and ice shelf deployment is currently under development. The main specifications of the multipurpose drill rig are set out in Table 5. The multipurpose rig will be set up at the ice shelf locations after the hot water drill has reamed the holes for deployment of the sea riser and drill string.

Table 5 Specifications of Drill Rig as expected in Antarctica.

Feature	Multipurpose Drill Rig (Deep Water Riser)
Water Depth (sea riser)	1000 m
Main Hoist (single line)	22 tonne
Coring Depth HQ drill string	1700 m
Coring Depth NQ drill string	2500
Core diameter ranges	83 mm (PQ3), 61 mm (HQ3) and 45 mm (NQ3)
Core recovery rate	Faster than CRP rig

The new multipurpose drill rig is a modern minerals top head drive drill rig with the capacity and flexibility to drill all the generic drilling targets proposed in ANDRILL. The rig will be able to recover core from beneath the sea floor in water depths up to 1000 m and deploy a sea riser casing through 200 to 250 m of ice on the ice shelf. Rotary mud coring will be used in the seafloor targets. This will result in higher recovery rates and improved sea-riser embedment and anchoring to the sea floor than previous drilling.

Modern minerals rigs, such as the multipurpose drill rig, are designed to accommodate different drilling technologies including a wide range of drill string sizes and types, are more automated and are expected to deploy the casing and drill strings and recover core in a deep drilling operation appreciatively faster than was possible in CRP. The rig will be mounted on a sledge and will be enclosed to provide protection from extreme weather conditions (Figure 11).

Equipment trials will be conducted at Scott Base when the multipurpose rig arrives in Antarctica, before the equipment is deployed into the field. This will enable any modifications to be made more easily than could be conducted in the field, if required.

3.4.2.5. Sea Riser

At all sites the first drill string to be deployed is the sea riser casing that 'connects' the drill rig to the sea floor. The sea riser used in the past is a threaded steel casing although plastics and composite materials could also be used (see Appendix V for options). One of the requirements of the new larger rig is to be able to deploy a heavier (and longer) sea riser and it is also desirable to “make up” the large threaded joints automatically, especially for deepwater deployments to increase the speed of deployment and recovery.

The shallow (<500 m) sea ice sites are considered to require the least technical development, and may be able to be drilling using the existing CRP riser. The new deep-water riser will incorporate the following design considerations:

- Use of a larger rotary drill string (HWT) especially for soft sediment coring and initial spudding into the sea floor.
- Deployment of the riser both from the sea ice and through the ice shelf.
- Thermal characteristics of the riser in the ice shelf for drill fluid circulation and tidal compensation (options) and riser recovery after the completion of drilling.
- Water column currents.
- Tidal compensation and lateral offset of the riser deployed through the ice shelf.

The design of this equipment is crucial as if any of the design considerations are not properly addressed, loss gear loss becomes more likely, impacting both the environment and the project itself.

The sea riser used in the ice shelf situation is likely to include buoyancy modules that reduce the load both on the drill rig and on the deformable and limited strength sea ice platform. For CRP, inflatable buoyancy was used both on the sea riser and under the sea ice below the drill rig to minimise the loads on the sea ice (Figure 7). The riser used on the ice shelf will be deployed through a long, small diameter hole that will not allow attached buoyancy modules or large diameter sea floor assemblies. The riser will be hung from the ice shelf itself, which is well capable of taking these loads. In both the sea ice and ice shelf situations the platform is floating and will move vertically with the tide, hence tidal compensation is required to prevent the sea riser being disturbed (or disconnected) at the sea floor. In the sea ice situation the riser is free floating, disconnected from the sea ice, and automatically adjusts for tidal movement. On the ice shelf a hydraulic compensation system will be required to maintain a constant tension on the top of the riser.

The sea riser must be prevented from buckling and failure due to currents within the water column and horizontal movement (offset) of the floating platform. This is normally achieved by anchoring the riser at or in the sea floor and applying tension at the top greater than the total riser weight to keep it straight. The amount of tension required in part is dependant on the magnitude of currents (see Section 3.2.5) and platform offset. Anchoring the riser can be achieved with a sea floor mass (large weight) or by cementing the riser into the sea floor (Section 2.4.2.6), or a combination of both.

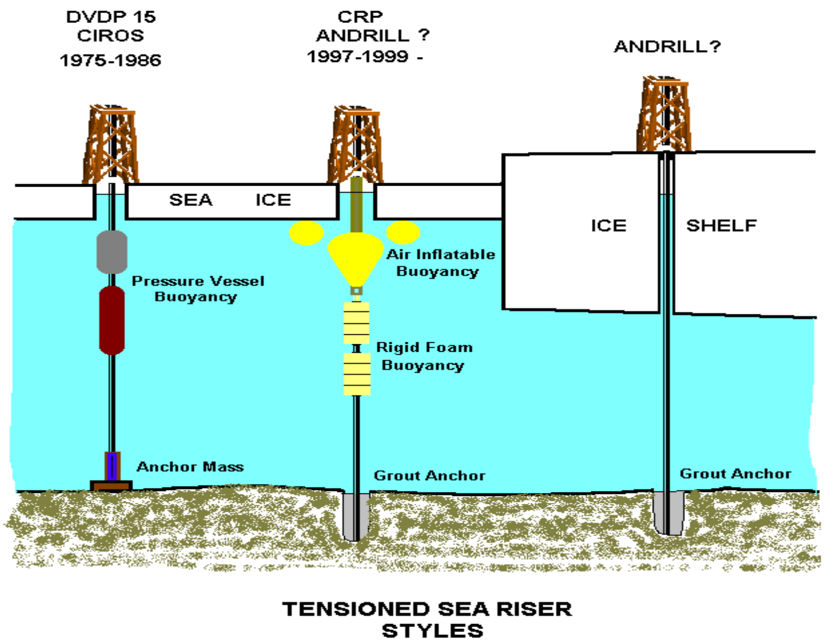


Figure 7 **Sea riser styles used from 1975 to 1999 and proposed for ANDRILL sea ice and ice shelf drilling.** From 1975 to 1986 a riser tensioned with an anchor mass and integral steel pressure vessel buoyancy was used. From 1997 to 1999 CRP used a riser anchored into the sea floor and tensioned with a combination of rigid "syntactic foam" buoyancy and adjustable air filled buoyancy. Both risers are self-supporting and float free of the sea ice. The third style uses the ice shelf for support after anchoring into the sea floor (Pyne, 2001).

The deepwater sea ice sites will require development of a 1000m or greater sea riser and drilling techniques that are compatible with soft sediment coring starting at the sea floor. Existing CRP rigid and adjustable flotation for the riser can be used in conjunction with increasing the under-ice flotation for the drill rig due to the extra weight. New drill strings of different diameters may be required in addition to existing ones for the deep water operation and compatibility with a larger range of borehole logging tools (see Figure 8).

As noted, the ice shelf drilling operations will require a slim sea riser casing without the flotation used in the deepwater sea ice operations. The same casing pipe should be used to minimise the costs of design and manufacture, but a different approach to tidal compensation and tensioning will be required. Drilling through the ice shelf to set the casing will require capability such as hot water drilling both to drill the initial hole and to ream out and recover the sea riser, which is likely to become frozen into the ice shelf during the drilling process (Appendix V).

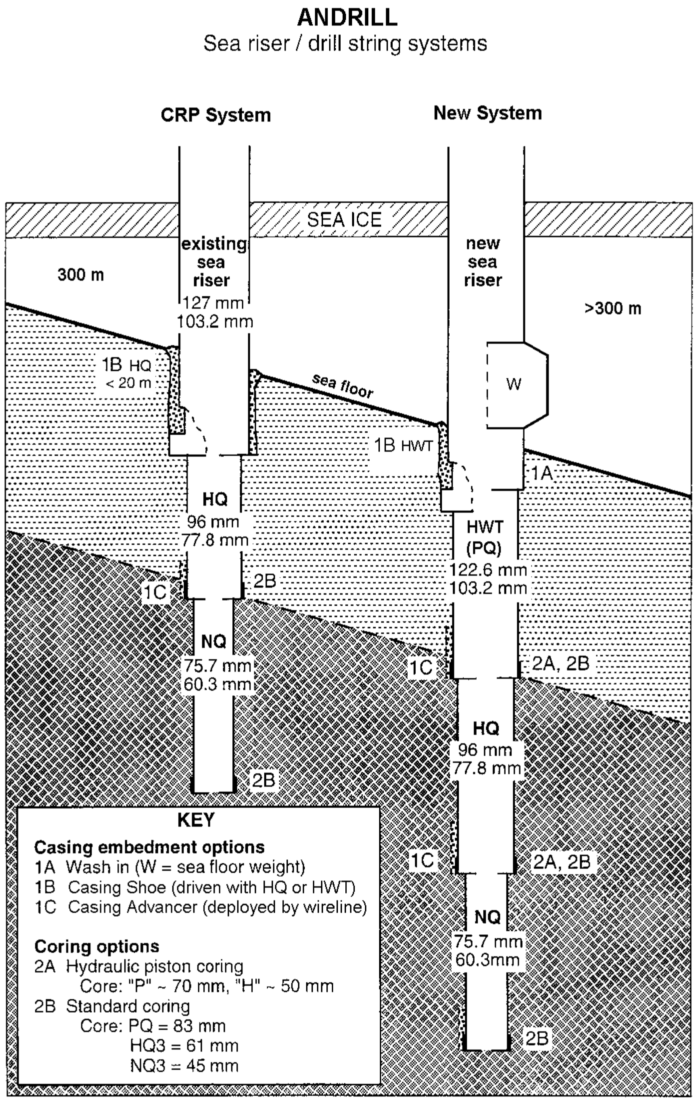


Figure 8 **Sea riser and drill string systems used for the Cape Roberts Project and proposed new system. The new riser will enable the use of a third coring string (HWT/PQ). The outside and inside diameters of each drill string and core are shown in millimetres (Pyne 2001).**

The sea riser is most likely to be constructed of high tensile strength steel tubulars commonly used in the oil industry although the preferred dimensions compatible with the minerals industry drill string may not be a common industry size. Specific machining of couplings may be required. A steel riser will be the heaviest option but the strongest material of the options considered. Steel tubulars are commonly used and their performance well understood and modelled.

Less conventional materials that could be used for riser tubulars include heavy wall polythene pipe combined with a steel strength cable. This has the advantage of lightweight in water but may be difficult to model and may not be strong enough in deeper water situations. Another alternative is epoxy composite tubing with integral screwed connectors. This material is also lightweight and relatively strong and is manufactured for some drilling operations. This is likely to be an expensive option and appropriate size tubulars may not be readily available.

Steel, polyethylene and epoxy composites are relatively inert and likely to have minimal impact submerged in normal marine waters. Some corrosion of steel tubulars will be expected and the value of biodegradable protection products will be investigated and considered. In the past for the CRP the epoxy resin composition of syntactic foam floatation modules was investigated and considered to be unreactive in marine water.

3.4.2.6. Cementing

Portland cement was used to grout the sea riser into the sea floor for the CRP. The HQ casing was then grouted deeper in the bore hole to allow pressure diversion and deeper drilling. This was done for safety reasons in the deeper holes. Calcium chloride (CaCl) was added to the cement fluid to promote setting and was vital at the sea floor where the sea water temperature is -1.8ºC. At the sea floor, with a mix of up to 4% CaCl, the cement grout was sufficiently hard to allow drilling after 36 - 48 hours. Deeper in the bore hole the temperature increased and less CaCl was required to achieve a set, but at least 24 hours was allowed before drilling continued. Small quantities of viscosity-reducing cement additives were also used in addition to CaCl.

ANDRILL cementing requirements are expected to be similar and the primary cement is likely to be Portland cement with the possibility of smaller quantities of faster setting gypsum cement used at times. CaCl is likely to be used again as a cold temperature setting accelerator and possibly minor quantities of commercial viscosity-reducing agents.

Dedicated pumps and mixing equipment will be required for improved cementing operations. The use of faster setting gypsum-based cements will be considered for this project.

3.4.2.7. Soft sediment coring

The capability to drill soft sediment immediately below the sea floor will be required at most of the locations, including the deep water sites in MSV and the younger section in NH, and the less well known environment under the ice shelf. Several techniques and tools compatible with the operation of standard coring drill strings are available to achieve good core recovery and are expected to be used for several metres below the sea floor if soft sea floor sediments are present. Both specific soft sediment tooling and rotary coring tools (TT series) that recover semi-lithified sediments will be necessary. This will require changes in the installation procedure of the sea riser at the sea floor to complement soft sediment coring to ensure undisturbed cores are recovered prior to sea riser anchoring. Retractable drill bits will also be considered for deep coring operations.

3.4.2.8. Drill fluid or 'mud' systems

The primary use of drill fluid (mud) is to cool the drill bit and to circulate the cuttings from the drill bit out of the hole to prevent the drill string becoming stuck. The mud programme is a vital part of the drilling operation and will be a sophisticated part of the operation because of the variation of geological targets and sediment types to be investigated by ANDRILL.

The mud to be used for ANDRILL will be similar to that used for the CRP. The primary mud fluid will be seawater based with KCl to weight the fluid, and natural gum viscosity additives (XCD and PAC-R polymers). This mix is completely biodegradable, is essentially the same as used for CIROS-1 and is commonly used in the off-shore oil industry. This drill fluid mix does not form a wall cake, unlike bentonite clay based fluids and is relatively low viscosity and suitable for the slim-hole core drilling. Mica flake products were used on occasion in the CRP to reduce fluid loss in porous unconsolidated sand zones. Powered Barite will be mixed with sea water to form a high density 'kill mud' in the event of a 'pressure kick' from a gas or fluid in the hole. A tank of kill mud will always be on hand during drilling.

After the first drilling season of the CRP in 1997 when the geological sequence was shown to be significantly younger than expected, guar gum was added to the mud products available. This natural biodegradable material is used as a sea floor spud mud by the off-shore oil industry. The primary use of this product in the off-shore oil industry was similar, i.e. to make a high viscosity fluid for setting the sea riser casing into the unconsolidated sediments of the sea floor. The KCl polymer fluid is successful in Antarctic conditions but some new products are required to reduce fluid loss in the young unconsolidated formations that are expected to be found in ANDRILL.

The cumulative experience of drilling seven holes from the sea ice platform in the south-western Ross Sea has shown the value of well managed drill fluid systems to improve core recovery and depth of penetration. CIROS-1 in 1986 pioneered in Antarctica the continuous use and re-circulation of seawater, potassium chloride and polymer fluid to achieve 98% core recovery in diamictites and mudstones to a depth of 702 metres below the sea floor (Figure 4). The CRP built on this successful operation and has used similar drill fluids as well as others for more specific purposes, e.g. spudding into unconsolidated sea floor sediments.

The drill fluid mixing systems will be housed in two ISO containers, with a space for mud supply on one side and a hot water supply container on the other side. The existing CRP mud equipment that will be used by ANDRILL will need some modification to provide increased mud programme flexibility. A review will be made by the technical working group to consider new ANDRILL requirements that will most likely include recovery of soft sediments. Modifications will include a reduced fluid loss mud programme for unconsolidated sediments, a greater heating capability for faster drill fluid production and reconfiguration of some pumping systems specifically for grouting requirements. An increased heating capability may also be required for ice shelf operations and will be integrated with hot water drilling requirements.

Mud usage and density

Until the exact formations the drill encounters are known, it is hard to calculate the mud usage levels. The unexpectedly young and less consolidated formations drilled in the CRP required higher mud usage than calculated based on CIROS-1 experience. There was high mud loss in CRP-2 due to the unconsolidated sediments in the upper part of CRP-2. Two levels of the borehole enabled circulation with seawater and mud loss was high in these zones. The use of a fluid that is heavier than sea water (overbalanced) is common drilling practice as it can apply pressure to the bore hole wall reducing collapse and it can control the release of down hole fluids. It is possible however, that in the CRP-2 borehole, where many zones were permeable, the use of an overbalanced fluid probably contributed to the high mud use rates. In CRP-3 the mud use rates were much lower than previously and mud reticulation was possible for most of the time. A lower weight-balanced mud fluid was used but these older formations were now generally well-consolidated and equivalent in age to most of the CIROS-1 sequence.

Diamond drilling will be used to drill as small a volume of rock as possible, thereby maximising core size for a given hole size. The space between the hole or casing and rotating drill string is therefore normally small (<10 mm). To remove cuttings from this space, it is desirable to increase the viscosity of the drill fluid but to maintain a relatively low density, especially in weak sedimentary strata where high pressures created by dense fluid can fracture the formation and degrade core recovery. However, higher density fluids are used to control high pressures down hole and would be the normal approach to balance hole conditions after initial containment if over pressured formations are encountered.

Mud Programme

The mud system will consist of mud tanks, pumps, mixing equipment, a solids removal system and mud degasser. CIROS-1 and the CRP both showed that mud could be re-circulated, thereby saving on the amount of mud required and lessening the size of mud fluid storage tanks. However, drill cuttings, including microfossils, will have to be removed from the re-circulated fluids. A small version of a centrifuge system like that now commonly used in oil field mud solids removal systems was considered to be the best equipment to minimise the microfossil contamination of the core by re-circulated mud fluid. This design was incorporated into the CRP and will be used by ANDRILL.

A specialist on site mud technician is considered an important new addition to the drilling operation.

3.4.2.9. Pressure control

Pressure control will be approached in the following ways:

1. High density kill mud will be available at all times.
2. For the boreholes deeper than 500 m (MIS and SMIS), pressure control (diversion) equipment will be installed. This will require the HWT or HQ casing to be cemented down hole to achieve a high pressure seal in competent formation and a hydraulic annular diverter rated to 2500 psi to be installed on the top of the HWT or HQ casing in the cellar area under the drill rig floor. Fluid diversion lines will be set up exiting away from the drill platform. NQ coring will then be possible below the HQ casing.

Abnormal downhole fluid pressures are not expected in this drilling project. Experience with previous drilling in the region (Logan et al., 1984), together with expected age, depth/pressure and temperature gradients downhole suggest strata cored by this project could possibly contain pockets of biochemical gas and be deep enough for the generation of hydrocarbons if there were suitable source rocks. However, the drill sites have been chosen using geological criteria, which make it unlikely that hydrocarbons or other formation fluids e.g. water, have been trapped in sufficient volume to cause a subsea hazard. It is believed that solid methane gas hydrates are unlikely to be present at the temperature and pressures expected (Logan et al., 1984) and have not been encountered in past drilling at similar sites in the region.

Most scientific drilling projects deliberately choose sites to avoid possible subsea hazards. The Ocean Drilling Programme does this and for these reasons does not employ systems to control over pressures. Although abnormal downhole fluid pressures are not expected, planning for the proposed activity involves the ability to control excess pressures by recirculating with weighted muds and diverting excess pressure at the surface with annular diversion equipment.

The mud system will be chosen for pressure control as well as to improve drilling efficiency and core recovery. Specific high pressure blowout prevention hardware is considered unnecessary due to the site selection procedure, the relatively shallow depths involved, the low risk of encountering abnormal pressures and the planned use of the mud control system.

Monitoring for the presence of hydrocarbons and abnormally high fluid pressures will be carried out routinely as per Table 6. If hydrocarbons are detected under normal hydrostatic pressure, drilling will proceed cautiously. If abnormal pressures are encountered, drilling will stop but mud circulation will continue with the mud weighted up to equalise the pressure. If fluid pressures return to near normal, drilling will proceed again cautiously. If fluid pressures remain high and flow sustained, cement will be pumped down the hole to plug it, and the hole will be abandoned.

Table 6 Monitoring procedures for the presence of hydrocarbons and abnormally high fluid pressures.

Action	Monitoring Reason
Pump pressure monitoring	Monitoring to detect gas or other sedimentary fluids being encountered under pressure.
Flammable gas detector	Checking for detection of slow gas buildup in mud.
Mud return check	Checking for gas bubbles before each core is pulled (the most critical time).
Checking each core	Checking both visually (gas bubbles) and with ultraviolet light for oil stains.

3.4.2.10. Downhole logging

The running of downhole logging surveys is normally integrated into the well programme to enable access to part of the open hole for the logging instruments prior to casing off and cementing. This will often happen progressively as the hole is drilled. Most of the electric logging instruments require open hole or bore hole wall contact and few work through casing. A few tools such as the density (neutron) tool contain a small radioactive source and this tool would not be run in a hole without first running other tools including a bore hole calliper to ascertain the hole stability. Logging tools would not be run in unstable parts of the hole and these areas may well be cased and inaccessible.

The downhole logging programme may use downhole tools similar to those used in CRP2 and CRP3 holes, although combination tools rather than single tools may be available. This will be determined by the science programme. Modifications may be made to some of the tools used, but for the most part they will remain the same. The downhole logging will be carried out in phases.

Downhole logs from the CRP provided a representative record of *in situ* physical properties of formations adjacent to the drill hole. Interpretations of continuous measurements in the drill hole provided detailed lithological, stratigraphical, geophysical and mineralogical information. At the CRP drill site, the downhole tools were lowered individually into the drill hole on a four-conductor cable (diameter 4.7 mm). Table 7 lists vertical resolution, logging speed, and the sampling interval from individual measurements, which is variable and tool dependent.

Table 7 Downhole logging tools run in CRP3 along with tool specifications. These tools will most likely be run in ANDRILL.

Tool Name	Units	Diameter (mm)	Speed (m/min)	Sample Interval (m)	Vertical Resolution (m)
Spectral Gamma Ray (GR, Potassium (K), Uranium (U), Thorium (Th))	API, %, ppm, ppm	52	1	0.1	0.3
Density	gcm^{-3}	48 eccen	4	0.1	0.25
Neutron Porosity	%	42	3	0.1	0.5
P-wave Velocity	kms^{-1}	42	4	0.1	0.4
Vertical Seismic Profiling		48	na	7.5	na
Borehole Televiewer (Acoustic)		40 cen	1	0.003	0.003
Dual Laterlog (Resistivities Rdeep, Rshallow	Ohmm	43	4	0.1	0.3
Array Induction (Resistivities at 4 frequencies)	Ohmm	52	4	0.1	0.6
Borehole Geometry (Inclination & Azimuth), 4-pad Conductivity, 4-arm Caliper, Magnetic Field (deltaZ)	degrees, degrees pad units, mm, nT	52	3	0.005	0.02
Magnetic Susceptibility	10^{-4}SI	42	5	0.05	0.4
Mud Temperature (Temp), Mud Conductivity (mud R)	^{o}C,1/0hmm	40	10	0.1	0.2

Two of these tools have radionuclide sources: the density tool uses a caesium - 137 (Cs^{137}) gamma ray source; and the total count neutron-neutron tool had an American-Beryllium neutron source (half life of 433 years) (Logan et al 1984; Terra Antarctica, 6).

The handling, transport and use of these radionuclides in the programme will be carried out in accordance with international regulations and the Antarctic Treaty. The standard logging procedures include assessing hole stability with non-radioactive tools before logging with a radioactive source tool.

3.4.2.11. Recovery of casing, sea riser

At the completion of coring and logging the drill strings and casing are progressively removed. The uncemented casing is normally severed either with cutting tools driven by the drill rod or small explosive cutting charges and recovered for reuse. Cement plugs are normally placed at intervals in the hole as the casing is removed to prevent fluid mixing between different levels in the borehole. Finally the sea riser is severed at the sea floor, if anchored by cementing, and recovered.

3.4.2.12. Explosives

Explosives could be used as part of down-hole logging measurements and have been used previously to cut the casing at the completion of each drill hole.

Casing cutting explosives

At the completion of each of the drill holes the outer casing or sea riser casing, which is embedded and cemented into the sea floor, is cut so that the remaining part of the casing in the water column can be recovered. Two methods are normally used for this operation - one is to use a mechanical cutter and the other is to use an explosive tool.

The proposed explosive is a 'shaped charge' type, in this case called a Colliding Detonation drill collar Cutter (CDC). Each CDC charge is contained in a cylinder 750 mm long x 45.5 mm diameter and weighing 5.2 kg. The actual amount of explosive in each charge is 0.5 kg. The principle of the shaped charge is that an equal amount of explosive is simultaneously detonated at both ends of the cylinder generating shock waves which, when they meet in the middle, collide and are deflected outwards to give a clean cut through the casing. The advantage over conventional 'packed explosives' methods is that considerably less explosive material has to be used to achieve a cut and shock waves are highly focused and not 'widely scattered' (Cowie, 2002).

The concern with using explosives is that they could crack the sea ice. The alternative is to use a casing cutter tool. Technical reasons and the lack of suitable mechanical cutters led to the use of explosives for the CRP, and this situation is expected to remain for ANDRILL.

Downhole logging explosives

Vertical Seismic Profiling (VSP) is a down-hole logging procedure that uses explosives. VSP has been used in earlier drill holes and was used in the CRP. VSP is a procedure where multiple small charges are set off, in this case just under the sea ice. If seals are in the vicinity then a permit will be required under New Zealand's Marine Mammals Protection Act for this procedure to take place.

The VSP experiment is normally carried out on the completion of each stratigraphic drill hole and can take several hours to a day. A borehole wall clamping hydrophone(s) tool is progressively raised up the borehole as small explosive charges are detonated at the sea surface near the drill rig or in the ice shelf. In CRP3 the size of charges detonated 3-5 m under the sea ice ranged from 175 g to 400 g and had little effect on the sea ice platform. A VSP experiment undertaken on the ice shelf is likely to use larger charges buried in the ice shelf to a depth of 20 m, which causes minimal impact, no surface effects and is remote from marine life. To achieve this two (ca. 5-10 cm diameter) shot holes will be augured through the surface ice layer (approximately 50-100 m) away from the drill-hole.

3.4.2.13. Core Management and Processing

Initial core curation will take place at the drill site. Core description and site studies will follow the procedures developed for earlier drillholes in the area. The core will be received from the rig, labelled, split (into archive and working halves), probably photographed and then boxed. It will then be transported to the support camp for description and sampling. The core will not undergo detailed processing at the drillsite to keep numbers there at a minimum, but it is considered important to have processing completed on-site so that decisions about drilling or core features can be made quickly with the involvement of all relevant personnel. Measurements and samples will be taken at the site for further laboratory work and evaluation - micropaleontology, magnetic stratigraphy, texture, mineralogy, chemistry, radiometric dating etc - by a number of a different investigators.

The four drilling areas are located within a radius of 150 km from Scott Base. Core will be stockpiled, if necessary, on site and then transported to the Crary Lab at McMurdo from the 'closer' locations of MIS and SMIS. It will be stored in the core storage facility at McMurdo. More analysis is required on the preferred method of core transportation from MSV and NH.

3.4.3 Camp activities

3.4.3.1. Overview of Camp Operations

The 24-hour drilling operation required for this proposed activity necessitates a camp support system enabling shift work. A self-sufficient support camp is imperative at the remote locations but also at the sites nearer to Scott Base and McMurdo Station. A self-sufficient camp will ensure continuous 24-hour operations and provide safety shelter for drilling personnel, which is even more important during the colder months of the season. The amenities and standard of accommodation at the support camp will play an important part in sustaining a high level of morale and determination in succeeding in spite of the extreme and difficult conditions drillers and scientists work in.

Some of the proposed locations for drilling are a significant distance from MCM and SB and require self-sufficient support for success. The MSV targets in the GH area, for example, are approximately 150 km from MCM and SB. Past experience (CRP) has shown that the support camp for a large drilling activity in this area requires a nearly self-sufficient camp. This is due to the long supply route that is susceptible to adverse weather conditions, primarily locally around MCM and SB, but also along the surface supply route for bulk materials that takes up to 2 days on the sea ice. A support camp in this area may require a large scientific group. In comparison, the MIS drill sites may only be 20 km from MCM and SB and can be accessed on a formed snow road on the ice shelf. Past experience has shown that even this close to MCM and SB intermittent weather conditions could prevent the continuous operation of drilling without a camp supporting the drilling crews at least.

The varying distances of the locations from the logistic support centres of MCM and SB varies, and this may influence the size and scope of the drilling and support activity. It is for these reasons that the scientific objectives and related science activities vary between the different areas. This Draft CEE often defines a range of requirements to cover the different objectives and activities.

Camp accommodation will consist of converted ISO shipping containers. The CRP camp has been gifted to ANDRILL but more containers will be purchased for the ANDRILL project. An assessment of the CRP camp was conducted in the 2002/03 season and refurbishment will take place in 2003. The CRP camp can be used for the varied drilling environments in this proposed activity with some adaptation to sledges and buildings so that they will be set up to cope with mobilisation, operation and storage on thick snow surfaces with significant snow accumulation but also on ablating (and windy) blue ice surfaces.

The main camp for each drill site will be established at the closest practical position to drilling, and personnel will either be within walking distance to the drill site or will be shuttled between there and the drill site using Hagglund all-terrain vehicles.

The main criteria for the ANDRILL support camp will be the same as for the CRP camp. The camp had to be:

- surface transportable;
- easily and relatively quickly assembled and disassembled;
- able to withstand severe weather while exposed on both sea ice and the ice shelf; and
- warm and reasonably comfortable for occupation.

ANDRILL operations will require the movement of about 60 - 65 sledge units.

Support Camp Set up

The core of the support camp will be made up from insulated ISO shipping containers, fitted to sea ice sledges, as were used in the CRP (see Figure 9). The support core will consist of 18 ISO20 (20 ft) containers joined to two ISO40 (40 ft) containers, which will act as a linkway between the smaller containers. An extra container for waste collection will be added to this block but will remain separate as it may be towed away when full. The ISO20 containers will be sealed with contained foam seals, which will be attached to the linkway before buildings are pushed up against each other. Trials have proven this to be a very effective simple seal.

Each container will be sledge mounted thereby making it mobile. The core support camp will consist of two kitchen containers, one ablutions container, one toilet and one sewage handing container, one laundry, one plant room, one hot water drilling container, one generator container, one fuels container, one waste container, one workshop, one store container, three laboratory containers, one drying container, the food store with freezer, and an office attached to a small cold porch (see Figure 9). The mess and recreation areas will be tents to be built on purpose built sleds, which will incorporate a floor. These tents will be either Rac tents or Polarhavens. There will also most likely be 3 bulk fuel tanks fitted to Aalener sleds, which will all be parked at a distance from the camp (see Section 2.4.7).

The accommodation units will consist of four containers, which will interlock with an ISO20 container acting as a cold porch (Figure 9). Two such blocks will be used. Each accommodation container will contain six beds making a sleeping capacity of 24 people in each block and a total sleeping capacity of 48 people.

The final composition of the ANDRILL support camp will be approximately 31 containers. The footprint of the core support camp will be 24.5 m x 16.5 m (405 m^2). The footprint of the tents used for the mess and recreation will be approximately 70m^2. The footprint of the accommodation units will be 150 m^2. Fuel storage will be approximately 45 m^2. The final area of the camp will be much larger than the footprints of the buildings as there will be vehicles, paths, and some equipment stored around the area.

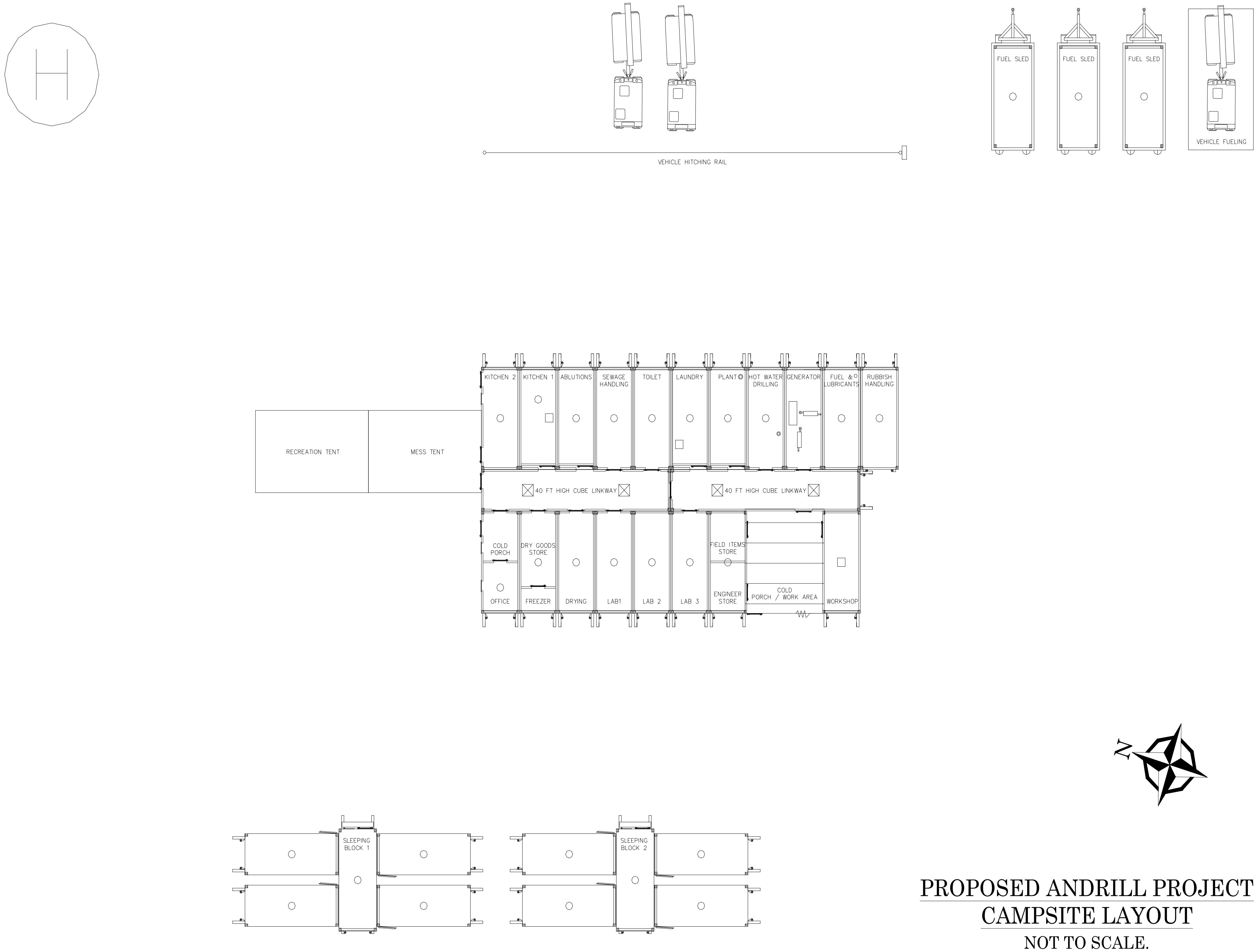


Figure 9 The proposed ANDRILL project support camp layout (not to scale) including the main block, accommodation units, the vehicle hitching rail and fuel area.

(Drawing by Doug Bell, Scott Base, 2002. Design by Alex Pyne, Johno Leitch and Jeremy Ridgen)

Support Camp locations

The locations of the support camps are accurate to within a five km radius of the latitudes and longitudes given (see Figure 10). The exact locations of the support camps will be dependent on more site visits, the state of the sea ice in the drilling season and the results of geophysical survey work still underway. Support camp locations may also change if it becomes apparent that only one hole will be drilled in a season – an occurrence that may take place at the sea ice locations.

<u>New Harbour</u>
The support camp (163.747 E, 77.573 S) will be situated on the sea ice, between the two drill sites. NH is a biological study area, with a semi-permanent camp set up in Explorer's Cove from which divers conduct their research. NH also contains large quantities of multi year sea ice, which has a very rough surface. These two factors may dictate where the camp will be situated.

<u>McMurdo Ice Shelf</u>
The support camp (167.239 E, 77.874 S) will be situated within a sufficient proximity of the drill sites to allow the drillers the possibility of walking to the drill site. This will ensure that noise will not interfere with sleeping, and that in the unlikely event of fire, gas leak or sudden break up of sea ice at either site, the support camp will be safely isolated form the drill sites and will provide emergency back up shelter. The support camp should be a minimum distance of least 200-400 m away from the drill site.

<u>Southern McMurdo Ice Shelf</u>
The support camp (166.078 E, 77.874 S) will be located on the ice shelf. Ablation can be extreme in this area. There is a possibility that the camp may be positioned on or close to land. Impacts of a land-based camp will be addressed in a separate EIA should the case arise.

<u>Mackay Sea Valley</u>
The location of the support camp (162.958 E, 76.951 S) is dependent on whether one or two drill holes will take place in a season. If there are 2 sites targets in a season then the camp will be situated between the two camps. If only one site is targeted then the support camp will be situated inland of this drill site.

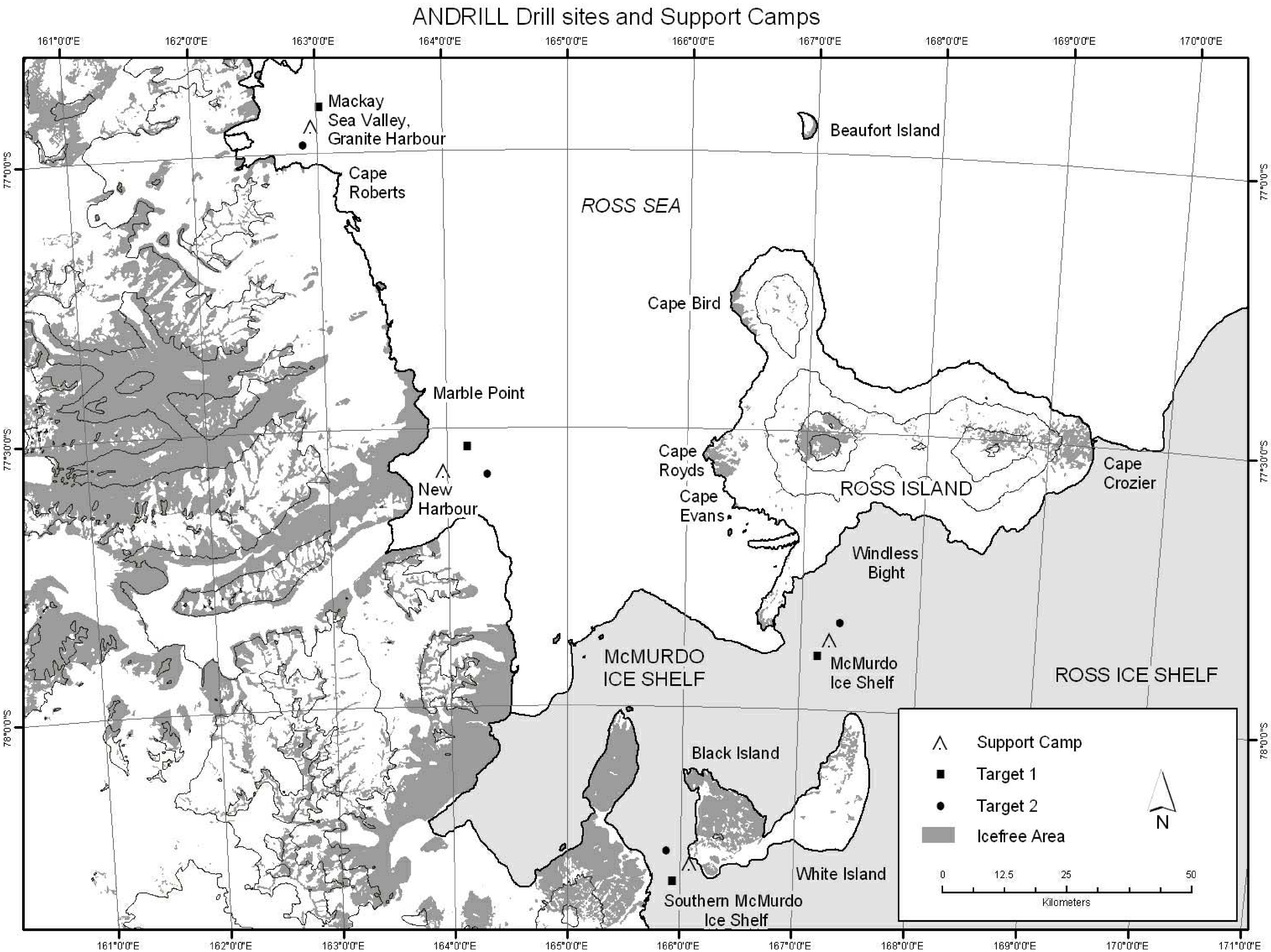


Figure 10 **Map of the proposed ANDRILL drill camps and drill sites.** (Map by Gateway Antarctica, 2003).

Drill Site Camp Set Up

The drill camp will be smaller than the support camp but will still consist of approximately 15 ISO containers (14 ISO20 and one ISO40) (see Figure 11). Each container will be sledge mounted thereby making it mobile. The drill camp will consist of the drill rig, the drill rig power pack, a rod ramp/services stairway, a drill rod sledge, a core tube and pumpout linkway (P.O.L.), the hot water drill, a workshop/engineer store, a cold porch and mud supply space, two mud hut containers, a water heating and supply container, a generator container, and a fuel and lubricants container. These will mostly be attached to utility flatbed sleds with heavy timber decks. The other cluster of containers will consist of three laboratories, a mess kitchen, ablutions and an office, and a linkway.

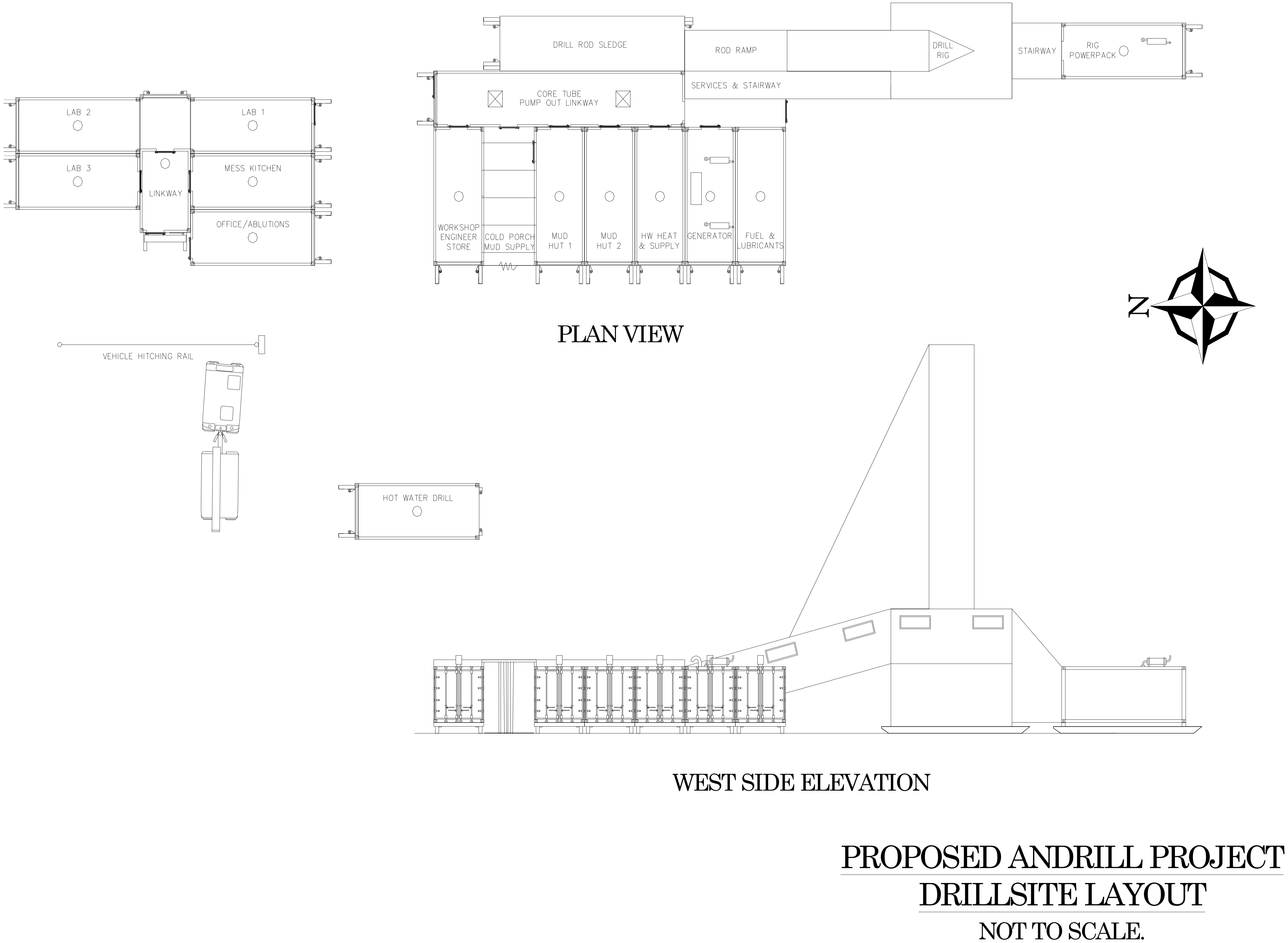


Figure 11 **The proposed ANDRILL drill site outplay.**

(Drawing by Doug Bell, Scott Base, 2002. Design by Alex Pyne, Johno Leitch and Jeremy Ridgen).

3.4.4 Personnel

Camp and drilling support staff numbers are likely to remain fairly constant. The number of science personnel at each site is likely to be variable dependent on both the distance of the drill site from MCM and SB, and on the primary scientific targets and rational. MSV, due to its distance from the facilities of McMurdo's Crary Laboratory, may require a higher science contingent on-site than other sites. However, the close proximity of the MIS site should allow facilities at SB and MCM to be used for scientific analyses.

The support camp would need to house 31 to 47 personnel as outlined below (Table 8). The minimum values (31) represent a camp support operation with minimum scientific personnel for sites close to MCM and SB where scientific work can be carried out in established laboratories. The maximum value (47) represents a self-sufficient camp operation supporting a large scientific contingent both at the drill site and the support camp. Fewer people would be needed during the "construction and mobilisation" phases and would comprise primarily support staff and part of the drilling team. Personnel numbers at the drill site camp will continue to be refined for each site as the drilling technology and camp details at each drill site are further developed.

The support camp will provide accommodation for up to 48 people.

Table 8 Personnel for support camps at the four locations to support offshore drilling during operational phases.

Drilling	N (min)	N (max)	Support	N (min)	N (max)	Science	N (min)	N (max)
Drilling supervisor (24 hour call)	1	1	Camp Manager	1	1	*Co Chiefs	1	2
Shift Driller/ Supervisor (12 hour shifts)	2	2	Camp Maintenance	3	3	*Staff Scientist	0	1
Assistant Driller (12 hour shifts)	2	2	Plant operators	1	1	Physical properties	3	4
Offsider/mud Room (12 hour shifts)	2	2	Helicopter crew (Temporary)	0	2	*Downhole logging	2	3
Mud Engineer	1	1	Chef	1	1	Fracture studies	3	3
Rig Engineer	0	1	General Assistants	1	2	Core description	0	4
Drill Services Manager	1	1				Petrography/ smear slides	0	2
Core processors	3	3				Core splitters	0	2
Core splitters (12 hour shists)	2	2				Paleontology (Diatoms (2) or +/- nannos (1))	0	2
Science Drilling Co-ordinator	1	1						
Totals	15	16		7	10		9	21

* Not permanent and will rotate. However 1 co-chief or staff scientist will probably always be at the drillsite camp, and all 3 only for meetings.

Although ten or more personnel will be at the drill site at any one time (shift supervisor, drillers and science personnel), all will be sleeping and eating at the support camp. A bed needs to be designated to every person even though shifts will be worked, because of the high possibility that drilling may be postponed for periods of time due to weather. To maximise the efficiency of drilling and science personnel and their tasks it has been estimated that seven to eight personnel, including a manager, cooks, plant operators/drivers, engineer/mechanics, electrician and general duties person(s) would be required to run the camp and service the drilling operation. Both the CRP and CIROS have shown the importance of a well-run clean and comfortable camp to maintain a 24-hour drilling operation, as the drilling operation is continuous and can be arduous.

The ANDRILL operations aim to achieve more than one drilling target in a summer season. It has been suggested that there be a continued re-evaluation to minimise field personnel from all groups to improve the process of mobilisation to maximise drilling time each season. The requirements for support staff, drill crew and field science staff are likely to change with the different scientific objectives and a flexible approach to field operation planning will be required.

3.4.4.1. Shift operations

The ANDRILL programme will have 12-hour shifts as used so successfully in the CRP. The shifts will involve two drill site crews (scientists and drillers), a drill supervisor and a science co-chief who will be on call. The camp service personnel (support staff) will also be on 12-hour shifts and some will also be on call.

The longer field season required for some ANDRILL locations may necessitate a different shift approach. The option of eight hour shifts (such as those run on CIROS-2, 1984) was discussed but was discredited as it was determined that rotating shifts are disruptive to the body clock and would require further personnel.

3.4.5 Water supply

Water supply is critical at all of the camp locations. Water is needed for drilling, for production of drilling fluid, water heating for drill fluid production, and to produce fresh water for the support camp.

3.4.5.1. Sea ice

Option 1.

Use a reverse osmosis (RO) system, which is capable of making sufficient water for up to 48 people based on an estimated production of 5000 litres per 24 hours. This system would be similar to that used in the CRP which pumped sea water from about 5 m below the sea ice, heated the water to 15 - 20°C, separated off 10 percent freshwater and returned the heated brine in addition with grey water on the outside of the water intake pipe to prevent freezing the sea ice hole. Separation of a few vertical metres between the water intake and the brine grey water outlet was sufficient at the CRP location to minimise cross contamination. Currents beneath the ice will be monitored to determine the distance needed between intake and outlet.

Option 2

Use a snow melter. This is a high energy cost (fuel) and labour intensive option because snow has to be gathered and at many sea ice sites may not be present in sufficient quantity. Snow on the sea ice will also have a high sea salt content and the water produced will require further processing (RO) to make it drinkable.

3.4.5.2. Ice shelf

Option 1

A hole through the ice shelf maintained by a re-circulating HWD system to source seawater will provide a low energy production of freshwater by RO. Thermal modelling of the energy requirements to maintain an open hole through various thickness of ice shelf is required to design the system but this option is likely to be the most energy efficient once established and lowest labour cost. Keeping a hole open through the ice shelf will require a continuous supply of heat either from heated water returned and lost into the hole (open circulation) or via closed recirculating loop charged with a non freezing fluid such as food grade antifreeze (propylene glycol).

Option 2.

Melting ice *in-situ* with a HWD in a well below the firn-ice boundary is also a high-energy cost and may produce saline water from brine infiltration of the ice shelf requiring further RO treatment to make fresh water.

Option 3.

Use a snow melter. Although more snow will be available than at sea ice sites, this is high energy cost (fuel) and high labour intensive because snow has to be gathered.

3.4.6 Waste

Waste outputs from this project will include human waste, grey water, general solid wastes, and drill fluids and cuttings. There will also be hazardous waste such as antifreeze, batteries and oil products including waste mogas, JP8, kerosene, engine oil, lubricants, any soil or water containing oil products (should any small spills occur), waste oily rags and oil filters.

3.4.6.1. Solid Waste

All food waste and other rubbish will be sorted using Antarctica New Zealand's waste management policy and returned to Scott Base for appropriate disposal. They will be stored in the waste container on site and then transported back to Scott Base. Normal waste minimisation and separation procedures will be instigated at all the sites. Wastes will be separated and collected according to substance type (glass, paper, plastics, metals, organic waste). Appropriate containers will be taken to the sites for subsequent transportation purposes.

Drill cuttings i.e. rock and sediment, including microfossils will be removed from the used drill fluid to allow re-circulation. The drill cuttings will be returned to the sea floor.

3.4.6.2. Liquid Waste

Human waste
Article 4 of Annex III to the Protocol on Environmental Protection to the Antarctic Treaty states that, "*sewage, domestic liquid wastes and other liquid wastes not removed from the Antarctic Treaty area in accordance with Article 2, shall, to the maximum extent practicable, not be disposed of onto sea ice, ice shelves or the grounded ice-sheet, provided that such wastes which are generated by stations located inland on ice shelves or on the grounded ice-sheet may be disposed of in deep ice pits where such disposal is the only practicable option…….Wastes generated at field camps shall, to the maximum extent practicable, be removed by the generator of such wastes to supporting stations…….*"

Changes in technology since the Protocol was drafted also mean that maceration, then considered a minimum level of waste water treatment, is no longer accepted as an environmentally sound practice, or in fact a form of 'treatment'. The introduction of new wastewater plants at McMurdo Station and Scott Base reflect this shift in attitude. The intent of the Protocol should therefore probably be understood as requiring a basic level of treatment according to current practices, rather than maceration specifically. Human waste disposal methods for field camps remain an issue (see Appendix VI for a table of all waste options researched).

The CRP CEE (Sect 3.6) stated, "*that black and grey water go into the sea following maceration*....". However, an amendment was made to the CEE in 1996, which allowed for the disposal of sewage in a non-macerated form directly into holes drilled in the sea ice at both the main camp and the drill site camp. The amendment was made because it was decided that in CRP's case the requirement to macerate was too severe an interpretation of Annex III, Article 5, because the CRP camp and drill site camp could not be equated with "*a station where the average weekly population over the austral summer is approximately 30 individuals or more*....". It was also argued that there would be difficulties in operating a system capable of macerating sewage in a temporary camp on sea ice in October where temperatures can range from -20º to -30ºC. The high cost in installing such a system and the lack of a feasible alternative also led to the decision to abandon maceration.

Untreated disposal of waste to the environment is less acceptable now than when the CRP began, due partly to increased concerns about introduced organisms and diseases. The maximum personnel numbers on-site for ANDRILL will also be higher than for the CRP. The disposal of untreated waste would have more effect at some of the proposed ANDRILL sites than the CRP sites. This includes close inshore where currents may be poor and the sea floor closer, or in nutrient poor and little understood marine environments beneath the ice shelf.

The human waste to be disposed of has been be calculated from figures based on the average adult excreting 1.8 litres of urine and faeces per day[1]. The maximum number of personnel at an ANDRILL camp would produce approximately 5000 litres of human waste per season (48 people x 60 days = 2880 person days. 2880 x 1.8 litres = 5184 litres of human waste per season), or 86.4 litres per day (48 people x 1.8 litres). The ice shelf camps could be operational for longer than the 60 days estimated for the sea ice camps and would therefore create a larger amount of waste over a season. This estimate does not include grey water or flush water should flushing toilets be considered. Both the support camp and the drill site will need toilets unless the drill site is situated within a short walking distance to the support camp. Research is still being conducted into the different products available on the market. Waste disposal techniques that have already been eliminated are in Section 2.5.6.2.

Two options of waste disposal are being considered by the ANDRILL project. The viable options identified are on-site treatment or return of waste back to MCM and SB where it could be treated or returned to New Zealand.

Option 1.

<u>Treatment on-site.</u>

Treatment of human waste on-site is preferable. A number of options have been considered and the most preferred is incinerating toilets. Two brands of incinerating toilet are currently being investigated by the ANDRILL project for use at the camps.

Storburn International Inc. manufacture a propane or natural gas-burning incinerating toilet that is equipped with a three gallon storage chamber which can accommodate 40 to 60 uses before an incinerating cycle. To initiate the cycle, an anti-foaming agent is manually added to the chamber, a pilot is lit using a built-in piezo-electric

[1] (1.8 litres GCAS 2000; 2.2 litres GCAS 1999; 1.3 litres of urine and faeces per day - Cold Climate Utilities Manual - Canadian Environmental Protection Programs Directorate; p.16-23)

igniter, and the burner activated. This procedure automatically locks down the unit so that it cannot be used while the burner is in operation. A complete incineration cycle takes approximately 4.5 hours for a full chamber.

Studies in the cold have been conducted on these toilets and they have performed well (EPA). The Storburn was found to effectively reduce human wastes to ash, even at low temperatures. On the coldest day tested, the exhaust temperature was measured as going from -11°C to 100°C (the boiling point of water) only one minute after ignition. On average the ash remaining after incineration amounted to 2.23 % of the total weight of waste treated in the Storburn. Moreover, microbiological examination of the resulting ash revealed no faecal contamination. The coldest temperatures tested did adversely impact incineration, however, because contents of the propane tank could not vaporise properly. To maintain an optimal fuel supply to the toilet, it has been recommended that the propane tanks be kept sheltered or heated when used in sub-zero conditions.

The maintenance in the gas incinerator toilets is fairly minimal. Storburn gas-fired toilets have no moving parts and routine maintenance involves periodic cleaning of the burner and regular removal of ash.

The Mikolet is a rotary incinerating toilet that uses kerosene. It is capable of processing 25 l of waste per hour and uses 10 l of kerosene per hour. It can be used while the burn cycle is on and should be burnt after each use. The Japanese have three such toilets installed at their Syowa Station in Antarctica. A small amount of ash remains in the drum when burning is complete (for more details see Appendix VI). The gas discharged from the drum is emitted to the air through a platinum catalyst, which diminishes the smell.

Option 2

<u>Removal from location</u>

Human waste would be removed from the location and returned to MCM and SB where it could be input into one of the systems (either at SB or MCM). This option may only be viable for the MIS location and perhaps SMIS because of the long distances to the other locations. Two tanks will be required so that they can be rotated. Tanks would have to be insulated, heated tanks if they were to be used as both holding tanks and to transport the waste. Tanks could be sled mounted. The electricity needed to heat these would be minimal. Resistance heaters would be built-in in case of failure in other areas.

USAP are currently making plans for waste to be picked up in a mobile tank from holding tanks at the airfields in McMurdo Sound and transported back to the treatment plant at MCM Station. The treatment plant at MCM Station has been set up to receive waste from this type of system. The treatment system at SB has the potential to handle the waste of up to 122 people equivalents (Scott Base has 86 beds). Waste, if transported back would have to be trickled into the system rather than added as a bulk amount. Flushing toilets at Scott Base produces 120 litres of water (including grey water) per person/per day. The amounts created at a field camp would be much less but a flushing system of some description would still be needed to get the waste into the tanks.

Grey water

Grey water is the liquid effluent from a household or building other than what comes from the toilet (i.e. kitchen, showers, laundry etc). It has fewer disease organisms and a lower concentration of nitrogen compounds than sewage or combined wastewater. All detergents used at the camps will be biodegradable. Approximately the same amount of grey water will be produced each day as the amount of freshwater produced each day. Based on the freshwater production of 4000 – 5000 litres of freshwater production at the CRP, it was estimated that approximately the same amount of grey water was produced.

There are units available on the market that will separate the solids out from the liquids and separate off the grease and fat. The remaining water will be filtered through fine meshes to remove particles and if clarity after screening allows UV treated on site, before being returned to the marine environment. Quantities of grey water will be too large to remove from the camp locations.

Liquid wastes will also include heated brine, formed during the fresh water production process from the RO unit. This will be which will be returned to the sea at a distance from the RO uptake and may be used to prevent the hole from freezing.

Disposal Options

Sea ice

Option 1.

Grey water strained using a grease/oil trap, followed by screening and UV treatment if possible. The liquid would then be disposed of through a hole or a crack in the sea ice.

Option 2.

Grey water strained using a grease/oil trap, followed by screening and UV treatment if possible. The liquid will then be disposed of into sea ice bulbs drilled into the sea ice. Disposal from the sea ice bulbs into the marine environment will be slower and will only occur when the sea ice breaks out.

Ice shelf

In options 1 and 2, grey water would be strained using a grease/oil trap, followed by screening and UV treatment if possible. UV treatment would take place if possible. Sludge created would be returned to MCM or SB.

Option 1:

Grey water disposal into a sub ice well initially melted with the HWD. There would need to be a heated drain from the plant buildings and a closure over the well entrance to protect it from snow fill and wind/cold air.

Option 2:

Grey water disposal into the sea at the base of the ice shelf with heated RO return in the seawater uptake. This would require water intake at depth. This process could be more susceptible to freezing and blocked circulation. A non-freezing circulation may be required (perhaps a propylene glycol loop).

Option 3.

A tanker will be used to transport the grey water back to SB where it will be trickled into the waste system. This option will only be viable with locations close to Scott Base (i.e. MIS).

3.4.7 Fuel management

Fuel management is a very important aspect of the proposed project, as large quantities will be consumed. Types of fuel, fuel containment, fuel usage, and re-fuelling of vehicles and machinery will all be discussed in this section.

3.4.7.1. Fuel types

A duel fuel system has been proposed for this project. Two types of fuel will be used in plant and vehicle operations for ANDRILL. These are Mogas (a military grade of unleaded petrol which is used in petrol and two stroke driven engines) and JP8 (also called AN8, which is a military grade of aviation kerosene containing an icing inhibitor), which is utilised for generators and diesel fuel vehicles (Table 9). Fuel containers will be coloured coded for identification purposes.

Table 9 Type, quantity, specification and storage of fuels and operating supplies for project duration of 9-10 years.

Type/use	Flash point (°C)	UN No.	Storage/transport
JP-8	38	1223	Tank containers, ISO
Mogas	37	1203	Drums / small tanks
LPG	-88	1075	LPG bottles

Liquified Petroleum Gas (LPG) will be primarily used for cooking and possibly heating.

3.4.7.2. Bulk fuel containment

The type of fuel containment for the project has not yet been finalised. There are two options currently under consideration, both of which involve secondary containment:

Option 1.

Fuel be stored in bulk fuel tanks of approximately 15, 000 litres. The tanks will be fitted inside modified ISO20 container units, which will be fitted to Aalener sledges. The tanks will either be double skinned or the ISO20 container will be modified to provide secondary double containment. All transfers of fuel will be conducted using electric pumps. The pumping system will be a transferable unit that can be fitted to the in-use tank, as there will be a number of tanks. It may be necessary to have an extra pumping unit to service the drill site if it is any great distance from the camp.

At least three tanks will be required for the more remote location MSV assuming refuelling at the Marble Point facility, and the SMIS, assuming refuelling at the Ice Runway or William's Field. Only 2 tanks may be necessary when bulk supplies are closer e.g. William's Field for the MIS site and Marble Point for NH. The bulk containers used this project will be checked on a regular basis to avoid corrosion.

Bulk fuel tanks will be kept at a distance from the drill site for safety purposes. A tank that will hold 15, 000 litres of fuel will weigh in the vicinity of 15 tonnes and on the sea ice this could cause depressions in the ice. Bulk containers will reduce the logistical demands involved with fuel drums.

The potential volume of a spill would be greater with bulk containment than several small containers. However, as noted in the *European Project for Ice Coring in Antarctica (EPICA)* CEE (October, 2000), the high risk of damage when drums have to be dug out is to be avoided. Proper and regular maintenance of fuel tanks should eliminate any accidents due to equipment ageing. Contingency plans will be made in case of any incidents and control measures will be in place (Section 5.3 and Section 5.5).

Option 2.

All fuel stored in drums (209 litre/55 US gallons). The advantage of storing fuel in drums is that it minimises the volume, which can spill, there is an ease of transportation both to the site (e.g. by helicopter) and at the site, and in retrograding unused fuels. Drums would never be filled to the top because of risk of spillage. The disadvantage in using drums is the high handling overhead (see the CRP statistics under Section 2.4.7.4).

Drums will not be stored on the ground as the risk of them becoming snowed-in and then damaged while being extricated is too great a risk. To overcome this problem fuel will be stored above ground in either sledges or on fuel frames built for the storage of the drums (as in the CRP). Tarpaulins will enclose the drums on the fuel racks and act as a secondary containment mechanism.

3.4.7.3. Daily fuel supply storage

The fuel needed for the running of the camps will be held in tanks fitted inside ISO20 containers (Figure 9 and Figure 11). Secondary containment will be part of the tank design or the ISO20 containers will be modified to provide secondary. It is intended that these tanks will have the capacity to run each site for approximately 5 days (approximately 5000 litres). The fuel containers will not open into the camp link at either camp and can be easily towed from sites in case of fire. The plant room and HWD containers will require a ring main type system probably fed via roof mounted pipe work. Small engine fuel containers will also be kept within the containers.

3.4.7.4. Fuel usage

A calculation of between 120, 890 litres and 223,170 litres of fuel per season (depending on the drill site) has been estimated for ANDRILL (Table 10). The MIS sites and the SMIS sites will require up to 50% more fuel than the sea ice sites, with a combination of the HWD and the new multipurpose rig being used. The multipurpose rig will use approximately 550 litres of fuel per 24 hours. This is a maximum effort estimate. The HWD will be run intermittently – to drill the hole at the beginning and then further intermittent reaming to maintain it.

Two generators will be running on this project at any one time - one at the support camp and one at the drill site. However, the extra energy requirement of ANDRILL, in comparison to those of the CRP, may necessitate the running of two generators at the support camp or the introduction of more powerful generator to the support camp, with one of the smaller generators retained as a back up (for energy requirements see Section 2.4.8.1). The fuel consumption of the current generators is 10 litres per hour when continuous and 11 litres per hour when on standby.

The CRP used a total of 1180 drums (209 litres) of JP8 fuel and 50 drums of Mogas over the duration of the CRP. The drums were refuelled as required at Marble Point. A total of approximately 212, 000 litres of fuel was used throughout the project. It has been estimated that each drum was handled approximately five times before being emptied, with a total of approximately 6000 drum movements. The CRP used approximately 80 tonnes of fuel per season.

Table 10 General fuel requirements including preliminary estimates of volume required for the McMurdo Ice Shelf.

	Fuel Type	Usage of fuel per 24 hours	
Support Camp		**Ice Shelf**	**Sea Ice**
Generator (Potential to use two generators)	JP8	250 litres primary unit (150 litres secondary unit)	250 litres primary unit (150 litres secondary unit)
Utility services (i.e. boiler, toilet, heating etc)	JP8	240 litres	240 litres
Ice shelf water circulation		205 litres	N/A
Total litres		695 litres	490 litres
Total days of operation		120 days	90 days
TOTAL		**83, 400 litres**	**44, 100 litres**
Drill Site			
Drill rig	JP8	550 litres	550 litres
Generator	JP8	250 litres	250 litres
Hot water drill	JP8	205 litres	N/A
Mud system/ sea water heating	JP8	240 litres	N/A
Total litres		1245 litres	800 litres
Total days of operation		90 days	70 days
TOTAL	JP8	**112, 050 litres**	**56, 000 litres**
Support vehicles daily average over a season			
Hagglunds x 2	JP8	100 litres (50 litres per hagglund)	100 litres (50 litres per hagglund)
Heavy Plant x 3	JP8	120 litres (40 litres per vehicle)	120 litres (40 litres per vehicle)
Skidoos x 4	Mogas/ 2 stroke mix	10 litres (2.5 litres per vehicle)	10 litres (2.5 litres per vehicle)
Total litres		230 litres	230 litres
Total days of operation		120 days	90 days
TOTAL		**27, 600 litres**	**20, 700 litres**
Miscellaneous Equipment			
Small engines	Mogas	1 litre per day	1 litre per day
Total days		120 days	90 days
TOTAL		**120 litres**	**90 litres**
Mogas total		**1320 litres**	**990 litres**
JP8 total		**221,850 litres**	**119,900 litres**
GRAND TOTAL		**223,170 litres per season**	**120,890 litres per season**

The fuel use for site preparation at the ice shelves will be considerably larger than the sites on sea ice because of the need for snow compaction. Site preparation at the ice shelve sites could take at least 30 days of preparation time, perhaps several seasons in advance (Table 11). The mobilisation of the camp and drill camp to the drill sites varies in distance from SB from 20 km to 150 km away. Up to 4 return trips may have to be made to these locations.

Table 11 Fuel estimates for preparation of sites and mobilisation of camp and drill camp to drill sites.

		McMurdo Ice Shelf	Southern McMurdo Ice Shelf	New Harbour	Mackay Sea Valley
Preparation of site					
Site preparation and access		30 days 2 machines 150 litres each = 300 litres per day	30 days 2 machines 150 litres each = 300 litres per day	Minimal	Minimal
TOTAL		**9000 litres** (Season)	**9000 litres** (Season)		
Mobilisation of camp and drill camp to drill site					
Distance (kms) from Scott Base to drill site		20 (x2)	85 (x2)	85 (x2)	150 (x2)
*Prime Mover Loads (PML)		18.5 PML 5 prime movers 4 return trips	18.5 PML 5 prime movers 4 return trips	18 PML 5 prime movers 4 return trips	18 PML 5 prime movers 4 return trips
Fuel usage	JP8	3256 litres	13, 840 litres 1020 litres (escort vehicle)	13, 464 litres 1020 litres (escort vehicle)	23,760 litres 1800 litres (escort vehicle)
TOTAL		**3256 litres** **9000 litres (preparation)**	**12, 680 litres** **9000 litres (preparation)**	**14,484 litres**	**52, 560 litres**
GRAND TOTAL		**12, 256 litres**	**21, 680 litres**	**14,484 litres**	**52,560 litres**

* Prime Mover Loads (PML) are the number of bulldozer or equivalent vehicle trips to mobilise the project equipment. The ice shelf sites will have more gear and therefore the loads will be larger and take longer.

3.4.7.5. Fuel handling procedures

Refuelling of tanks/drums will take place at Marble Point, William's Field or the Ice Runway depending on proximity of drilling sites to refuelling caches. Vehicle refuelling stations will be set up at each location and all refuelling of vehicles will take place at the station. The refuelling station will contain absorbent mats, shovels etc. Vehicle refuelling will be from an auto shut browser on the pumping unit. A fuel handling policy will be put in place for this project.

Option1. Bulk fuel tanks

The bulk fuel tanks would be taken to either Marble Point or McMurdo Station for refuelling. The smaller 5000 litre fuel tanks at the camps will be filled directly from the bulk fuel tanks.

Option 2. Drums

Drums will be transported on a sledge dedicated for refuelling purposes. The sledge will be fitted to contain any fuel spillage on the sledge. Fuel will be pumped from the drum using a pump screwed into the drum head. A small residue of fuel will remain in each drum when pumping is completed. The refuelling of vehicles will be carried out on the sea ice (when possible), with a portable drip tray under the fuel tank and in the designated re-fuelling area.

3.4.7.6. Lubricants

Lubricants and glycol will be stored in drums at the fuel storage area (the camp fuel sledge) at each location (Table 12). They will be transported as required to the ANDRILL camps and only the maximum needed will be taken out on site – the rest will remain at Scott Base. Lubricants are to be retained at the drilling locations on a very limited basis and held only at designated areas with drip trays to contain minor spills. Drip trays are to be used at all times when applying lubricants to plant or vehicles.

Table 12 Types of lubricants which may be used.

Type	Density at 15 deg C Kg/l	Pour point, deg C	Flash Point, deg C
Hydraulic fluid (Mobil DTE11 M)	0.86	-48	177
Synthetic engine oil (Mobil Delvac 1)	0.87	-54	228
Mineral engine oil (Mobil Delvac MX)			
Gear oil (Mobilube SHC (75W-90)	0.89	-48	204
Grease (Mobiltemp SHC 32)	0.95	Not established	204
Degreaser (ADP 8413)	MSDS not yet available		
Propylene Glycol	1.11	-57	107
2 Stroke Engine Oil	0.89	-30	228

Hydraulic fluids will be stored in marked drums. An inspection / maintenance programme will be put in place to ensure that the drums were in good condition and no leaks are apparent. One of the lessons learnt from the CRP is that drums do corrode. The drums would be placed on drum racks. Hydraulic fluid is to be handled in a similar fashion to fuel. A heavy-duty impervious polypropylene/nylon sheet will be suspended under the entire drill rig platform to contain any possible leakage or break in hydraulic lines. Permanent secondary containment systems will be put in place to retain the hydraulic fluid. Safety features such as an automatic shut off system may be added to the drilling system in order to identify a problem as fast as possible.

3.4.8 Energy and emissions

3.4.8.1. Energy

The power requirements for ANDRILL will vary depending on camp set up, personnel numbers etc. The power estimate for camp use is approximately 60-75kW and for the drill site 45-60kW. An emergency backup generator is required to support backup systems in the drilling operation.

The proposed ANDRILL project's power requirements are greater than can be met by the CRP generators (75 KVa; 60kW at continuous, 83 KVa, 66kW at standby) gifted to ANDRILL. If two of the generators are used to run the support camp and one is used to run the drill site then there will be no emergency generator available to either camp. Therefore, it seems likely that a new generator will be purchased.

Option 1

Both generators will be run simultaneously at the support camp with the ability to use only one generator at non-peak times. One generator will be used at the drill site and a second generator will be purchased to be present as an emergency backup.

Option 2

Purchase a more powerful generator (up to 126 kVA, 101 kW standby or 115 kVA, 92 kW) to use at the camp, with one of the current generators there as a backup. Use the two smaller generators at the drill site.

The CRP drill site generator logged a total of 5,727.45 hours. The camp site generators logged a total of 2,851.8 hours and 3,286.9 hours respectively. The proposed activity will be running generators for longer time periods especially at the ice shelf locations.

3.4.8.2. Emissions

The total quantity of gaseous emissions and particles released into the atmosphere are estimated for consumption of the entire fuel supply for the project. Total fuel consumption for the proposed activity is 789,100 litres. The fuel consumption of the generators is 10 litres per hour continuous and 11 litres per hour on standby. The exhaust gas volume will be 347 cu. ft/min. Table 13 shows the exhaust emissions of the proposed generators.

Table 13 Exhaust emissions of the proposed generators.

	CO_2	CO	HC	NO_x
Generator	450 gr/kWh	≤ 4.1 gr/kWh	≤1.5 gr/kWh	≤10.7 gr/kWh

The use of vehicles and the operation of the camp will cause emissions of CO, CO_2, HC and NO_x to the air, and ultimately the atmosphere and the snow surface. Total emissions from the generators per season have been estimated assuming 120 days of continuous operation at ice shelf support camps, 90 days at ice shelf drill camps and sea ice support camps and 70 days at sea ice drill camps (Table 14).

Table 14 Total emissions from generators per season.

	Ice Shelf		Sea Ice		Project total
	Camp site	Drill site	Camp site	Drill site	
CO_2	95.76	57.46	71.82	44.69	539.46
CO	0.87	0.52	0.65	0.41	4.92
HO	0.32	0.19	0.24	0.15	1.80
NOx	2.28	1.37	1.71	1.06	12.83

Hot Water Drilling

2500 litres of fuel will be burnt drilling the hole on the McMurdo Ice Shelf. This will involve emission of CO_2 and water vapour and small quantities of related gases.

Transport emissions

Vehicle movements will create emissions to air, which will eventually be deposited on the snow/ice surface or be carried into the atmosphere. Table 15 below shows the anticipated maximum output of emissions from heavy vehicles during site preparation and traversing with equipment, based on the EPA standards for particulate matter, carbon monoxide and nitrous oxides for a non-road 165hp diesel vehicle. New Caterpillar 'D6' model tracked tractors, which fit this category, would meet this standard.

Table 15 Heavy vehicle emissions in tons

		Site Prep	Traverses			
	EPA Standard	Ice Shelf	MIS	SMIS, NH	MSV	Project total
PM	0.22 g/bph-hr	0.01	0.00	0.00	0.00	0.02
CO	3.7 g/bph-hr	0.18	0.00	0.01	0.02	0.39
NOx	4.9 g/bph-hr	0.24	0.01	0.01	0.02	0.52

3.4.9 Transport

The form of transport to mobilise equipment to the drill sites is a major consideration. Air mobility (helicopters) may be required for remote sites, in addition to surface vehicle transport.

3.4.9.1. Helicopter operations

Helicopter usage is expected to be minimal for ANDRILL (compared to CRP), ranging from 10 hours for the MIS location, to 60 hours for the MSV locations in Granite Harbour. These hours vary according to the relative distance of each site from Scott Base, and assume helicopters will not be used for any main camp to drill site shift changes or frequent (e.g. daily) transport of core samples.

3.4.9.2. Ship operations

ANDRILL will utilise shipping for:

- Seismic surveying of MSV
- Transportation of ANDRILL equipment from Christchurch to McMurdo Station
    - Additional camp equipment including new containers and sledges
    - New multipurpose drill rig, riser & drill string
- Return transportation to Christchurch
    - At project completion - multipurpose drill rig & surplus camp equipment
    - Return of core to the United States.

The likely transportation provider for core to be returned to the United States is by the United States resupply ships ex Lyttelton.

3.4.9.3. Vehicle operations

It has been proposed that ANDRILL purchase its own vehicle fleet for project operations. The CRP placed a strain on existing vehicle resources at SB during drilling periods, a situation which would be worse with a longer ANDRILL project. The 8 to 9 year duration would mean that the purchased vehicles would be well through their useable life by the end of the project.

An initial assessment of vehicle requirements (100% dedicated to the ANDRILL project) is:
2 Hagglund all terrain vehicles
2 Heavy Plant vehicles (e.g. D6H Bulldozer - LGP)
1 Heavy lift Kassbohrer PB170, with Hiab crane
1 Heavy lift Kassbohrer PB170, with loader/bucket
4 Skidoos

It is worth noting that the CRP report recommended the availability of 3 Hagglund vehicles. Hagglunds should be available at both the drill site and the support camp site to ensure emergency rescue and evacuation is possible at all times. During the CRP, Hagglunds were not always in place for emergency situations, as they were used for other activities such as escorting fuel trains for refuelling. The availability of a third Hagglund vehicle would ensure that emergency rescue and evacuation procedures could remain in place and would allow the third Hagglund to be used for other purposes.

3.4.9.4. Roading requirements and site preparation

A road will need to be constructed to the MIS and SMIS drill sites and support camp area, approximately two seasons prior to drilling there. There are large time constraints for snow compaction for ice shelf sites, as it takes two years to make any sort of compacted surface. If a substrate base is used to form a compacted surface then the preparation time can be reduced. Compaction for the camps will take the form of berms or large compacted snow mounds.

Investigation into stability of the drilling rig at the different drill sites is also needed. In particular, the MIS is expected to require piles to underpin the drilling platform.

3.4.9.5. Mobilisation

A primary difference to the CRP style of operation is the need to deploy and mobilise equipment quickly to enable the drilling of more than one site in a summer season. During mobilisation from one drill area to another, the dedicated project vehicles will need to be supplemented by the Antarctica NZ and/or USAP fleets for periods of up to 3 or 4 weeks at a time. The availability of these vehicles will be a major consideration for the logistic support of these programmes. If plant is not available to move the project then there may need to be a mobilisation year in between the drilling years.

A prime mover vehicle of capacity equivalent to a D6 bulldozer (Challenger or large Kassborher) could be expected to tow up to 4 sledge-containers on a prepared sea ice route and travel 50 – 80 km in 10 –12 hours. The distances moved and the time it will take to mobilise the camp to a new site will be dependent on the number of vehicles available for this process.

Transport of cargo by sea may enable equipment to be off loaded near drilling areas but there is still a requirement to move from the ship to the camp sites, which may be a significant distance away. CRP drilling and camp equipment has all been sledge mounted to be towed on the sea ice. The sledge system enabled two ship offloads 22 km offshore of Cape Roberts and the return of equipment in excess of 270 tonnes 150 km back to Scott Base on the fast coastal sea ice in October and November 2000. The mobilisation of CRP equipment will only be practical on snow-covered ice shelves if roads are compacted but existing sledges may still have to be modified. Surface modes of transport are still the most practical, at least on the ice shelves in the vicinity of Ross Island.

It would seem prudent to consider aircraft mobilisation as a possibility for future operations and new equipment should consider the possible use of aircraft when defining specifications, design and costing. The ISO containers being used for the camp are too large to fit into C130 (Hercules) aircraft and can only be lifted by heavy lift helicopters, which are not available in Antarctica at present.

3.4.10 On site science

The Crary Laboratory at MCM will be used for much of the “on-site” science. However, core will not be transported before it has been split at the drill site as it would be hard to maintain the integrity of the core for later work if it was not all split and boxed immediately on retrieval. It is important that scientists are on-site for the ANDRILL project as core identification will be made as core is brought to the surface. If sediments of the target age and type are identified before the expected depths have been drilled, drilling may terminate early and equipment moved to the next target.

3.4.11 Storage areas

Equipment will need to be stored for winter between each drilling season. Snow accumulation in Antarctica can be a problem causing burial (and loss) of equipment. Storing equipment in snow proof containers or on mobile sledges largely eliminates this problem, especially during mobilisation and set up periods. The methods used to enclose structures such as the rig have to be designed not only for the operating period but also for conditions of winter storage.

Sea ice sites will require decommissioning/breakdown of camp and drill site and storage on land. Sites should be easily accessible from the sea ice; some consideration to the tide crack transition, e.g. bridging, may be necessary. Sites will be chosen for minimal impact and ability for natural healing. On the ice shelf the camp buildings may well be wintered where they stand. This will be dependent on the weather, as the extreme winds and snow accumulation in the Black Island area may preclude winter storage.

Each container will require 7.5 x 3 m ($22.5\ m^2$) of storage space. There are 65 separate sledgeable units (50 buildings and 15 associated sledges), which will need in the vicinity of $1463\ m^2$. If the containers are stored two deep they will need an area approximately 247.75 m x 6 m.

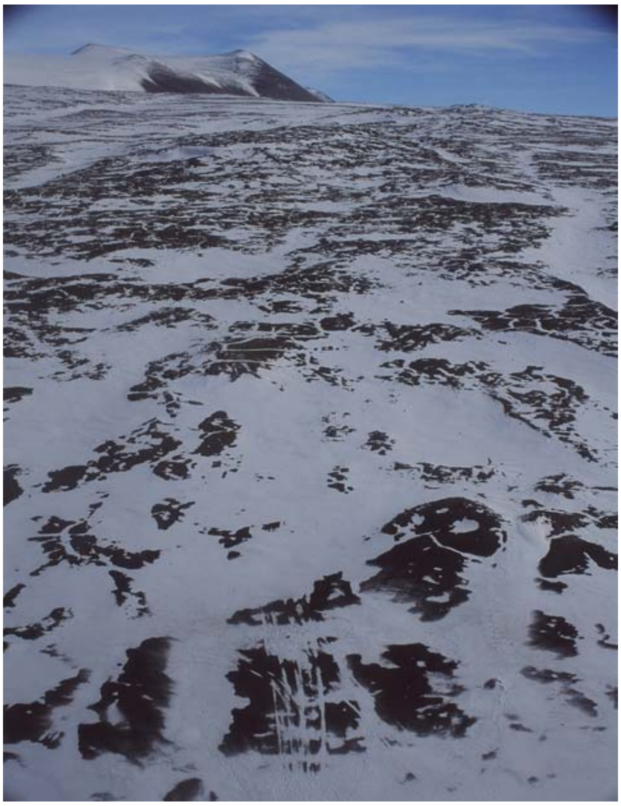
New Harbour

The camp will be disassembled at the end of each drill season and winter storage will be at one of two possible sites. It is proposed that the drilling gear used at the NH drill sites will be wintered onshore or close to onshore near Explorer's Cove. Gear would be wintered for at least one season if not two.

Summer ablation caused major problems for the CIROS drilling project, in which the camp was situated on the Bowers Piedmont Glacier at the southern entrance to NH. Remedial work was needed to re-level the camp area in 1984. Buildings had to be propped up and some materials iced in and were never recovered. Snow accumulation around buildings may reduce the effects of summer melt.

Option 1.

The drilling gear and camps will be stored at the decommissioned Commonwealth Camp site in NH (77° 34’ 944 S, 163° 35’814 E), which was finally removed in 1989. The beach at this location shows signs of disturbance in the form of track marks.



Jeremy Ridgen

Image 1 **Option 1: Storage site 1 with track marks, New Harbour (4 December 2002)**

Miranda Huston

Image 2 **Gravel surface at the proposed storage site 1, New Harbour (4 November 2002). Note the footprints in the top left corner for scale.**

The beach is a very fine gravel and sand with an even pebble surface cover. There is no soil profile and the permafrost is approximately 300 mm below the surface 100 m inshore on the beach, and down to 25 mm below the surface at the transition to the ice foot. Running the length of the beach, directly along the shoreline is the ice foot of Mt Barne, which stretches to Explorers Cove. The ice foot is approximately 25 m wide and could be used as the transport route to access the beach. It is estimated that if the area is raked after the storage phase, then the compacted areas will loosen and remediation of the area will be swift, 1-2 winters to remove visual evidence. This approach was effective at Cape Roberts.

<u>Option 2</u>

The drilling gear and camps will be stored at a bay immediately south of Cape Bernacchi (77°29' S, 163°50' E). There is a flat surface here with a slope of approximately 5° down to beach ridges. Vehicle tracks are clear with growser marks extending along at least 200 m of the beach. The vehicle tracks measure 30" x 6" and smaller tracks – possibly a sledge - measures 63" between tracks (centre to centre) with a 5" wide runner.

Miranda Huston

Image 3 **Track marks at the proposed storage site 2, New Harbour, 4 December 2002**

Miranda Huston

Image 4 **Growser tracks at the proposed storage site 2 in New Harbour. See footprints in centre of photo for scale.**

This location has a more established surface than the beach at Commonwealth Camp. The beach is solid coarse gravel with larger stones and pebbles. Algae are common on the underside of the stones. It is believed that remediation in this area will take a longer time than the site described in option 1 because the soil is more consolidated, with a more defined surface.

Miranda Huston

Image 5 **The solid coarse gravel surface with large stones and pebbles at Site 2, New Harbour, 4 December 2002.**

McMurdo Ice Shelf

Winter storage will be either on-site, which may require "dig out" operations as the snow accumulation here can be in the order of 9-40 cm per year, or at Scott Base.

Option 1.

The camp will be stored as it was set up and commissioned. The site will be prepared in advance of drilling work in the form of an elevated mound made from compacted snow or some sort of substructure (constructed of netting or steel poles).

Option 2.

The camp will be towed back to SB for storage.

Southern McMurdo Ice Shelf

The adverse weather conditions that occur around Black Island means that storage must be carefully considered. Further site visits are needed in this area.

Option 1.

The camp will be stored on land on Black Island, close to the road, which services a United States communication station.

Option 2.

The camp will be stored on the ice shelf in a snow area, with preparation having been made for the high snow accumulation renown in this area. Snow accumulation at potential sites will be monitored before use and natural shelter from the land will be utilised.

Gary Wilson

Image 6 **Snow accumulation around Hagglund and container-based camp of science group conducting seismic work south west of Black Island after 6 weeks, November 2002.**

The photo above shows a camp to the south of Black Island in November 2002. This camp was in place for one month and snow accumulation was severe. Snow accumulation is a major problem at this location.

Option 3

The camp will be towed back to Scott Base for storage.

Mackay Sea Valley, Granite Harbour

Several options are being considered as winter storage sites for the GH location. Further site visits will be made.

Option 1.

The camp will be stored at Cape Roberts where the CRP camp was stored each winter. Impacts were able to be managed well and recovery was swift.

AntNZ Pict. Collection

Image 7 Cape Roberts Project storage area.

Option 2.

The camp will be stored on the nearby Wilson Piedmont Glacier. This surface has an ablative ice / snow surface and may cause problems and damage to equipment when it is time to move the camp, if it is iced in.

Option 3.

The camp will be towed to Marble Point where it will be stored. A considerable area of the Point is already tracked and compacted and would receive little further impact from storage.

3.5 Alternatives

Consideration of alternative methods, logistics and support, locations, and timing is a fundamental method of minimising and mitigating environmental impacts of a proposal. There are a range of possible alternative methods, technologies, and sites for drilling and logistic support. As the options in the different sections are finalised they will be shifted to this section and become alternatives.

3.5.1 Alternative of not proceeding

This CEE provides an assessment of information to allow judgements on whether or not drilling should take place. With the long history of drilling in the Antarctic and the controls envisaged for this proposal it is difficult to see how not proceeding with the project would have significantly different consequences for the intrinsic, wilderness or aesthetic values of the region. Scientific values of the region would be enhanced by the project, assuming it will not have significant impacts on the different sites.

Without further records we cannot properly understand inter-hemispheric linkages and controls in the global climate and ocean system. The Antarctic region is conspicuously lacking in records of Cenozoic palaeoclimate, when compared to the North Atlantic and Arctic, yet the Antarctic craton supports a 30 million cubic kilometre ice sheet that if melted could raise global sea level more than 70 m (Denton et al., 1991).

A major motivation for ANDRILL is the recognition that while Antarctic stratigraphic drilling is logistically difficult, time-consuming and expensive, high quality well dated records are obtainable (Wilson et al., 1998; 2000). Such records are critical to understanding fundamental crypspheric behaviour and its influence on global climate. Moreover, given recent scenarios of CO_2 and temperature elevation (IPCC, 2000), the accurate prediction of future ice sheet dynamism relies critically on an accurate assessment of past ice sheet behaviour to compliment glaciological models.

Rock strata 40 million years old are not exposed in the region but erratics from this age transported by glacial ice can be found. Younger targets may be exposed in the region but are often of limited occurrence and are discontinuous. Drilling is the only way to obtain continuous samples of these *in situ* strata to determine a dateable geological record of an important time in the region's geological history. Hence drilling is the only way to achieve the objectives and obtain the resulting scientific benefits. The "do nothing" alternative would be to remain in ignorance, the consequences of which are very difficult to assess objectively.

3.5.2 Alternative regions

Several regions were proposed as possible drilling locations for ANDRILL including the eastern Ross Sea, the Weddell Sea, Palmer Basin, Terra Nova Bay, Beaver Lake, Prydz Bay, Lutzow-Holm Bay and Wilkes Land. It is possible that these target areas will be drilled in another phase of ANDRILL. The McMurdo Sound Portfolio was chosen because of logistical considerations, the extent of knowledge in the region, a proven chronological framework, and the level of international interest in this region.

3.5.3 Alternative locations and drill sites

Several alternative locations for drilling were considered in the development of ANDRILL - McMurdo Sound Portfolio. These locations are listed below with the reasons for non-selection. Science proposal were put forward at the Oxford Workshop (UK, April 5-7, 2001), a planning workshop to consider the ANDRILL initiative. From this workshop a science plan was formulated. The proposals presented were consolidated into a portfolio that consisted of a small number of carefully chosen target locations, which would answer the major climatic and rift history questions. Original drill holes located on volcanoes were combined with nearby ice shelf targets etc.

Ross Island

Mt Erebus is considered a geological hot spot, owing to its role in crustal extension and Gondwana break-up. A 1000 m deep drill hole was considered involving drilling from a land platform on the flanks of Mount Erebus. The aim would have been to investigate the early eruptive history of the volcano and understand the nature of magmatism with intraplate hot spot magmatism. Mount Erebus is the most active and largest volcano in Antarctica and may be the surface expression of an underlying mantle plume (Kyle 1990).

New Harbour

A third drill hole was proposed for NH. It was eliminated from the NH portfolio because the hole was determined to be too far off shore on the sea ice. There is a high risk that the sea ice would be unsuitable for drilling. It is more realistic that this would be a ship based target.

3.5.4 Timing Alternatives

It was originally proposed that ANDRILL would start drilling in the 2003/04 austral season. However, in March 2002, the ANDRILL International Steering Committee (ASC) met in Lincoln, Nebraska, USA to finalise the science plan, draft consortium agreement and scheduling for the McMurdo Sound Portfolio of ANDRILL and it was decided that drilling would be delayed a year to start in the 2004/05 austral summer. The alternative timelines are set out in Table 16.

Table 16 Compares alternative drilling options

	Option One	**Option Two**
Technology	New multipurpose drill rig with new (longer) drill string and sea-riser modified for drilling through the ice-shelf.	Use existing HD-44 Longyear (Emily) to drill New Harbour.
Drilling Season	**Drilling activities – Option 1**	**Drilling Activities – Option 2**
2002/2003		Emily refurbished in NZ then returned to SB in Jan 03
2003/2004	Multipurpose drill rig delivered to SB	**Drill New Harbour** & multipurpose drill rig delivered to SB
2004/2005	Test multipurpose drill rig (at SB ice shelf)	**Drill New Harbour** & Test multipurpose drill rig (at SB ice shelf)
2005/2006	**Drill New Harbour**	Transport - Mackay Sea Valley
2006/2007	**Drill McKay Sea Valley**	**Drill Mackay Sea Valley**
2007/2008	**Drill McMurdo Ice Shelf**	**Drill McMurdo Ice Shelf**
2008/2009	**Drill Southern McMurdo Ice Shelf**	**Drill Southern McMurdo Ice Shelf**
2009/2010	Final Cleanup	Final Cleanup
Advantages	• Lowest cost option, as no modification required to CRP rig, and expenditure is deferred. • Timing of MSV and NH sites may be interchanged.	• Drilling starts one year earlier than Option 1. • Early momentum gained for ANDRILL project. • More time available for testing of new technology. • Follows originally proposed sequence.
Disadvantages	• Drilling starts and finishes one year later than Option 2& 3. • Allows for no float or time contingencies.	• Higher cost – some mods will still be required to CRP rig. • Requires earlier expenditure for modification of the CRP rig. • May not be possible to

		mobilise from MSV to WB and drill in one season.

The disadvantages outweighed the advantages in these timelines and a preferred timeline was chosen (see Section 2.3).

3.5.5 Alternative drilling systems

Two alternative drilling options were considered for the ANDRILL programme.

Option 1: Purchase and develop only the multipurpose drill rig with modification of CRP platform for multipurpose drill rig powerpack.

Option 2: Refurbishment of CRP rig (Table 17) and system with modification of CRP platform for CRP and multipurpose drill rig platforms.

The HD-44 Longyear Drill Rig (Emily)

Table 17 Specifications of the Drill Rig as expected in Antarctica

Feature	HD-44 Longyear Drill Rig (CRP)
Water Depth (sea riser)	<500 m (300 m proven)
Main Hoist (single line)	8 tonne
Coring Depth HQ drill string	900 m
Core diameter ranges	61 mm (HQ3) and 45 mm (NQ3)
Core recovery rate	20-30 m/day

The CRP drill rig was not chosen because it is only capable of drilling one location – NH. It was decided that time and money would be better spent on developing a drill rig capable of drilling all four locations.

It was decided at the Shanghai meeting, 20 July 2002 that a new multipurpose rig will now be used for all sites.

3.5.5.1. Alternative antifreeze fluids

Alternative antifreeze fluids that have been considered for use in the HWD process are ethylene glycol, ethanol or isopropyl alcohol. These fluids were disregarded because they would have more impacts no the environment and the latter two fluids have higher flammability ratings.

3.5.6 Alternative Camp Operations

3.5.6.1. Alternative Storage areas

New Harbour

<u>Alternative 1.</u>
A USAP Jamesway structure has been positioned at Explorers Cove (77º 34'S, 163º 31'E) for several seasons and is occupied annually. This location is further away than the preferred storage options and is surrounded by rougher multi year sea ice. The flat area at this location is a delta environment. There have been experiments in the past to monitor the amount of water coming through this area.

Alternative 2.
An alternative storage option considered is at Butter Point on the nearby Bowers Piedmont Glacier (ablative ice/snow surface). This alternative was not desirable because of lessons learnt from CIROS. The CIROS drilling project had a camp at Butter Point. The main issue at this site was the considerable amount of ablation occurring. Buildings were frozen in and had to be dug out and supported with timber bearers. The timber bearers were then frozen in and recovery of these substructures became impossible. The risk of loss or damage to equipment is too great at this location and it has therefore been deemed unsuitable as a storage site for New Harbour.

3.5.6.2. Human waste alternatives

Several options for disposing of human waste were investigated. The options below were considered undesirable for various reasons. A table demonstrating the advantages and disadvantages of each alternative is in Table 18. More detailed information can be found in Appendix VI.

Dispose of waste into sea ice or ice shelf.

Mackay Sea Valley and New Harbour (Sea ice)
The MSV and NH support camps and drill camps will be based on sea ice in very similar conditions to those of the CRP camp. At the CRP camp holes of approximately 600 mm diameter were augured to around 1.5 m depth in the ~2 m sea ice. The holes could hold a volume of approximately 360 litres (5000 litres per season would mean approximately 14 holes).

Using the same methods for ANDRILL two latrines would be maintained, with each being moved to a new hole every week or so. Used holes would be backfilled with snow and marked with a flagged cane. It is expected that the sewage bolus will gradually thaw as the sea ice rots and breaks up in late January/early February. The pockets of sewage would be released at different times and widely dispersed. Dispersal is expected to be rapid with a very high dilution rate. The area of degraded water, i.e. where nutrient and bacterial levels may be higher than background, will be localised and temporary in nature. Consequently little, if any impact would be expected on marine communities. Holding sewage in the ice could affect the sea ice ecosystem within a radius of approximately one metre. However, impacts are likely to be transitory and negligible given the annually and seasonally varying nature of this extensive ecosystem.

The sea ice may not break out annually in Explorer's Cove, which could result in the waste being frozen in for several seasons. An option in this case may be to store the waste and periodically transport it to an open circulation area for disposal into a sea ice crack.

The EARP visit to CRP in November 1999 reported, "the unlined toilet pits (augured into the fast ice) are a practical, low energy approach that delivers what appears to be a satisfactory outcome".

Southern McMurdo Ice Shelf and McMurdo Ice Shelf (Ice Shelf)

At inland stations and camps, sewage and domestic liquid waste disposal has been approached in several ways. It is normal practice to dispose of domestic liquid and sewage wastes into ice pits at remote sites established on glacial ice and permanent snow fields, where logistical constraints prevent their removal. At Amundsen-Scott South Pole Station, such wastes are disposed of into a cavity approximately 38 m in diameter and 36 m below the ice surface, known as a "sewage bulb" (NSF, 1998). The bulb is formed by disposal of warm wastewater into a hole drilled in the ice, which gradually expands into a cavity at depth. A bulb can hold approximately 7.6 million litres of wastewater, and may last 5-6 years before a new bulb is required. Based on the average annual movement of the ice sheet, the sewage bulbs are not expected to be discharged into the sea for at least 100,000 when the ice calves at the continental margin. The hot water drill employed for ANDRILL makes it possible to drill such bulbs into the ice shelf at the two ice shelf locations.

Wastewater has been discharged directly into a snow pit at Williams Field for several years now. The ice where Williams Field is located will eventually reach the edge of the Ross Ice Shelf and break off into the ocean. It is expected that melting would occur slowly enough that dilution by ocean water would adequately prevent significant local water quality impacts. With the establishment of a new wastewater plant at McMurdo, waste will now be transported from Williams Field to the new wastewater system at McMurdo in customized tanks.

Chemical toilets

Chemical toilets were considered unacceptable by the very fact that they contain chemicals, (often sodium hydroxide) which would ultimately find their way into the Antarctic environment. The only way to avoid this would be to remove the waste from the continent - one of the other alternatives considered. Chemical toilets have to be heated and the contents still have to be handled.

Electric toilets

Incinolet - an electric incinerating toilet was closely examined for use on the ANDRILL project. This toilet costs US$1899 per unit and uses substantial amounts of electricity to reduce the sewage into ash. The relatively small loading capacity of these toilets - 4-8 people, made them unfeasible for a camp the size of ANDRILL at it's maximum. In a camp of 40+ people, there would be a need for 6+ of these units. Aside form the initial set up costs, the trialing of these toilets in Antarctic on this project seemed inappropriate. ANDRILL is a large project and needs to be running efficiently with equipment that has already been tried and tested.

The electricity demands of the Incinolet TR (a model recommended for heavy use, industrial and large family use) is set at 240 volts and 3600 watts. It uses approximately 15 (17) amps. Several people can use the toilet in rapid succession. Approximately 5 ml of ash are produced for each incineration cycle.

Composting toilets

Composting toilets are difficult to run effectively in Antarctica because of the low air temperatures. Greenpeace operated a composting toilet at their base at Cape Evans. Human waste was composted in a biological toilet (ROTA-LOO). This system required the addition of peatmoss and constant warm temperatures to maintain the composting process. Large amounts of peatmoss would have to be transported to Antarctica in sealed bags. The compost would then have to be removed. There could potentially be a high energy input. Only solids are treated, not the water content itself.

Table 18 Alternative field waste systems for ANDRILL camps

Type of system	***Reasons for not choosing this system***
Chemical toilets	• No solids would be removed. • Lime or chemicals would be added. These would have to be transported to Antarctica. • No organic matter would be removed. • Have to be heated. • Contents have to be handled.
Electric incinerating toilets	• Require large quantities of electricity. • Small loading capacity. • Maintenance requirements are high. • A high number of units would be required.
Composting toilets	• Requires the addition of peatmoss. Vast quantities of peatmoss would have to be transported to Antarctica. • Compost would have to be removed back to New Zealand. • Potentially a high energy input. • Only solids are treated, not water content itself. • Extraction needs to be frequent in a commercial type setting. • Quantity of waste produced will actually be increased rather than decreased.
Disposal of waste directly into the sea ice / ice shelf.	• Untreated waste will work its way back into the environment. • Protocol is now dated but still states that disposal into ice shelves and sea ice are not preferable options. • Environmental impacts in the marine environment could be high if nutrient rich waste is disposed of in the nutrient poor waters underneath the ice shelf.

4. DESCRIPTION OF INITIAL ENVIRONMENTAL STATE

4.1 The Regional Setting

The Ross Sea occupies part of a large triangular embayment between two crustal parts of Antarctica in the Antarctic continent (Figure 1) where the seaward edge of the continental shelf is 1100 km wide. Average water depth is about 500 m deep, much deeper than continental shelves elsewhere in the world. Four locations have been proposed as potential drilling areas for this project on the western edge of the embayment.

1. New Harbour (77º36´S, 163º51´E) is a bay about 18 km wide on the coast of Victoria Land on the western side of McMurdo Sound. It lies between Bowers Piedmont Glacier (Butter Point) and Cape Bernacchi. The Transantarctic Mountains, up to 1000 m high, form the western part of the embayment. New Harbour was discovered by the BrNAE (1901-04) and so named because this new harbour was found while the *Discovery* was seeking the farthest possible southern anchorage along the coast of Victoria Land.

2. The McMurdo Ice Shelf sites are proposed near the runway at William's Field on the McMurdo Ice Shelf. Hut Point Peninsula, where Scott Base is situated lies approximately 20 km to the west of the drill sites. The proposed drill sites are close to the area named Windless Bight (77º42´S, 167º40´E), which is the prominent bight indenting the southern side of Ross Island eastward of the Hut Point Peninsula. It was named by the Winter Journey Party, led by Wilson, of the BrAE (1910-13), which encountered no wind in this area.

3. The Southern McMurdo Ice Shelf sites are proposed beneath the McMurdo Ice shelf midway between Black Island (78°12'S, 66°25'E) and Brown Peninsula (78°06'S, 165°25'E). Black Island is located approximately 30 kms south of McMurdo Station in the McMurdo Ice Shelf. Black Island was so named for its colour, which occurs due to the perpetual high winds blowing the snow off the dark volcanic island. Black Island is 22 km long, projecting through the Ross Ice Shelf to a height of 1040 meters.

4. Mackay Sea Valley lies within Granite Harbour (76°53'S, 162°44'E), a bay in the coast of Victoria Land, between Cape Archer and Cape Roberts, in the southwest Ross Sea. Granite Harbour, about 22 km wide, was discovered and named by the BrNAE (1901-04) in the *Discovery* in January 1902, while searching for safe winter quarters for the ship. The name derives from the great granite boulders found on its shores. Mackay Sea Valley has been eroded beneath Granite Harbour and out to the Western Ross Sea by previous expansions of the Mackay Glacier, an outlet of the East Antarctic Ice Sheet (Barrett et al. 1995).

4.2 Description of Environment at each of the four locations

Table 19 gives a general overview of the environmental conditions at the four locations. Further detail I provided in the following sections.

Table 19 General environmental conditions of the four locations

	New Harbour	McMurdo Ice Shelf	Southern McMurdo Ice Shelf	Mackay Sea Valley / Granite Harbour
Geographical location	77º36´S, 163º51´E	77º42´S, 167º40´E	78°12'S, 66°25'E	76°53'S, 162°44'E
Ice thickness	Approx. 2 m of sea ice. Thicker multi-year sea ice is common.	60 – 160 m	9-20 m thick at the edge. Melt pools.	2-3 m of sea ice. Multi year sea ice occurs occasionally.
Drift velocity of ice sheet **Sea ice break out**	Sea ice does not break out every year in New Harbour.	75 – 120 m/yr	100-1700 m per year in the east to only 5-10 m per year in the west.	Sea ice breaks out most years.
Wildlife	Occasionally seals Lost penguins.	Rare lost penguins.	Rare algae – melt pools. Lost penguins.	Seals Skua Migrating penguins.

4.2.1 Weather and climate

(All weather data is from the Antarctic Meterological Research Center (AMRC), University of Wisconsin-Madison, http://amrc.ssec.wisc.edu).

A dominant characteristic of the large-scale weather pattern over Antarctica is the Circumpolar Trough (Waterhouse 2001). The weather at all of the proposed drilling locations is dominated by the cold polar climate with its strong seasonal cycle. Storms including major blizzards with blowing and drifting snow are generated by the weather conditions and may be more frequent and severe in autumn and spring.

Wind and low air temperatures will be the most likely weather elements to affect the proposed activity. Visibility and cloudiness would have lesser effects on the proposed activities although blowing and drifting snow during high winds could cause difficulties especially at ice shelf locations. The relative humidity around the Ross Sea coast is typically 60 to 70 percent, which at the low temperatures encountered represents a very small amount of water in the atmosphere. Over the Ross Ice Shelf, annual precipitation is generally below 200 mm (water equivalent), with slightly more falling over the mountains to the west (Waterhouse 2001).

General weather conditions at the different locations in the proposed activity are summarised in Table 20. No AWS are in New Harbour or Granite Harbour and the closest AWS to these areas, Marble Point, has been used for interpreting the weather conditions for this general area.

Table 20 General weather conditions at the different locations

	New Harbour, Granite Harbour (Marble Point)	**McMurdo Ice Shelf (Willies Field)**	**Southern McMurdo Ice Shelf (Black Island)**
Geographical location of nearest AWS	77°44'S, 163.69'E Marble Point	77°87'S, 167°02'E	SPAWAR/ Mac Weather AWS 130. 78°20.0' S, 166°45.1'E Data recorded at 78°07'S, 166°12'E
Elevation in meters	120 m	40 m	157.77 m
Predominant wind direction	South	East	South East
Mean wind speed (m s^{-1})	3.37 m s^{-1} (6 mph)	6.5 m s^{-1} (13 mph)	8 m s^{-1} (18.63 mph)
Max wind speed	24 m s^{-1} (53mph)	25.5 m s^{-1} (55 mph)	45 m s^{-1} (101.5 mph)
Mean air temperature in °C	-16.09°C	-22.4°C	-18°C
Minimum air temperature °C	-38.5°C	-53°C	-32°C
Maximum air temperature °C	2.6°C	5°C	4°C
Year of record	1994	1994	2000

4.2.1.1. Wind

NH, MIS, SMIS and MSV all have their own weather patterns and climates, which are determined by the interrelationships between the wind flow of the area, the terrain and the surface type (Waterhouse, 2001). The Transantarctic Mountains turn the prevailing easterly winds of the more open areas of the Ross Ice Shelf, to the north along the western side of the Ross Ice Shelf and the Ross Sea, so that prevailing winds, the "barrier winds" are from the south (O'Connor et al. 1994). Southerly winds run up against the mountains of Ross Island and are turned both eastwards and westwards around the high ground. Strong winds come in directly from the south and are funnelled between Black Island and Brown Peninsula where some of the highest wind velocities are expected at the SMIS locations. The turning of flows creates a region of calm along the southern coast of Ross Island in the MIS area.

New Harbour

Previous drilling experiences have shown that strong southerly winds can gust through this area and can cause quite substantial damage. The CIROS 2 drillsite was devastated by such winds in early November, 1984. The extremely strong wind gusts, which caused the major damage, occurred over a two-hour period. At Butter Point camp lesser winds were experienced, however, blowing snow prevented personnel movement during the same two-hour period.

Mackay Sea Valley, Granite Harbour

Katabatic winds from the west may be experienced in Granite Harbour because the Mackay Glacier is a conduit for cool plateau air. In the summer months these winds usually only last for about two-three hours and are not regular. More constant winds for periods of two or more days have been experienced rarely and are due to intense low pressure systems offshore.

<u>Marble Point</u>

The predominant wind direction at Marble Point is from the SE-SSE (Figure 12). There is little change in wind direction through the different months of the year. In January and February the wind direction is from the N for over 10% of the time and from the NNW for just under 10% of the time.

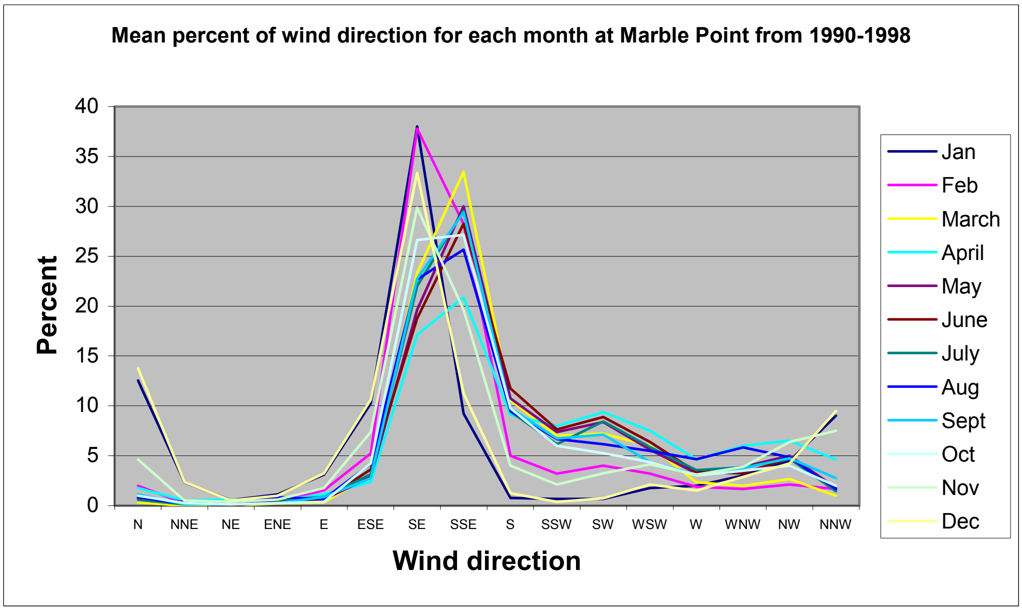


Figure 12 **The mean percent of wind direction for Marble Point from 1990-1998**

The wind speeds at Marble Point are predominantly in the 0-6 M/S (meters per second) range (see Figure 13). Extreme maximum wind speeds can reach up to 33 M/S.

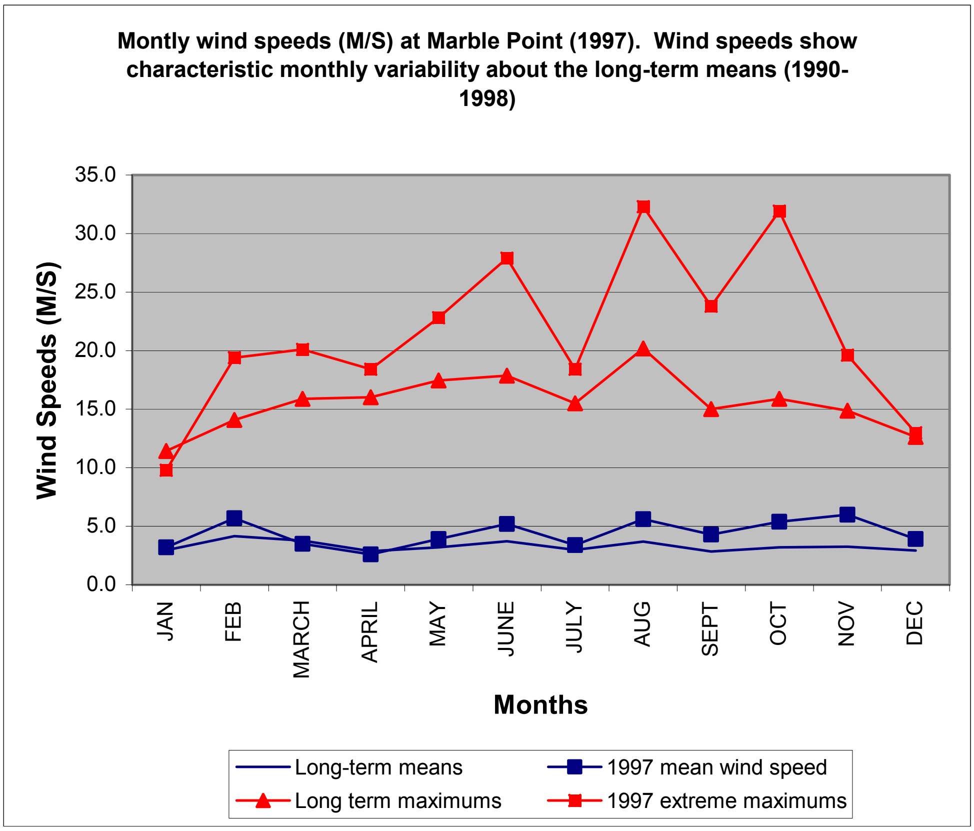


Figure 13 **Mean wind speeds (M/S) for Marble Point from 1990-1997/8.**

Southern McMurdo Ice Shelf

The southern McMurdo Ice Shelf is an area renown for high winds. Black Island was named because there is no snow cover due to the high winds that constantly blow the snow from it.

Black Island

An AWS is positioned at 78°20.0'S, 166°45.1'E to the south east of Black Island. Weather data from this station is now being archived by the University of Wisconsin. It is expected that by the time the Final CEE is due out a fairly good record will have been archived and analysis will have been done on this data.

Black Island Satellite Earth Station has been collecting weather information for several years now. The predominant wind direction at Black Island is from the south. The wind speeds are between 5 and 15 M/S on average but storms and high winds can blow as fast as 45 M/S as was recorded in July (2000). Figure 14 shows the variability of wind speeds experienced at Black Island.

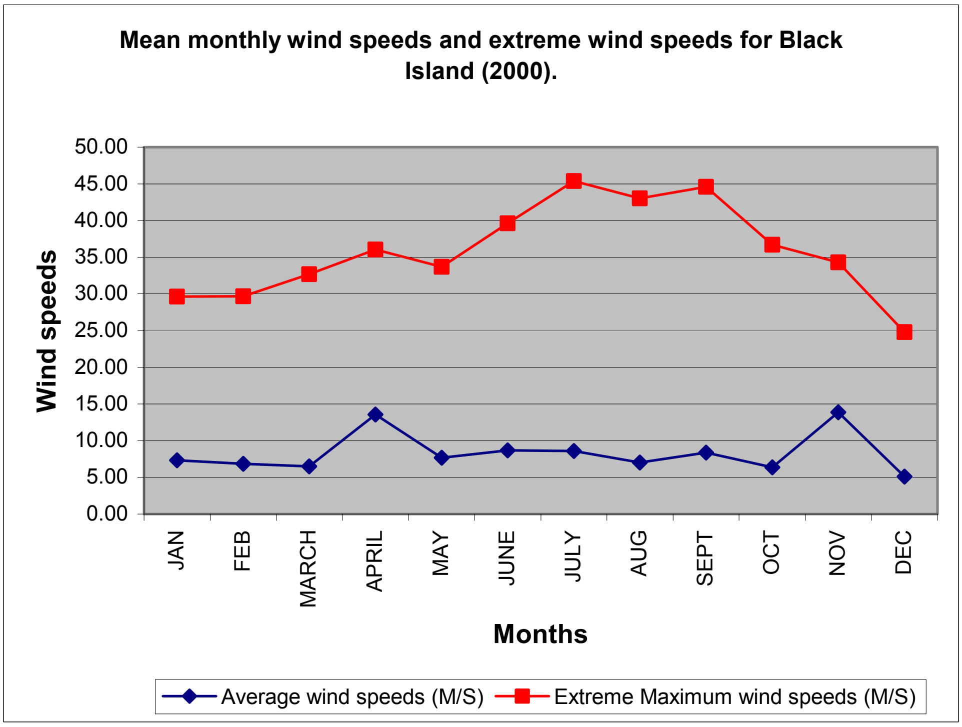


Figure 14 **Mean monthly wind speeds and extreme maximum wind speeds for Black Island 2000.**

McMurdo Ice Shelf

Ross Island is subjected to a strong southerly mountain-parallel wind regime. Scott Base, at the southern tip of Ross Island is frequently subjected to northeast winds, which in this region of southerlies is explained by the local turning effect described earlier (O'Connor and Bromwich, 1988). Windless Bight, within the vicinity of the proposed drill holes and is a region of anomalous calm. The flow of air around the terrain of Ross Island gives rise to locally strong winds; these are responsible for the ice breakout and polynya occurrences in McMurdo Sound (O'Connor and Bromwich, 1988).

<u>Williams Field</u>

Monthly wind speeds at William's Field are fairly low (Figure 15). The average winds experienced at this location are generally under five M/S. Extreme wind speeds can be as high as 27 M/S but are not commonly experienced and usually are not of long duration.

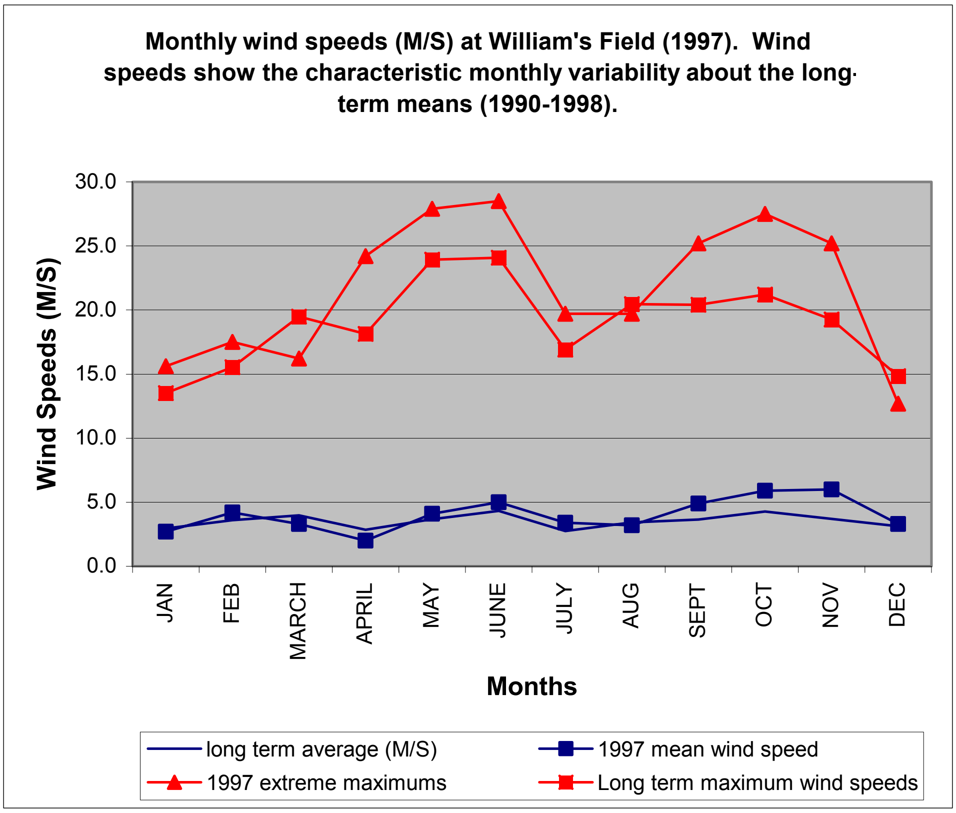


Figure 15 **Monthly wind speeds at William's Field for 1997 and long-term monthly wind speed averages (1990-1998)**

4.2.1.2. Temperatures

Most parts of the Ross Sea region experience surface temperatures which fall to below -40°C in winter, with temperatures above 0°C achieved only at the height of summer, usually on ice-free areas (Waterhouse, 2001). To accomplish the scientific aims and maximise the time for drilling especially on the sea ice it is necessary for drilling to start as early as possible in October when temperatures may be about -30°C. Minimum temperatures at Winfly (mid August through September) may be as low as -50°C. These colder temperatures will affect the ability of both staff and equipment to operate efficiently and safely. Design and operating criteria will take these temperatures into account.

New Harbour

Temperatures of sites on sea ice, such as the old CIROS sites, are characterised by lower mean and minimum temperatures resulting from frequent formation of surface based inversions. Strong winds destroy this inversion (Sinclair, 1982).

Mackay Sea Valley, Granite Harbour

It is expected that temperatures will steadily increase throughout the duration of each drilling season. Temperatures from Granite Harbour may be somewhat lower on average than for Marble Point where the closet AWS is situated.

Marble Point

Mean monthly air temperatures measured at the Marble Point AWS from 1990 to 1998 are displayed in Figure 16. Mean air temperatures will differ slightly at Granite Harbour and New Harbour but it expected that they will be fairly similar. December and January experience the warmest temperatures, followed by February and November. The mean monthly temperatures at the Marble Point AWS ranged from –0.8°C to –28.1°C. The extreme maximum air temperature recorded from 1990 to 1998 was 5.9°C recorded in December 1990. The extreme minimum air temperature recorded was –42.1°C, which was recorded in April 1992.

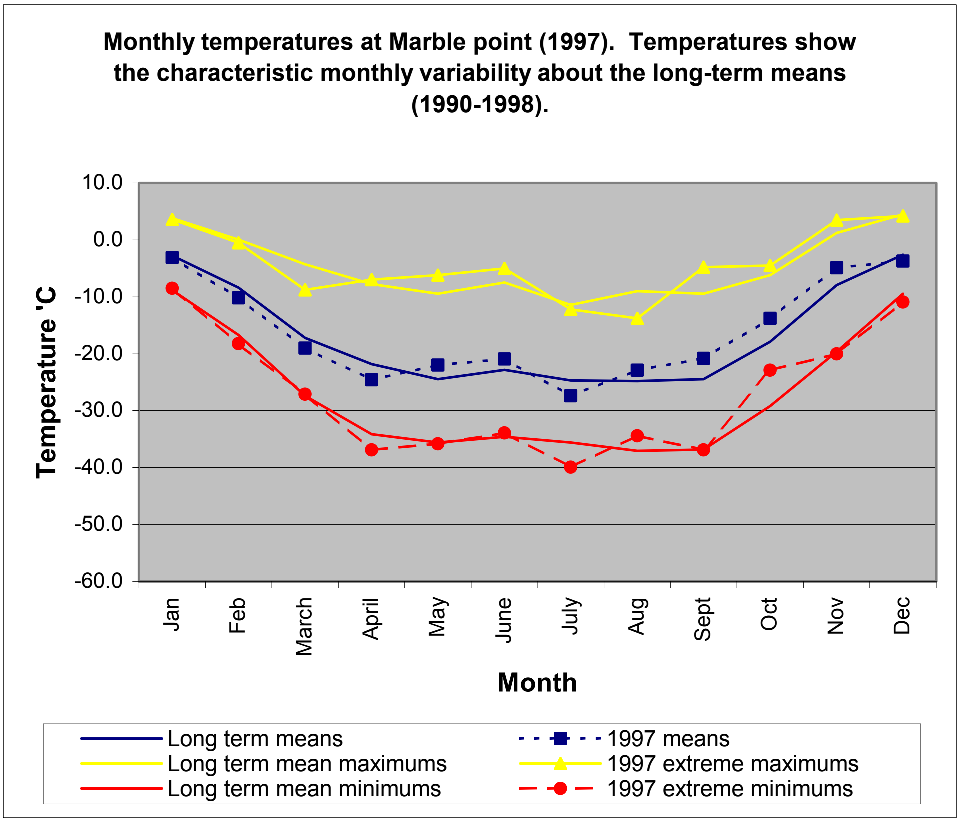


Figure 16 **Monthly temperatures at Marble Point (1997). Temperatures show the characteristic monthly variability about the long-term means, as well as the "coreless" winter.**

McMurdo Ice Shelf

The average air temperatures for Williams Field and the Windless Bight area are lower than at other locations within the near vicinity (Figure 17). There is a cold layer of air well established in these areas because of the light winds typical here. Minimum air temperatures of -51°C to -53°C were recorded at Williams Field in the 1992-1997 period. Scott's 1910-1913 expedition recorded the lowest temperature of their entire expedition -60°C in the Windless Bight area.

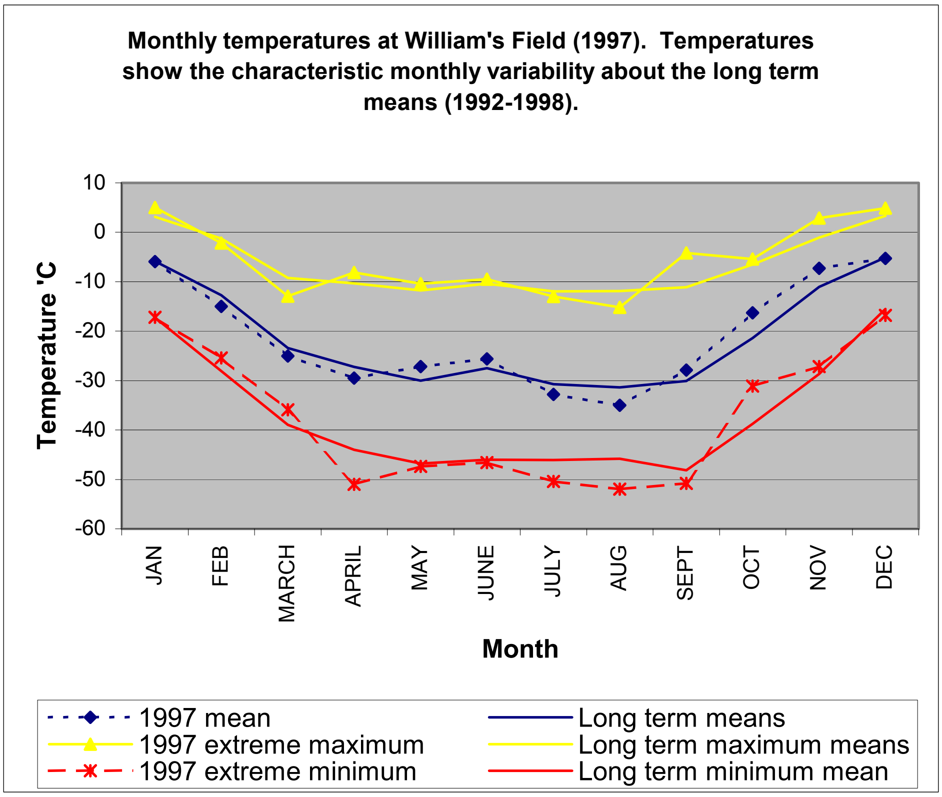


Figure 17 **Monthly temperatures at William's Field (1997). Temperatures show the characteristic monthly variability about the long-term means, as well as the "coreless" winter.**

Southern McMurdo Ice Shelf

The average air temperatures around the Black Island location range from –9°C to -23°C. However, the maximum temperatures can be over 0°C and the minimums below -30°C. The variability in the temperatures is typical of areas within Antarctica and illustrate the clear fluctuations in temperature between the winter months and the summer months when drilling is proposed to take place.

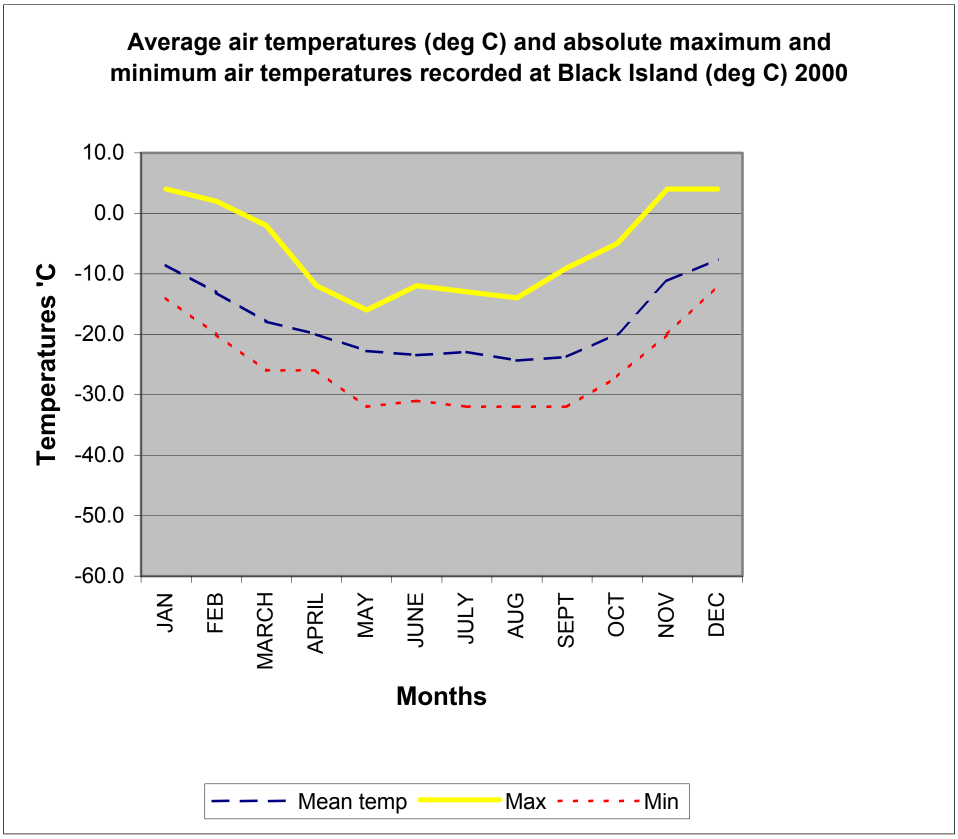


Figure 18 **Average air temperatures (°C) and extreme maximum and minimum temperatures (°C) for Black Island 2000.**

4.2.2 Terrestrial biota and soils

4.2.2.1. Soils

The camps may be stored on land at NH and Granite Harbour (MSV) (Section 2.4.11). There is also potential for storage on land at the SMIS location. Most soils in Antarctica are 'cold dessert soils' and lack topsoil, or accumulations of organic matter (Waterhouse, 2001). In the Ross Sea region, cold desert soils are characterized by extremely low soil temperatures, with mean annual temperatures ranging between -15°C and -40°C. As snowfall is extremely low, available soil moisture is also low and there is minimal biological activity. Soils lack distinct layers and are underlain by permafrost, a permanently frozen mixture of ice and soil. The processes that form the soils, including weathering and leaching, operate at extremely slow rates due to the harsh climates. The surfaces are diverse due to the harsh climate.

MSV storage at Cape Roberts (see Section 2.4.11)
Soils at Cape Roberts are young and only weakly developed (Campbell 1993). They typically have a pebbly to cobbly and boulder pavement surface that is unoxidised although some surface boulders occasionally show patchy staining. Beneath, the soil is loose and uncohesive, grey cobbly to bouldery sand. Soil depth at time of maximum thaw in mid January is generally about 55 cm (i.e. to permafrost). Summer soil moisture values at dry sites range from about 1% at the surface to 4.5% at the top of the permafrost (Keys, 1994).

NH storage at Option 1 and Option 2 (see Section 2.4.11)
Soils at the decommissioned Commonwealth Camp site in NH (Storage option site 1) are very young and very weakly developed (Image 2). They typically consist of fine gravel and sand with no soil profile. The surface is an unoxidised, fine pebble surface, beneath which is a fine sandy-silty material with few stones. The soil is loose and unconsolidated, which will make the finer particles vulnerable to wind dispersal when the soil is disturbed. Soils at the second option for storage in the NH area are more consolidated but still young soils with no signs of oxidization. The surface is a solid coarse gravel with largish stones and pebbles (Image 4 and Image 5).

Black Island
Black Island is of volcanic origin, with shallow scoria-derived soils. Should storage on land become the preferred option, site visits will be made to investigate the soils.

4.2.2.2. Terrestrial biota

There are no land based vertebrate animals or flowering plants in the McMurdo Sound region. Primary producers are bryophytes (mosses and liverworts), lichens, cyanobacteria (the most primitive group of organisms, which includes bacteria), and algae. Terrestrial fauna includes collembola (springtails insects), mites and groups of microscopic organisms (protozoa, rotifers, tardigrades and nemotodes). Extensive biotic communities occur sporadically where there is light, warmth, water and shelter from the wind (Waterhouse 2001). Moss and to a lesser extent lichens and alga are easily damaged by physical disturbance including trampling, although the alga are quick to recover.

Granite Harbour

The 1901-1904 National Antarctic "*Discovery*" Expedition collected plants and invertebrates from Granite Harbour. The type specimen (the first collected specimen of an original organism, which is used in the naming and description of that new species) of one species, *Didymoden gelidus*, was obtained from Granite Harbour in 1902. Botany Bay in Granite Harbor is the southern-most known location for the liverwort *Cephaloziella exiliflora*.

Botany Bay at Cape Geology has been designated an Antarctic Specially Protected Area (ASPA) No.154 (formally SSSI No. 37). It was proposed because of being an extremely rich botanical refuge for its high latitude location. This area has a lichen (more than 30 species) and moss (8 species) species diversity and abundance that is unique for southern Victoria Land. The structure and development of the moss and lichen communities are similar to those found more than 10° of latitude further north, with several species at their known southern limit. This area contains the most southerly record hepatic (*Cephaloziella exiliflora*). Of great significance is the size (up to 15 cm) diameter) of some lichen thalli (e.g. *Umbilicaria aprina*). The boulder beach has rich populations of both epilithic and endolithic lichens.

In addition to the lichens and mosses there are abundant growths of algae and large populations of invertebrates (collembola, mites, nematodes, rotifers) are also found in this area.

At Cape Roberts the vegetation is comparatively prolific relative to most ice-free area in the region but less extensive and diverse than in Botany Bay. Algal communities, and moss (probably *Bryum argenteum*) occur at Cape Roberts and are widespread in this region (Broady and Vincent, 1990). Vegetation is common where the soils are moist but uncommon in the drier gravel beach ridges. Invertebrates such as tardigrades, nematodes, mites, collembula and rotifers inhabit moss and alga communities and the moister soils.

Further quantitative information needs to be collected from all potential storage site areas.

4.2.3 Marine biota

Recent research has confirmed that the Ross Sea is one of the most biologically productive regions of the Southern Ocean, with estimated annual production four-fold higher than the average global ocean production (Saggiomo et al., 2000). An important component of the annual primary production is the microalgae that grow in association with the sea ice (Horner et al., 1992). The sea ice provides a growth substratum and refuguim for a complex microbial community consisting primarily of microalgae, bacterium, protozoa and small metazoa. Microalgal production follows a predictable pattern in the Ross Sea. Diatoms dominate early in the season. Zooplankton are also found in the Ross Sea region. They include protozoa, the larval and juvenile stages of copepods, herbivorous adult copepods, krill and molluscs. The zooplankton in the Ross Sea region are characterised by a complete absence of benthic larvae (Hecq et al., 2000), low biodiversity and diurnal and seasonal migrations (Mackintosh 1973).

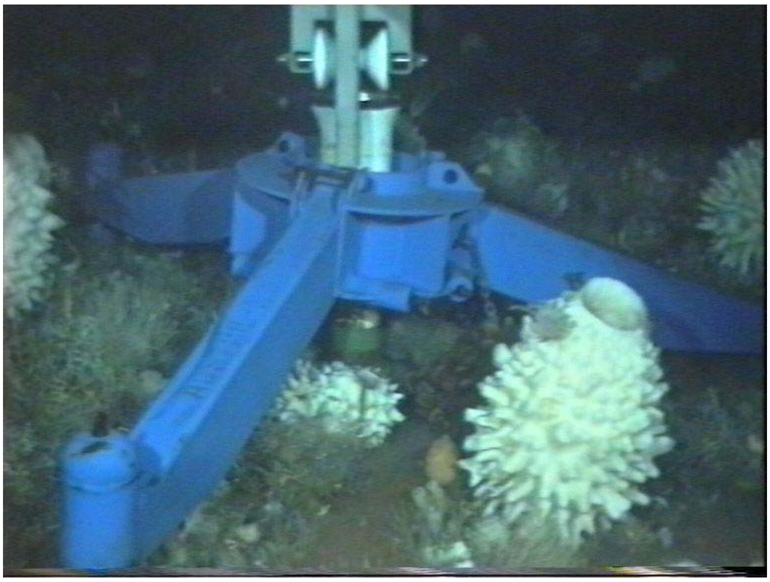
The marine ecosystem in the Ross Sea is believed to be stable although few reliable trend sets are available. The Antarctic marine ecosystem is quite variable naturally due to the massive annual change in sea ice cover– a phenomena that is currently being exemplified with the low breeding seasons being experienced by Adelie penguins in the McMurdo Sound area. Icebergs have made the break out of sea ice impossible forcing Ross Island penguins further a-field in search of food, resulting in the desertion of many nests.

4.2.3.1. Benthic communities

Rich and diverse communities of plants and animals, many of which are unique to Antarctica, live on the bottom of the sea floor in the Ross Sea region area. The relative species richness and high biomass of the benthos is more likely to reflect long-lived species, and stable communities, rather than high productivity. Attached species such as sponges grow very slowly and show little change from year to year. These habitats and communities may take a long time to recover fully from natural disruption and disturbance by icebergs grounding on the sea floor. However, benthos succession and recolonisation of iceberg scours by the more mobile species has been noted after only one year in Bay of Sails near Marble point (Oliver et al. 1976).

Virtually all studies that have looked at subtidal ecosystems in Antarctica have remarked on the extremely high diversity and level of endemism. With perhaps the only exceptions being decapod crustaceans (shrimps, crabs and crayfish) and cirripeds (barnacles), the species diversity in nearly all major groups of Antarctic marine invertebrates is at least 50-100 percent higher than in the Arctic and is comparable with temperate or even tropical environments (Dearborn 1968; White 1984, Arntz et al., 1997). Levels of endemism in the major groups of Antarctica's marine benthic fauna range from 50-90 percent of all species present, indicating a long period of isolation and independent evolution. One unusual feature of such specialisation is that a few groups account for much of the diversity (they have a high degree of dominance).

Soft sediments dominate the sea floor of the Ross Sea region. Barrett et al., (1983) sampled the seabed throughout Granite Harbour and McMurdo Sound and, with a few exceptions found muddy sand with relatively sparse macrofauna. In shallower soft sediment areas of McMurdo Sound, total biomass is generally lower than in those areas with hard substrates dominated by sponge communities, although the sponge spicule mat, and its associated abundant macrofauna sometimes occurs on consolidated soft sediment as well as rock. However, infaunal abundance in soft sediments may be extremely high, particularly in the east of McMurdo Sound where densities of up to 155,000 individuals per square metre have been recorded (Dayton and Oliver 1977). In contrast, densities were much less in the western McMurdo Sound with the total number only reading 10,036 at New Harbour. This decline has been attributed to oligotrophic conditions caused by nutrient impoverished water flowing north from under the Ross Ice Shelf.



Alex Pyne

Image 8 **The three legs of the blue sea riser guide base on the floor at Cape Roberts in Granite Harbour surrounded by white siliceous sponges, a sea floor silica needle sponge mat and numerous other benthic organisms.**

Under the Ross and McMurdo Ice Shelfs

Relatively little is known about the biological environment below the Ross Ice Shelf. In the late 1970's a major study was conducted to investigate life beneath the shelf 450 km from open sea (82°22.5'S, 168°37.5'W), and revealed some interesting results (Clough and Hansen, 1979). Results showed that although animals were present they were mostly sparsely distributed and possibly errant individuals that had strayed under the shelf. Mostly mobile crustaceans were observed. Remotely operated cameras also recorded one or two species of fish. Measures of productivity below the Ross Ice Shelf returned extremely low values combined with an almost complete absence of any animals living either in or on the bottom sediments (Azam et al., 1979). It is expected that more biota will be encountered at the proposed drill sites in McMurdo Ice Shelf and near Black Island as they are situated closer to open water than the sites discussed above.

New Harbour

Explorers Cove in New Harbour is at the mouth of the Taylor Valley and is completely dominated by soft sediments. The Antarctic scallop *Admussium colbecki*, the brittlestar *Ophionotus victoriae*, and the heart urchin *Abatus nimrodi* dominate epifaunal communities. No microalgae were observed at New Harbour, but there are visible growths of both seafloor and sea-ice microalgae (Hawes et al., 2002).

4.2.3.2. Marine Birds

Skua

The main fauna at any of the locations will be skuas (*Catharacta maccormicki*) which are the only bird species nesting close to any of the areas. The precise locations of territories and number of breeding pairs in the Ross Sea region is unknown. Adults arrive in October and settle on their territories from mid November to early December. Eggs are laid thereafter and chicks are present from about mid December (with peak hatching late December to early January) until fledging in April.

The CRP CEE sought expert advice on defining acceptable levels of change in skua breeding success. The opinion stated that:

> *"There is no point attempting to measure impact on skuas by comparing breeding success of this small sample within and outside the disturbed area. Antarctic skuas have variable and very low breeding success in most season and the causes of egg and chick loss are mostly not able to be documented."*
>
> *(Dr. Euan Young, December 1994).*

Cape Roberts information reflects the statement above with total pairs breeding and chick numbers fluctuating dynamically between years (Table 21). Results from this skua monitoring programme showed that skua population monitoring over six consecutive seasons showed fluctuations in numbers that was consistent with population trends noted in other long term skua studies (Waterhouse, 2001b).

Table 21 Skua Counts at Cape Roberts in January and December from January 1992 to 2001.

	Date	Western Colony	Eastern Colony	Storage Area	Total Pairs	Chicks
Dec 92	01/12/92	24-26	4-5	9-10	37-41	
Jan 95					No count	
Dec 95	12/12/95	No count	4	7-8	Data missing	
Jan 96					No count	3
Dec 96	30/11/96 01/12/96	28-32	6-8	9-11	43-51	
Jan 97	18/01/97				No count	28
Dec 97	02/12/97	38	11	3	52	
Jan 98	28/01/98	40	6	6	52	0
Dec 98	01/12/98	40-42	8-9	11-12	59-63	
Jan 99	26/01/99	30-32	5	5	40-42	17
Dec 99	04/12/99				Data missing	1 egg
Jan 00	21/01/00	29-33	6-7	6	41-46	4
Dec 00					No count	
Jan 01	18/01/01	11-14			11-14	7
	26/01/01	11	0	0	11	1

There is a colony of between 40 and 50 breeding pairs (and numerous non-breeding pairs) of South Polar Skua (*Catharacta maccormicki*) at Botany Bay, Cape Geology, Granite Harbour (Table 22). This is approximately the same number present in 1911-12. No other birds are known to breed in the Cape Geology area.

Table 22 South Polar Skua (*Catharacta maccormicki*) breeding populations on the coast of South Victoria Land (from Ainley et al., 1986 and McGarry 1988).

General area	Specific area	Date	Number counted from air	Adjusted number of breeding birds
Granite Harbour area				
	Cape Archer	29/12/1982	2	6
	Lion Island	29/12/1982	1	3
	Point Retreat	29/12/1982	15	44
	Cuff Cape	29/12/1982	1	3
	Discovery Bluff	29/12/1982	42	124
	Cape Roberts	29/12/1982	37	109
New Harbour	Marble Point	29/12/1982	23	68
		Dec 1997		35
	New Harbour Coast	29/12/82	45	132

New Harbour

There are no bird breeding areas in New Harbour although skua and occasional individual Adelie and Emperor penguins do frequent the area later in the summer as the sea ice edge retreats. Skuas have been reported nesting at Marble Point and the Strand Moraines (Spellerberg 1967).

4.2.3.3. Marine Mammals

Weddell seals are commonly hauled out in spring and summer (October-February), when they breed and molt at predictable cracks and leads in the fast ice. They are generally associated with inshore fast ice throughout the summer, where they establish breeding colonies and maintain access to the water by using perennial tide cracks.

Weddell seals migrate into McMurdo Sound annually, a first influx of pregnant seals occurring in October and a second influx of the main population in November period at sporadic periods along the sea ice tide cracks from the Koettlitz Glacier northwards. Concentrations of over 200 adults have been recorded near the Strand Moraines, south of New Harbour, in November (Ross et al., 1982). A few breed at the Cape Bernacchi tide crack and Marble Point.

Similar to the CRP, it is likely that in New Harbour and Granite Harbour transient individual seals may be present. At all CRP drill sites a seal was present and used the video sea ice hole 6 m away from the drill hole for breathing. General drilling activity did not affect the seals in any observable fashion. Potential impacts of the explosives on seals were noted. A second hole was drilled 600 m away from the drill hole to allow a breathing hole for the seal away from the explosives (seismic shooting) and drilling. The seal subsequently took up residence at this hole for the short time explosives were being used but reoccupied the video hole within an hour of the shooting finishing.

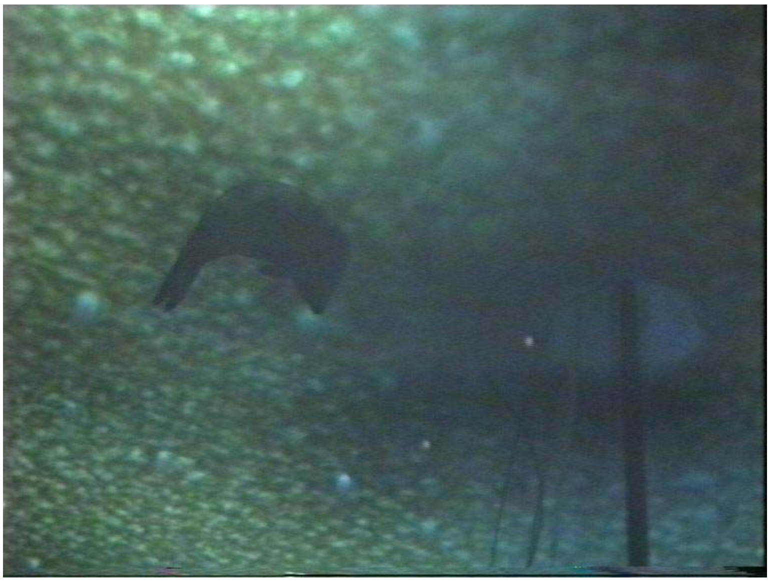


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Image 9 **Weddell seal swimming under the sea ice near the sea riser and sea ice access hole at the CRP-1 drill site.**

4.2.4 Ice and snow

4.2.4.1. Sea Ice

The unique sea ice environment of the McMurdo Sound Region has allowed for drilling projects in this area to be successfully undertaken. The stable fast sea ice that is present most spring and summer seasons in the southern part of McMurdo sound and in a 15-20 km wide strip along the western coast to Granite Harbour has enabled logistic and operational activities for over forty years. This has included a seasonal aircraft runway near McMurdo Station, surface vehicle access from McMurdo Station across the Sound to Marble Point, vehicle access along the coast to Granite Harbour and use as a platform for offshore drilling intermittently since 1975. The existence and use of the fast ice has been well proven over these forty years with an extensive operating knowledge developed primarily in the area of the annual ice runway where measurements of ice thickness and temperature are routinely made. However, for most of the larger area of McMurdo the sea ice winter growth and spatial distribution has not been well understood until satellite imagery was available beginning in 1988.

Drilling projects from 1979-1986 recorded some late winter ice thickness and a general ice growth model was established for the late winter and spring, (see Barrett and Davey, 1992) and showed strong seasonal variability primarily attributed to the frequency and severity of storm events during the autumn and winter.

The availability of DMSP imagery has enabled a major step forward in the understanding of local winter sea ice formation. To track the sea ice development DMSP images are required regularly at least once a week from the end of March, preferably after each storm event when the area is cloud free. At present DMSP imagery requires propriety Terrascan software. It would be preferable for individuals or groups carrying out near real-time interpretation to have the software and daily access to the McMurdo server on which image files are placed. Satellite imagery (especially high resolution infra red images) should be used to identify the extent of the sea ice during the period of ice formation (June - August) for a planned drilling season. However, it would still be necessary to 'ground truth' these data by measuring ice thickness at prospective drill sites at the end of August to decide if drilling should proceed for that season.

Polar satellite imagery received at McMurdo Station was made available to the Cape Roberts Project by the US Antarctic Program. DSMP infra red imagery with a pixel size of 0.5 km was found to be the most useful and cloud free mages were provided when available with a frequency of one or more per week. This was found to be sufficient to track the ice formation between storm events and calculate the age of the ice and approximate thickness as the winter progressed. This near real time data was, however, unsuitable for the prediction of future fast ice stability because of the unpredictability of storm events that cause ice breakout.

Satellite Imagery – SAR images have been extremely useful for activities requiring operations on the spring sea ice and enable route planning and pre-drill site evaluation. An annual image set including the ice runway area at McMurdo Station would be a useful resource for all sea ice based activities. An image acquisition in late July to mid August would probably be satisfactory for most spring users. The reliability of the acquisition timing is subject to failure of ground receiving stations.

The interpretation of fast ice requires not only good imagery but expertise in ice surface conditions and local knowledge. Ground truth and ice thickness measurements are necessary to calibrate imagery. The understanding of winter ice formation in the McMurdo Sound Region could be improved with successive years of satellite imagery adding to the analysis undertaken for CRP from 1989-99. Weekly images from the subsequent years should be made available from analysis.

Mackay Sea Valley / Granite Harbour

Granite Harbour, a basin reaching depths in excess of 800+ m, is commonly covered by 2-3 m of thick fast sea ice for most of the year. Some years the ice in Granite Harbour does not break out but instead forms rough multi-year ice.

New Harbour

The annual sea ice of McMurdo Sound begins forming as early as late March. Rare breakouts and refreezing in early August have been recorded (1975). In some years the sea ice does not break out at all in New Harbour.

4.2.4.2. Ice Shelves

Ross Ice Shelf (RIS)

The Ross Ice Shelf is a flat-topped body of snow-covered glacier ice floating over most of its area but grounded along coastlines and over other shallow parts of the sea floor. It is the largest ice shelf on earth, covering 532 000 square kilometres and with a volume of 23 000 cubic kilometres. The thickness of the ice shelf is not uniform at the local level and its surface is not always flat. Broad intrusions of ice up to 1000 m thick enter the shelf from West Antarctic ice streams and East Antarctic outlet glaciers, whereas the shelf thins to less than 100 m at the ice front.

McMurdo Ice Shelf (MIS)

The McMurdo Ice Shelf is the portion of ice shelf bounded by McMurdo Sound and Ross Island on the north, and Minna Bluff on the south. Studies show that this feature has characteristics quite distinct from the Ross Ice Shelf and merits individual naming.

The floating glacier system that occupies the southern part of McMurdo Sound is an unusual and complex feature composed of different ice masses. The eastern part of the McMurdo Ice Shelf is formed from snow accumulating on ice flowing westwards between Ross and White Islands from the Ross Ice Shelf contributed to by the Aurora and Terror Glaciers on Ross Island. Much of this ice is removed by melting (up to 3 metres per year) at its base.

Southern McMurdo Ice Shelf

This is the area between White/Black Island and Minna Bluff and Brown Peninsula. There is surface accumulation and ablation and basal freezing is possible. There is little distributary flow from the Ross Ice Shelf between Black and White Islands. In the west, the Koettlitz Glacier flows down from its upper part in the Royal Society Range out to McMurdo Sound (Hatherton, 1990).

The central portion of the glacier complex of the McMurdo Ice Shelf, between the Daily Islands and Black Island, seems to be formed from frozen sea water. This central zone protrudes farthest into the sound because it is thickest, and is clearly marked by moraine patterns on the surface. Apparently, ice in the central zone is formed in the tide cracks along the shores of Brown Peninsula, Mount Discovery, Bratina and Black Islands, in the water column or on the sea floor ("anchor ice") beneath the ice shelf, or directly on to the bottom of the shelf. Fresh or brackish water draining off the ice shelf through holes in it may also contribute after it freezes.

Prevailing southerly winds, low in moisture and warmed slightly while descending over Mount Discovery, probably accelerate ablation in this area and elongate meltwater features downwind. Ice velocities and thickness is much less than on the Ross Ice Shelf. Along the 9-20 metre thick ice front, speeds range from 100 and 1700 metres per year in the east to only 5-10 metres per year in the west.

4.2.5 Bathymetry; tides and currents

The drill sites are all found in south-western Ross Sea. The water depths exceed 900 metres in places less than 10 km from shore. Bathymetry and tides and currents all affect the drilling process. Currents beneath both the sea ice and the ice shelf will affect the sea riser pipe. Vertical tide movement of the floating platform must be accommodated by the rig platform. Specific site surveys and information gathering are presently being undertaken including bathymetry, ice movement, oceanography as well as geophysical and geological surveys to identify sea floor structure and specific drilling targets.

4.2.5.1. Circulation pattern of the south western Ross Sea

There are only a few current measurements made near the McMurdo Ice Shelf (Heath 1971) and these are only very short term over a period of a few days. In McMurdo Sound, Barry and Dayton (1988) report on mooring data spanning up to 27 days and Barry et al (1990) report on a longer term moorings of 294/272 days.

In southern McMurdo Sound around the Hut Point area of Ross Island (and specifically the embayment formed in the McMurdo Ice Shelf approximately 5 km from Cape Armitage to the ESE through to the SW), current circulation is complex with strong cyclicity and oscillatory flow. The main tidal constituents (dominantly diurnal K1 and O1) can be recognised but there is general consistent southerly to easterly flow at depth (below 200 m) under the ice shelf with a northerly trending flow from under the ice shelf above 100 m nearer Pram Point and Cape Armitage (Heath 1971b). Velocities are stronger in the intermediate water depths and are reduced by friction near the sea floor and under the ice shelf or sea ice. The north flowing water mass has higher temperature and salinity and was assumed by Heath (1971) to be sourced east of Ross Island from under the Ross Ice Shelf rather than from modification of the deep water McMurdo Sound flow.

In the southern part of the larger McMurdo Sound, Barry and Dayton (1988) show a similar pattern with strong oscillatory diurnal components based on 21 - 30 day duration current measurements. These are generally consistent with a longer-term measurement of 294-272 days made by Barry et al. (1990). Barry and Dayton (1988) note a consistent southerly flow of intermediate and deep water under the ice shelf in the eastern Sound with more oscillatory flow and a northwards component in the shallow water around Hut Point Peninsula and also in the western part of McMurdo Sound. They and earlier workers, argue from the lower salinity, temperature and other characteristics of the western Sound north flowing water that it could result from mixing beneath the McMurdo Ice Shelf of the deep south flowing water with eastern Sound water, sub ice shelf and terrestrial glacial melt water.

The late summer and winter measurements of Barry et al. (1990) show seasonal variability at a site 600 m deep in the southeastern McMurdo Sound. Deep water flow is to the south but there is a greater variability of flow in the upper water column which has a mean north flow component.

To estimate the likely range of current velocities, long-term current meter data from north of Ross Island and immediately in front of the Ross Ice Shelf Barrier are considered together with numerical modelling studies of Tidal Rectification (MacAyeal 1985) and a General Ross Sea Circulation model (Bergamasco et al. 1999).

Pillsbury and Jacobs (1985) from several moorings in front of the central part of the Ross Ice Shelf have measured mean annual velocities ranging from 6.4 to 11.8 cm/s and maximum ranges of peak flow, 3 to 4 times stronger between 18.7 and 41.7 cm/s, and are stronger in the winter. In this central area in front of the Ross Ice Shelf temperature and salinity stratified water masses are identified: High Salinity Shelf Water (HSSW), Low Salinity Shelf Water (LSSW), Ice Shelf Water (ISW) and Modified Circumpolar Deep Water (MCDW). In this central area current flow directions vary with position but from east and west occur under the ice shelf, along the ice shelf barrier and from under the ice shelf and are related to the different water masses. In the western area near Ross Island stratification is simpler with HSSW being dominant. MacAyeal (1985) has numerically modelled tidal rectification which is consistent in direction with the observed data but the mean velocities are under-estimated by 6 to 10 times and concludes that the thermohayline plus tidal rectification components drives currents in this area. Bergamasco et al's (1999) Ross Sea General Circulation model shows monthly transport directions (Lagrangian currents) and indicates significant differences in current direction compared to the tidal model circulation especially in the larger area of the Ross Sea. However, both models show the same south trending current in McMurdo Sound. The general model appears to estimate yearly mean current velocities better in the Ross Sea.

Regrettably neither model is much use in estimating velocities under the McMurdo Ice Shelf except acknowledging that some water column stratification is present in this area although weaker than in the south central Ross Sea near the ice shelf barrier (Pillsbury and Jacobs 1985). Although rectification from steep bathymetry near Ross Island could have a significant influence.

North of Ross Island and near the Ross Ice Shelf barrier, long-term current measurements have been obtained but these have less direct relevance to the McMurdo Ice Shelf (Pillsbury and Jacobs 1985; Picco et al 1999). However, these measurements together with more extensive temperature and salinity measurements do indicate the nature of flow beneath the Ross Ice Shelf that may also have relevance to McMurdo Ice Shelf circulation.

New Harbour

Current direction was recorded in New Harbour in 1984. Current speeds were below the threshold (~1.0 cm/s) of the instrument. Consequently, only current direction was recorded. The short currents records from this site indicated sluggish flow toward the NNE (20°) at both depths sampled (Barry and Dayton, 1988). In 1987 short term (12-24 hours) measurement in "central New Harbour" recorded currents within 1.5 m of the sea floor of less than 12 cm/sec (NZARP Event Report 1987-88, unpublished). Current speeds measured in embayed areas such as New Harbour and Granite Harbour were lower than those on the exposed coast.

Tides were recorded at the MSSTS Drill site immediately offshore of New Harbour from 1 to 25 September 1979 and 1 to 24 November 1979. The maximum tidal amplitude was 0.89 m. The main tidal variations fell within periods of about 24.20 and 12.20 hours (Pyne et al, 1981).

Mackay Sea Valley, Granite Harbour

Results from bathymetry studies carried out in 1983 showed that the bathymetry of this area is quite complex, for although Granite Harbour can be described in terms of gross terms as a broad basin almost 900 m deep, the floor is hummocky with a relief of 200-300 m (Barrett et al. 1983). Three Acoustic Dopler (ACDP) current meters were set up at the two proposed drill sites in November and December 2000 in Granite Harbour. Current velocities were no greater than 5-10cm.

An investigation of currents was undertaken in November 1998 in Granite Harbour (77.0151°S, 163.6190°E) showed that during spring tides, currents move in an anti-clockwise direction, through 360° over a 24-hour period with the larger flood tide of the day moving towards the northwest and continuing to swing around to the southeast for the subsequent low water. At a water depth of 55 m during spring tides, current speeds reach a maximum of 0.3 ms^{-1} around low water and may remin above 0.2 ms^{-1} for up to 6 hours on the largest spring tides. During neap tides, current speeds are mostly below 0.2 ms^{-1} throughout the water column, and at the sea floor, current speeds are less than 0.1 ms^{-1} (*Terra Antarctica*, Volume 7, No. 12 – 2000).

Southern McMurdo Ice Shelf and McMurdo Ice Shelf

The likely current regimes under the McMurdo Ice Shelf in Windless Bight and Southern McMurdo Ice Shelf area are currently being investigated. For sea riser (drill string) modelling the maximum velocities profile through the water column are required to analyse maximum stress in the pipe.

4.2.6 History of human activities

Drilling to recover sedimentary and rock core for numerous scientific investigations has been carried out in the McMurdo Sound region spanning the period 1975 –1999 (DSDP, DVDP, CIROS, MSSTS, CRP). Earlier drilling was also carried out on land by the McMurdo Dry Valleys Drilling Project (DVDP), which established relatively limited sedimentary records in the Dry Valleys. Seven offshore sites (Figure 19) have been cored from the local fast ice in McMurdo Sound since 1975 and a large amount of experience has been gained in both operational support and drilling procedure. The ANDRILL proposal is an extension of previous drilling projects carried out.

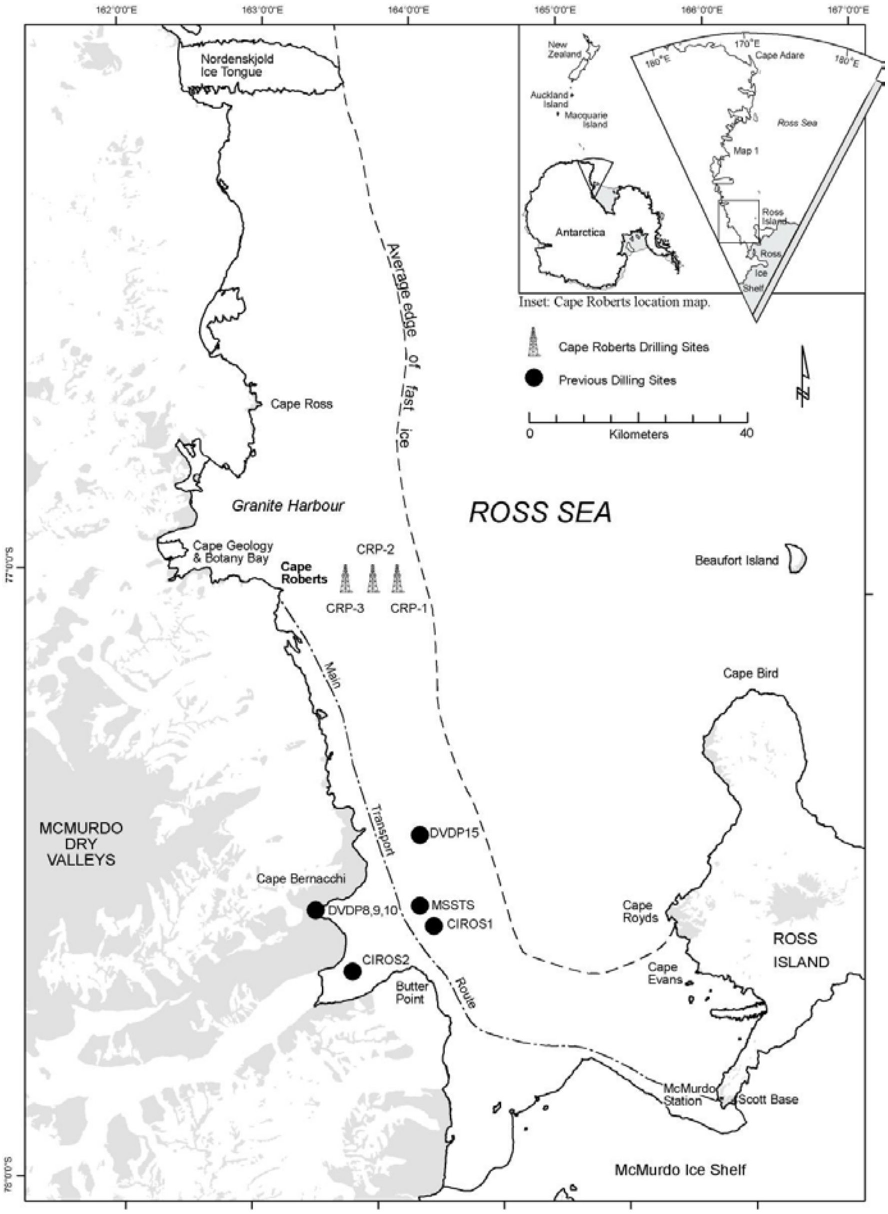

Figure 19 **Map showing the location of drilling sites from previous drilling projects in the McMurdo Sound Region (MSSTS, DVDP, CIROS, CRP).**

New Harbour

Historically there has been human activity based in the New Harbour area. On 14 October 1902, Scott cached some food at Butter Point in New Harbour. In 1908 Mawson and Mackay of the *Nimrod* expedition deposited food and clothing at Butter point. The first geological party from the *Terra Nova* deposited a cache here in January 1911. The *Terra Nova* expedition arrived from Cape Roberts on 8 February 1912 and set up a survey camp and established an emergency depot with one week's provisions at Cape Bernacchi, a rocky cape between Bernacchi Bay and New Harbour. On 1 November the Northern Party, also enroute for Butter Point, replenished their supplies from Taylor's depot. Further supplies were left here in November 1911 and then again in April 1912. The final visitors to Butter Point during the 'heroic era' were Shackleton, Joyce and Wild on 11 January 1917, searching for Mackintosh and Hayward at the close of the *Aurora* Relief expedition. The Ross Sea Party of the TAE placed a depot at Butter Point in 1957.

There have been several past drilling programmes based in New Harbour. In the 1970s MSSTS1 was drilled 12 km NNE of Butter Point. Drilling equipment and fuel were staged near to Cape Bernacchi. Between 1984 and 1986 CIROS-1 and CIROS-2 were drilled. The camp and equipment were stored for winter at Butter Point on the Bowers Piedmont Glacier. Camp Herb and Commonwealth Camp were also both located in New Harbour and were established from buildings remaining after CIROS-1 in 1986. Both of these camps were decommissioned in the late 1980s.

There have also been many short term endeavours in the New Harbour area. New Zealand science events have been visiting this area since the early 1970s. Research conducted in this area has included geological surveys, seismic surveys, drilling projects, visits by distinguished visitors, environmental management and monitoring, research into aquatic ecosystems and benthic communities, education and media initiatives. Explorer's Cove in New Harbour has a semi-permanent USAP camp set up as a staging post for many of the science events (especially the diving operations) that take place in this area.

McMurdo Ice Shelf / Windless Bight

William's Field, located on the Ross Ice Shelf provides support facilities for flights into and out of Antarctica when the ice runway is closed down usually mid December. The skiway complex itself is bigger than many of the Antarctic stations operated by other nations. Buildings are constructed mostly on sleds or skis. Numerous science events take place in this area. The US Instructors' Hut and the New Zealand A-Frame are both within this general vicinity as is the New Zealand ski field.

Southern McMurdo Ice Shelf

There has been a satellite earth station on Black Island, situated at the northern end, since 1985. It is a summer only station and has three staff over the summer. SPAWAR / Mac Weather Automatic Weather Station (AWS) 103 is located at 78.3° South and 166.8° E. A road traverses down the east side of Black Island, past ASPA 137 Northwest White Island, McMurdo Sound.

Mackay Sea Valley, Granite Harbour

In the summer of 1911-1912 during Scott's *Terra Nova* expedition, a field party of four men surveyed the coast and hinterland of Victoria Land. During their stay at Cape Geology, Granite Harbour, the members of the 'western geological party' built Granite House, a rock shelter used as a kitchen. This field party were based in Granite Harbour until January 1912.

Prior to 1982 the Cape Roberts area received only occasional passing visits from people based at McMurdo and Scott Bases, or expeditions from the "heroic" era on Ross Island, and from Marble Point. The only human feature of any historic note is the cairn on the promontory constructed apparently during the late 1950's but possibly dating back to the "heroic era".

Icebreakers and research vessels have worked off the area and entered Granite Harbour in the last 20 years after the ice has gone. Research has been mainly geological and geophysical involving seismic surveys and bottom sampling. The biodiversity and performance of lichens and mosses have also been studied extensively in this area over the last few years.

In the 1997-98 season the tourist vessel Marco Polo visited Granite Harbour and 349 people took part in small boat cruising.

4.2.7 Protected areas and other values

There are currently 20 existing protected areas under Annex V of the Environmental Protocol. in the Ross Sea region, 15 of which are in the McMurdo Sound area (Figure 20). Botany Bay at Cape Geology, Granite Harbour has been designated as an Antarctic Specially Protected Area ASPA 154 (SSSI No. 37), due to its rich and diverse plant life and also historic significance as the 1901-1904 the National Antarctic "*Discovery*" Expedition collected plants from this area.

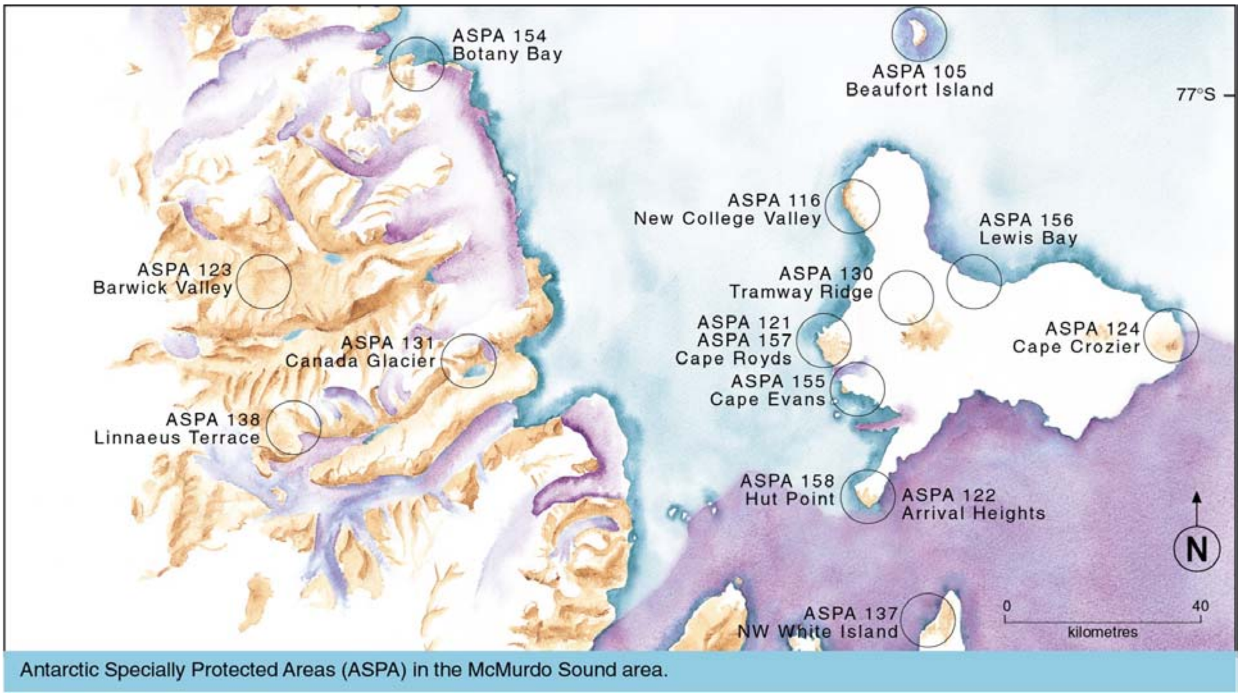

Figure 20 **Antarctic Specially Protected Areas (ASPA) in the McMurdo Sound area.** (Waterhouse, 2001)

ASPA 137 Northwest White Island, McMurdo Sound (167°20' E, 78° 00'S), is an area of 130 km^2 of coastal shelf ice on the northwest side of White Island. This locality contains an unusual breeding population of Weddell seals which is the most southerly known, and which has been physically isolated from other populations by the advance of the McMurdo Ice Shelf and Ross Ice Shelf. A flagged access route between the New Zealand and United States research stations at Pram Point and Black Island traverses within one kilometre of the Area.

4.3 Environmental state in the absence of proposed activities

The environments of the different locations are mostly in a relatively pristine state. Human activity has taken place at these locations in the past and will continue to take place in the future. The level of human activity at each location will continue to have a minor effect on the environment and cumulative disturbances will slowly increase as people continue to visit the areas. However, much of the disturbance is eliminated by natural processes such as sea ice break out, wind, and snow accumulation.

5. ASSESSMENT OF ENVIRONMENTAL IMPACTS

5.1 Methodology and data sources

5.1.1 Data Sources

In order to assess the impacts of the planned activities, relevant information has been collated on the purpose, type, duration (Sections 2.1, 2.2, 2.3), and nature and intensity of the proposed activities (Section 2.4). Outputs of these activities have been quantified wherever possible (Section 2.4). Environmental conditions in the proposed areas and the variability of those conditions have been described (Section 3). The following section will build on this information to discuss the potential impacts on the environment.

The Guidelines for Environmental Impact Assessment in Antarctica (COMNAP, 1999) gives suggestions on methods, procedures and evaluation criteria in respect to activities in Antarctica and the processes for writing EIAs, and was followed wherever practical.

Sources of information used for this Draft CEE included previous environmental impact assessments for Antarctic activities, which provide an insight into and knowledge base on potential environmental impacts, procedures for assessing those impacts and ways of minimising them. EIAs consulted include *CEE for Antarctic Stratigraphic Drilling East of Cape Roberts in Southwest Ross Sea, Antarctica*, Keys 1994; *CEE for Recovering a Deep Ice Core in Dronning Maud Land, Antarctica*, Oerter (Ed. 2000); and the *Final Impact Statement for the Modernization of the Amundsen-Scott South Pole Station Antarctica*, NSF, 1998. The *IEE for Deep Ice Core Drilling Activity at Dome Fuji Station, Antarctica* (the second Dome Fuji Project – NIPR, 2000) also provided some useful information.

The *Cape Roberts Final Environmental Report 1995-2001* (Waterhouse, 2001), and the *Cape Roberts Project Final Report* (Cowie, 2001) were both useful sources of information, providing the most relevant information and experience for forecasting impacts of the ANDRILL project. The proposed activity follows five previous drilling projects in the region (Appendix VII), and reports and personnel from these were also consulted.

Information regarding the initial environmental condition at sites, the outputs of activities, and the impacts, which could be expected from their interaction, were taken from published scientific journals, web accessible data sets and communications from equipment manufacturers and other relevant personnel.

5.1.2 Methodology

The matrix method has been chosen for this Draft CEE as the main tool to identify, forecast and communicate likely and potential impacts of the proposal. Matrices have been used successfully in all of the EIAs mentioned above as well as many others and enable the potential environmental impacts to be described in a concise and logical manner.

A large amount of information on diverse and complex interactions will be summarised concisely in the matrices, and the range of cause-effect relationships between individual actions of the proposal and the environment will be systematically identified. The matrices will give information about the exposures of the environment to these actions and their outputs, but not their intensity which will be explained in the preceding sections.

Article 3 of Annex I of the Environmental Protocol to the Antarctic Treaty specifies three impact categories, which are as follows:

(1) likely direct effects (clause 3.2d)

(2) possible indirect and second order impacts (clause 3.2e); and

(3) cumulative impacts (clause 3.2f).

A **direct impact** is a first order effect, which is a change in environmental components that results from direct cause-effect consequences of interaction between the exposed environment and outputs (e.g. decrease of a limpet population due to an oil spill). Impacts of low probability are included (COMNAP 1999).

An **indirect impact,** or second order effect, is a change in environmental components that results from interactions between the environment and other impacts - direct or indirect - (e.g. alteration in seagull population due to a decrease in limpet population which, in turn, was caused by an oil spill) (COMNAP 1999).

A **cumulative impact** is the combined impact of past, present and reasonably foreseeable activities. These activities may occur over time and space and can be additive or interactive/synergistic (e.g. decrease of limpet population due to the combined effect of oil discharges by base and ship operations). Cumulative impacts can often be one of the hardest impact categories to adequately identify in the EIA process. When attempting to identify cumulative impacts it is important to consider both spatial and temporal aspects and to identify other activities, which have occurred and could occur at the same site or within the same area (COMNAP 1999).

A textual description is provided of these types of possible impacts on the relevant environments that may result from each particular activity.

To enable a description of the direct impacts of the proposed activities on the affected environmental resources in respect of type, extent, duration and intensity, the possible direct environmental impacts are evaluated using a matrix. This method complies with the recommendations and methodologies for previous environmental impact assessments of activities in the Antarctic (COMNAP, 1999).

The criteria used for assessing impacts on each environmental resource or element are:

- extent of the affected area
- duration of the environmental impact
- intensity of the environmental impact (Oerter 2000).

Potential impacts of transportation, preparation of the camp sites and erection of the support camp and drilling camp and the drill hole itself relate primarily to the ice/snow environment and ambient air quality. Winter storage of equipment is the only activity expected to take place in the terrestrial environment. The criteria for the assessment of potential impacts on the environment is displayed in Table 23. Within the matrix the term 'snow/ice environment' embraces both the ice shelf and sea ice. These criteria have been adapted from the EPICA CEE.

Table 23 Criteria for assessment of potential impacts on the environment

Impact	Environment	Criteria of assessment: Low (L)	Medium (M)	High (H)	Very High (VH)
EXTENT OF IMPACT	*Air* *Snow/ice* *Marine* *Terrestrial* *Aesthetic & Wilderness*	Local extent Confined to the *site* of the activity.	Partial extent Some parts of an *area* are partially affected.	Major extent A major sized *area* is affected.	Entire extent Large-scale impact; causing further impact.
	Flora and Fauna	Confined disturbance of fauna and flora within *site* of activity, e.g. individuals affected.	Some parts of the community are disturbed.	Major disturbance in community, e.g. breeding success is reduced.	Impairment at population level.
DURATION OF IMPACT	*Air* *Snow/ice* *Marine* *Terrestrial* *Aesthetic & Wilderness*	Short term Several weeks to one season; short compared to natural processes.	Medium term Several seasons to several years; impacts are reversible.	Long term Decades; impacts are reversible.	Permanent Environment will suffer permanent impact.
	Flora and Fauna	Short compared to growth period/ breeding season.	Medium compared to growth/ breeding season.	Long compared to growth/ breeding season.	Permanent.
INTENSITY OF IMPACT	*Air* *Snow/ice* *Marine* *Terrestrial* *Aesthetic & Wilderness*	*Minimal Affect* Natural functions and processes of the environment are minimally affected. Reversible.	*Affected* Natural functions or processes of the environment are affected, but are not subject to long-lasting changes. Reversible.	*High* Natural functions or processes of the environment are affected or changed over the long term. Reversibility uncertain.	*Irreversible* Natural functions or processes of the environment are permanently disrupted. Irreversible or chronic changes.
	Flora and Fauna	Minor disturbance. Recovery definite.	Medium disturbance. Recovery likely.	High levels of disturbance. Recovery slow and uncertain.	Very high levels of disturbance. Recovery unlikely.
PROBABILITY		Should not occur under normal operation and conditions.	Possible but unlikely.	Likely to occur during span of project. Probable.	Certain to occur -unavoidable.

Organisms in or on the ice and snow that may be impacted along the transport route, at the camps and at the drilling sites include seals, birds, and micro-organisms such as algae. There is considerable interaction between environmental elements, and organisms particularly, may not fit neatly into one category. Seal and bird individuals (which may be either above or below on the ice shelf or sea ice surface), are more likely to be affected at an individual level while oganisms, such as plankton, nekton and benthos, are more likely to affected at a community level.

Consideration was also given to the *likelihood* of potential impacts or environmental strains actually occurring. A forecast is made on the basis of the planned activities and their known characteristics and risks (Section 2). A distinction is made between impacts that are certain to occur (unavoidable impacts), impacts that are likely to occur given experience to date (probable impacts), impacts that could possibly occur but that are unlikely to occur if all precautionary measures are implemented (possible impacts), and impacts that should not occur under normal operation and conditions.

5.2 Assessment of direct impacts of the planned activity on the environment (includes a matrix)

The potential impacts of the ANDRILL operations on the protected environmental resources specified in Article 3 (2b) of the Protocol of Environmental Protection to the Antarctic Treaty are examined in more detail in this section. This analysis is based on the description of the activity itself (Section 2) and the initial state of the environment at each ANDRILL location (Section 3).

The impacts are considered in terms of each of the following environmental resources:

- snow/ice environment (sea ice, snow, ice shelf);
- air quality;
- climate and weather patterns;
- flora and fauna (in the vicinity of the transport route and camps);
- marine environment;
- terrestrial environment; and
- aesthetics and wilderness.

5.2.1 Snow/ice environment

The impacts on the ice surface structure from land transport, camp assembly and operation, and drilling are described below. Physical disturbance will be evident, particularly at the camp sites, however, the effect will be localised and on completion of the activity most changes will gradually disappear due to snow deposition and wind.

5.2.1.1. Support camp and drilling camp operations

The probable direct impacts on the snow/ice environment include surface structure changes due to camp erection, vehicles and activities in the camp areas; emissions from fuel combustion, removal of snow for melting if RO is not used for making fresh water, and the discharge of treated grey water. The duration of the changes will depend on the extent of the impacts, the amount of snow/ice affected and the characteristics of snow/ice accumulation in the area. It is expected that the snow/ice surface changes will not be visible after a period of one to two seasons due to snow accumulation and sea ice break out.

Physical surface structure changes initially be mainly compaction of the snow surface by vehicle movement, foot traffic and preparation of the camp sites. Compacted areas may accrete and ablate differently from surrounding areas. However, the most obvious effect of the camp on the snow/ice environment will be the snowdrifts that will form downwind of the buildings in the camps, especially at the ice shelf locations (MIS and SMIS). The design, size and duration of the camps will all influence the level of this impact. The ANDRILL camps have been re-designed from the CRP model to prevent snow accumulation as much as possible, and the relocation of the camps and drill equipment to a more suitable storage site at the end of each drill season on the sea ice will reduce this effect. Prevailing winds and snow accumulation have been taken into account in storage area assessments.

Access roads and camp sites at the ice shelf locations may be prepared by mounding and compacting additional snow to provide a firm platform for vehicles and buildings. These could be expected to persist longer, and affect accretion and ablation than other compacted areas. If any structures are used in the road and site preparation, these will be totally removed after use, which would by necessity loosen the compacted snow.

Greater than usual snow and ice melt may occur around the camps due to the altered accumulation patterns and the lower albedo of the buildings and equipment compared to the surrounding snow. This is expected to be particularly evident at high ablation or melt areas like SMIS. It is expected that the snow/ice environment will return to its normal formation within one or two seasons of completion of the project. The surfaces used at the sea ice sites may also break out and completely melt within a shorter timeframe.

Generator and vehicle usage and will lead to the deposition of aerosol contaminants on the snow/ice environment. As described in Section 2.4.8, generator emissions are expected to include a maximum of 96 tons of carbon dioxide, two tons of nitrates and less than a ton each of carbon monoxide and hydrogen chloride each season. Vehicle emission data was not available. Wind strengths will determine how widely distributed the contaminants become. It can be expected that aerosols resulting from generator and vehicle operation will be deposited on the snow on the downwind side of the camp and roads. Local depositions of aerosols and contaminants on the snow and ice surface are gradually loaded to firn layers under the surface by the accumulation of snow. If incinerating toilets are introduced into the camp, they will have similar emissions and lead to the deposition of contaminants onto the snow/ice. Changes in the albedo of the snow/ice environment will be minimal as visible contaminants are likely to be quickly covered by blowing or falling snow.

As human waste will either be treated on-site or removed, the only waste that will have impacts on the snow/ice environment will be grey water. Several options of disposal are still being considered. All but one involve disposal of thoroughly screened grey water into the sea, either directly through a sea ice or ice shelf hole, or in a delayed manner by disposing of the waste within the sea ice or ice shelf to break out at a later date. Because grease and large particles will have been removed from the grey water, it is expected that there will be neglible nutrient loading in the output, and only a very small concentration of biodegradable cleaning products. Apart form he highly localized impact of drilling or melting the disposal hole, the impacts of grey water disposal options one and two for sea ice and ice shelf are therefore expected to be negligible impact on the sea ice and associated microbiota.

If a reverse osmosis (RO) process is used to produce fresh water supplies for the support camp, the resulting brine is likely to be disposed of into the sea. The salt concentration is likely to have little effect, since brine is naturally found in both sea ice and ice shelf. The brine will be warmer than sea water, and will therefore assist in keeping the disposal hole open.

The only significantly different option for grey water diposal is option three for ice shelf locations, where it may be removed in a tanker and taken to SB for treatment and disposal into the sea. Direct impacts on the snow/ice environment would then be from the tanker, i.e. contribution to change in the surface structure of the snow on roadways and emissions, some of which will settle onto ice and snow.

5.2.1.2. Traverse

The vehicle traverses to the different locations will cause changes to the snow/ice environments. It is expected that no more than the upper 30 cm of snow will be disturbed on the traverses. Already - established routes will be followed where possible (e.g. the US road to Black Island for the SMIS location), on which the additional impact would be minor. Direct impacts on the snow/ice environment will be confined to a width of two to three metres and a distance varying from 20 km to 150 km. The number of traverses to each location remains unknown as it depends on heavy plant available to move the proposed activity.

A certain level of emissions from the vehicles is unavoidable, and hence deposition of some particulate matter onto the snow and ice. The impacts of this output (e.g. changes to chemistry or surface albedo) are expected to be negligible, as the contaminants will be dispersed by wind and covered and diluted by snow very rapidly. The natural processes of wind and snow accumulation will obliterate visual evidence of vehicle traffic over a short period.

5.2.1.3. Drilling

The direct impacts of drilling at the four locations will vary between the ice shelves locations and the sea ice locations, due to the different duration and equipment.

The maximum drilling depth through the snow/ice environment will be at the ice shelf locations where depths of 100-200 m will be drilled using the HWD. At the sea ice sites the holes will be conventionally drilled. The ice will be affected over the entire vertical extent of the holes, with the inner portion removed completely and the ice surface at the hole walls being altered. Once no longer kept open, the holes will quickly refreeze. Sea ice holes will disappear when the sea ice breaks out (probably one to five years) and effects would be unlikely to be detected after break out. Over tens of years, the ice shelf holes may be melted from below (and replaced by snow and ice accretion above) before breaking out.

The HWD process at the ice shelf locations will require the melting of large quantities of snow and ice. Surface snow will be melted to start the process and then melt wells will be created below the surface. On completion of the HWD process, it is expected that the water in the subsurface wells will refreeze. A small residue of preheat fluid may be mixed in with the water but any effects from this will be minimised by using a food grade anti-freeze (propylene glycol) that has a low health risk and a slight flammability rating.

All casing and other equipment will be removed from the ice drill holes on completion of drilling.

In summary, most of the direct impacts on the snow/ice environment from this proposed activity will be transitory, as equipment and materials will be removed from the locations and wind and snow will remove visible signs. Soot particles, grey water, and tiny amounts of drilling fluid residues may remain in the snow/ice environment thereby having long-term but minor effects.

5.2.2 Air Environment

Emissions will be caused by the fuel consumption of vehicles, aircraft and generators and will include CO, NO_X and soot particles. Dispersal of these contaminants will depend on wind conditions.

The quantities of emissions are small compared to those generated by existing station and transport activities in the McMurdo Sound area, for instance SB and its vehicle fleet is estimated to produce approximately 345 tons of nitrous oxides (Waterhouse, 2001). Despite its total emissions (several times those predicted for ANDRILL), SB's air is well within a wide range of New Zealand air quality indicators, and only occasionally meets or exceeds dust and suspended particulate parameters (*ibid*). The project's emissions are also dwarfed by natural emissions from Mt Erebus, which include almost 100,000 tons of particulate matter and almost 10 million tons of nitrous oxides each year (*ibid*). It is therefore expected that vehicle, aircraft and generator usage for ANDRILL will not have any significant effect on air quality.

Camps will only operate for two to four months each drilling season and seasons may be interspersed with off seasons where no drilling will take place.

5.2.3 Climate and weather patterns

The proposed activity is not expected to have any direct impacts on weather or climate. CO_2 and other emissions from vehicle operations, drilling equipment and the operation of the camp will be borne by air movement into higher strata of the atmosphere and remain there for longer than drilling activities continue. Due to atmospheric circulation, the impact of this occurrence can only be assessed in the context of global scale cumulative impacts.

5.2.4 Flora and Fauna

Noise of vehicles, camp operations, drill rig operations, and overflying aircraft may affect birds and mammals living in the area. Physical disturbance of vegetation and invertebrates is also a potential impact at storage sites.

5.2.4.1. Camp

The main noise from the support camp will be the noise of the generator, although most of the noise will be contained by the ISO20 container housing. Vehicles will be used to support the camp, and will create but moderate, discontinuous noise. These sounds, as well as human voices and other noises from general camp operation could disturb skua or seals which may be in the vicinity. None of the proposed drill locations are in close proximity to bird or seal concentrations, and therefore such disturbance would influence only transient individuals and not interfere with breeding populations.

Storage of the camps and equipment at Cape Roberts would, however, be at a skua breeding area. The CRP noted that displacement of birds from the storage area did occur, however, following removal of the equipment from the area, birds reoccupied these territories. Impacts on skua populations are very difficult to monitor owing to their highly variable and generally poor breeding success. During six seasons of skua counts with the CRP numbers of pairs and chicks identified fluctuated greatly. The immediate impacts of storage of the camps and drill rig on skua populations would be of medium extent as the disturbance of skua is possible. The duration of the impacts would be short and of medium intensity as it is fully expected that the skua populations will recover quickly from any displacement or disturbance.

Possible direct impacts of the storage of the camp and drill rig on terrestrial biota could include disturbance by crushing, flattening, and contamination or poisoning of any terrestrial vegetation and invertebrates. Terrestrial communities and their habitats would be largely destroyed if impacted in such ways. However, areas of visible vegetation will be avoided and any area of vegetation and invertebrates affected would be highly localised. Most impacts would be of medium to high duration and would be confined to the vicinity of storage. Practices such as pushing the containers onto the land from the ice rather than towing them, and then reversing in the same tracks, will limit the ground covered by the plant equipment and will be a practice employed where possible at storage locations.

Helicopters will have direct impacts on the terrestrial biota and skua if used in the storage areas for site visits. Impacts could be noise disturbance and contamination by the blowing snow, dust, and exhaust emissions. It seems unlikely that helicopters will be used often in these areas and therefore impacts will be negligible.

5.2.4.2. Traverse

If seals are noted on the traverse routes, deviations in the route will be made where possible. There may be sections on the routes where deviation is not possible due to tide cracks or rough ice and recommended minimum distances to wildlife may not be kept. It is possible that seals may be disturbed in such instances. The noise from transportation in such instances would be of very short duration and it is expected that impacts from the traverses on fauna will be temporary and insignificant.

5.2.4.3. Drilling

The noise of drilling and post-drilling explosives use may affect seals and any other mammals (e.g. whales) swimming within several hundred metres of the rig, possibly causing disturbed individuals to move away. As noted, drill sites are not in close proximity to any established bird or mammal colonies. A seal was present at all three CRP sites, suggesting that drilling activity did not affect the seals in any observable way. In the 1999/2000 season a seal regularly visited the video camera and drill holes (see Image 9). During downhole logging explosive use, another hole was drilled in the sea ice 600 m away and the seal subsequently took up residence at this hole. Such incidents cannot necessarily be planned for but all practical precautions will be taken to avoid wildlife disturbance by the ANDRILL project (e.g. intensive activities such as explosives use will not be conducted when mammals are within a 500m radius). Direct impacts from the drilling equipment and noise on other marine biota will most likely be negligible. Video footage from the seafloor at CRP drill sites show fish and benthic organisms undisturbed in the immediate vicinity of the drill hole.

Other possible but unlikely impacts include:

- bird, mammal or other mortality from a significant fuel spill; and
- introduction of non-native organisms, particularly microbes. Normal procedures (e.g. cleaning clothing and equipment) will be taken to avoid this possibility.

5.2.5 Marine environment

The proposed activity could impact the marine environment in a variety of means including drill noise, brine, grey water, drill cuttings, explosives, and the return of drill cuttings. The campsites and drill sites would have minor local and transient impacts on some trophic levels to the marine ecosystem.

5.2.5.1. Camp

The marine environment may be affected by the disposal of grey water from the camp sites. Grey water will be treated as much as possible on-site as the volumes are too great to remove the grey water from most of the locations. Treating it to the best standards available on site is the most environmental cost effective alternative. Treatment on site should remove solids but may leave some dissolved nutrients and other compounds. Harmful effects of any such residues will be minimised through the use of biodegradable, neutral pH and otherwise harmless cleaning products (and any other substance which will enter the grey water stream) wherever possible.

As discussed above, the options regarding grey water disposal almost all involve release of thoroughly screened liquid into the sea, either directly or via a sea ice or ice shelf pit or 'bulb'. In the latter case, release may be delayed by many years and any nutrients or other residues would be in small quantities and output gradual as the frozen grey water melts out. In accordance with Article 5, Annex III of the Protocol, direct disposal of liquid wastes will be conducted "where conditions exist for initial dilution and rapid dispersal". Therefore, whether the disposal is direct or delayed, any nutrient loading (which could result in increased biological activity in surrounding sea water and ice surfaces) or contamination (possibly reduced biological activity) impacts are expected to be highly localised and short-lived.

If fresh water for the camp is produced through a reverse osmosis (RO) process, brine will be released directly into the sea, possibly with the greywater. Ten percent of sea water pumped into the RO unit will become fresh water while ninety percent will be heated brine returned to the marine environment. The temperature of the brine on return to the seawater may be 6-8°C and can be pumped down the outside of the RO intake line to keep the hole open. The salt content (approximately 10% higher than usual) is likely to be of little consequence in the marine environment, particularly given the naturally-occurring concentrated brine channels that develop in both sea ice and ice shelves. Along the length of the ice access hole to the sea water, cooling will occur. Any further cooling and dilution of the brine to receiving water levels is expected to be rapid. At the cool and nutrient poor ice shelf sites it is possible that along the warmed column of water there could be an effect on growth of algae or other micro-organisms, particularly in combination with any slight nutrient loading from the grey water disposal. It is uncertain how much biotic potential for such growth may exist at the ice shelf sites, but any influence would be likely to cease with the discharge.

5.2.5.2. Traverse

There will not be any impacts on the marine environment from the traverse.

5.2.5.3. Drilling

The most significant unavoidable impacts of the proposed activity will be local damage to benthic communities at the drill sites due to return of drill cuttings and biodegradable drill 'mud' to the seafloor and to the drill hole itself.

During the embedment and early coring phases some mud and cuttings may escape from the drill annulus up to the sea floor, forming a small mound around the hole (see Image 10). It is expected that this will cover some immobile or slow-moving benthos organisms on the sea floor. The area covered is expected to be small (approximately $3m^2$ per hole) and the most mobile benthic species are expected to begin recolonising within a year (Oliver et al 1976).

Drill cuttings, including microfossils, will be removed from the drill fluid to allow re-circulation of the mud. The drill cuttings will be returned to the sea floor. The cuttings are small particles (less than 1cm), which can be expected to disperse on their descent from a sea-ice access hole to the seafloor. Damage to benthic organisms by return of cuttings is therefore unlikely. .

Alex Pyne

Image 10 **Cuttings accumulated on the sea floor on the CRP-3 site as the casing was advanced to 9.5 m and the hole cored ahead to 14.5 m. The embedment and coring depth was shallower than for CRP-2 and a smaller volume of cuttings was produced that built a small cone less than 2 m in diameter and about 0.3 m high. A fish is resting on the cuttings in the middle right of the image.**

It is likely that there will be some loss of drill fluids to the marine environment and sediments below the sea floor (Image 11). Drill fluid (or 'mud') temporarily accumulates in depressions on the sea floor as the casing is washed in. Direct losses will be small, and loss into the sediments will be confined to those sediments. The drill fluid used is totally biodegradable and currents will dilute and disperse the fluids. Dilution will occur rapidly and components in the drill fluid would not be detectable more than a few hundred metres from the drill site and then for probably for no more than a couple of weeks.

Viscosity additives may be required in the mud to maintain the hole. It is expected that substances such as guar gum, which is biodegradable and non-toxic, will be used with no effect to the surrounding marine environment.

Alex Pyne

Image 11 **Drill fluid (foreground) temporarily accumulates in depressions no the sea floor as the casing is washed in.**

Explosives will be used for downhole seismic logging and may be used for cutting the casing at the completion of each hole. The amount of explosives used will be minimal and, in the case of the cutting detonators, designed to achieve a clean cut with shock waves that are highly focused and not 'widely scattered' (Cowie, 2002). Approximately 50% of the energy from the explosion will be consumed in the cutting of the casing and the remaining 50% will be "drawn off to the surrounding material", i.e. the sea floor and silts. Clearly there will be shock waves travelling up the casing to the surface but these will be largely contained within the casing.

Any emissions from radioactive downhole logging equipment are extremely unlikely owing to the sealed nature of the instruments and their use only in stable holes.

Traces of food grade antifreeze from the HWD process may enter the marine environment, but is not known to have any effects on marine organisms.

A number of instruments and measuring devices will be deployed through the ice shelf for use in the water column, and corers will be used to sample the sea floor. There is a possibility that some equipment could be lost down the hole. The outcome for such an event would be the item remaining on the sea floor until it had corroded away - probably centuries.

5.2.6 Terrestrial environment

5.2.6.1. Camps

The main impacts on terrestrial surfaces will be at designated storage areas such as those proposed for NH and MSV, with the possibility of storage on land at Black Island for the SMIS location. Possible direct impacts include disturbance by crushing, flattening, compaction and contamination of fine soils, beach ridges (New Harbour site option two only), and damp areas. At Commonwealth Camp (New Harbour storage site option one) and Cape Roberts, most impacts would be of low to medium duration. At New Harbour storage site option two, it is possible impacts could be of high or very high duration (e.g. if beach ridge formations were damaged), although at all sites physical impacts would be confined to the vicinity of storage. All storage locations proposed have had previous human disturbances.

Helicopters used for site visits may disrupt the terrestrial environment due to the blowing, compaction and contamination of soils and surface disturbance. Any such impacts would be highly localized and probably not more than medium duration.

5.2.6.2. Traverses

Vehicles will only be used on land when moving the camps and drill rig onto the storage locations from the ice. Practices such as pushing the containers onto the land from the ice rather than towing them, and then reversing in the same tracks will limit the ground covered by the plant equipment and will be a practice employed where possible at storage locations.

5.2.6.3. Drilling

No drilling will take place on land. If the possibility of such activity arises then a separate EIA will be completed for this activity.

5.2.7 Aesthetic and wilderness values

Although there is no agreed definition of wilderness value in the Protocol, the term is generally understood to refer to the impression or experience of an environment unaffected by humans. Aesthetic value usually relates particularly to visual appreciation. It is hoped that within a matter of years following completion of the ANDRILL McMurdo Sound portfolio, there will be no visible evidence of the project's activities. The most possible impact observable to visitors in the long term is physical disturbance at the storage sites, which are not currently free from signs of human disturbance.

5.3 Nature, extent, duration, intensity

Potential environmental impacts are assessed in Table 24. The extent, duration, intensity and probability of each environmental impact has been assessed according to the criteria in Table 23.

Table 24 Environmental impacts assessment

			Environmental Impact					Possible measures for avoidance and minimisation
Activity	**Duration of Activity**	**Output**	**Environment**	**Extent**	**Duration**	**Intensity**	**Probability**	**Description**
Transport								
Vehicle use	Site preparation Ice Shelf - 30 days Traverses 8-30 days Camp 60 or 90 days Length of duration	Emissions	Air	M	L	L	VH	• Suitable fuel – light diesel, soot filters • New heavy plant meets EPA standards • No unnecessary excursions
			Snow/ice	M	M	L	VH	
		Surface pressure (compaction and associated ablation and accumulation processes. Change in surface structure).	Snow/ice	M	L	L	VH	• Use of existing routs • Any in-snow structures removed after use (snow loosened)
		Loss/leakage of fuel/fluid from vehicle >10 litres	Snow/ice	L	M	M	H	• Checks and regular maintenance
		Noise	Fauna	L	L	L	H	• Sufficient distances kept from wildlife whenever safe
Helicopter use	10-60 hours per season	Emissions	Air environment	M	L	L	VH	• Helicopters fitted with hydraulic re-circulation • Sufficient distance will be kept from wildlife when observed • Adhere to helicopter guidelines • Land in impacted areas on land/designated sites
			Snow/ice environment	M	M	L	VH	
		Noise	Fauna	L	L	L	M	
		Wind disturbance	Flora and Fauna	L	M	M	L	

			Environmental Impact					Possible measures for avoidance and minimisation
Activity	**Duration of Activity**	**Output**	**Environment**	**Extent**	**Duration**	**Intensity**	**Probability**	**Description**
			Terrestrial	L	M	M	M	
Camp								
Set up and presence	Ice shelf – 120 days Sea ice – 90 days	Surface pressure (compaction and associated ablation and accumulation processes. Change in surface structure). Wind breaks.	Snow/ice	M	M	M	VH	• Camp arrangement • Grading during and after activity • Site selection for shelter/minimum wind
Generator operation	Ice shelf – 120 days Sea ice – 90 days	Emissions	Air	M	L	L	VH	• Suitable fuel • Noise confined by ISO container • Regular maintenance • Maximize efficiency of generator energy use
			Snow/ice	M	M	L	VH	
		Noise	Fauna	L	L	L	VH	
Water supply (RO or HWD bulbs)	Ice shelf – 120 days Sea ice – 90 days	Warm brine discharge	Marine	L	L	M	H	
		Water discharge Well melted	Snow/ice	L	M	L	H	
Grey water	Ice shelf – 120 days Sea ice – 90 days	Grey water	Snow/ice (bulb)	L	M	L	H	• Thorough filtering and UV treatment if possible
			Marine	M	L	M	H	
			Aesthetic/wilderness values	L	L	L	H	
Fuel storage and handling	Ice shelf – 120 days Sea ice – 90 days	Fuel spill 10-200 litres	Snow/ice	L	M	L	M	• Secondary containment • Compliance with safety regulations • Suitable precautions for fuel handing
			Marine	L	L	M	L	

			Environmental Impact					Possible measures for avoidance and minimisation
Activity	**Duration of Activity**	**Output**	**Environment**	**Extent**	**Duration**	**Intensity**	**Probability**	**Description**
			Fauna	L	L	M	L	• Maintenance checks
		Fuel spill >200 litres	Snow/ice	M	M	L	L	
			Marine	M-H	M	H	L	
			Fauna	M	M	M	L	
Chemical use and storage	Ice shelf – 120 days Sea ice – 90 days	Spill/leak	Snow/ice	L	M	M	L	• Suitable precautions for handling • Compliance with safety regulations • Use of food grade antifreeze and biodegradable chemicals
			Marine	L	M	M	L	
Explosive storage	Ice shelf – 120 days Sea ice – 90 days	Explosion	Snow/ice	L	M	M	L	• Explosives stored in a magazine remote to the campsite • Explosive detonators secured away from explosives
			Fauna	L	M	M	L	
Storage of camp	Winter – 10 months	Surface pressure	Flora and Fauna	L	M	M	M	• Storage on land will take place at impacted site • Push containers onto land, reverse back in same tracks • Avoid significant features (minimizing crossing beach ridges) • Site surveys
			Ice/snow (ice shelf only)	L	M	M	VH	
			Terrestrial	L	H	H	VH	
Drilling								
Drilling	2-4 months each season	Noise Emissions	Fauna	L	L	L	H	• Compliance with safety regulations • Regular maintenance • Experienced personnel
			Snow/ice	M	M	L	VH	
Drill fluids and drill	6-16 weeks	Drill fluid and drill cuttings	Marine	L-M	M	M	H	• Thorough record of drill fluids maintained to alert if leaking

			Environmental Impact					Possible measures for avoidance and minimisation
Activity	**Duration of Activity**	**Output**	**Environment**	**Extent**	**Duration**	**Intensity**	**Probability**	**Description**
cuttings			Fauna	M	M-H	M-H	M	• Use of biodegradable drill fluid
Pressure control	6- 16 weeks	Pressure kick or explosion	Marine	M	M-H	M	L	• High density kill mud readily available • Pressure control diversion equipment installed • Monitoring procedures in place
			Fauna	M	M-H	M-H	L	
			Snow/ice	L	M	M	L	
Chemicals	During HWD process	Loss of chemicals from HWD	Snow/ice	L	L	L	M	• Use of food grade antifreeze – propylene glycol
			Marine	L	L	L	M	
Use of downhole logging equipment	End of drilling each hole	Pollution from loss of gear Leak of radionuclides	Marine	L	M	L	L	• Run other downhole logging tools down hole before density neutron tool • Check hole stability
			Snow/ice (ice shelf)	L	M	L	L	
Explosives	End of drilling each hole	Noise/waves	Marine	L	H	L	H	• Check for mammals in 500 m radius
			Fauna	L	L	M	L	

5.4 Impacts on science and other values

The McMurdo Sound region attracts a wide range of marine and terrestrial-based science from a variety of disciplines. It is not expected that the impacts at any of the proposed sites would preclude or compromise future scientific work in either related or different disciplines in the future. If anything, the results of ANDRILL could increase the scientific value of the areas by adding significantly to understanding of the processes and conditions, which have given rise to the current environment.

5.5 Indirect impacts of the proposed activity

Particulates from vehicle and generator emissions may accumulate on the snow/ice surface, lowering the albedo of the surface and causing melt. In case of heavy snow melt this could possibly have a destabilising effect on the camps and drill rig could result in non-recovery of equipment. The impact of such an occurrence would depend on the nature of the equipment and any associated substances, and on the type of receiving environment (e.g. freezing into ice versus ending up on the seafloor). However, the released particulates will be in trace amounts, and those that do accumulate on snow surfaces are expected to be quickly covered with new snow, making it unlikely that heavy snow melt will occur due to this exposure.

Direct impacts on the snow/ice surface, such as compaction from site preparation, vehicle use and buildings, possible melt surrounding the lower albedo building surfaces, and build up of drifts around buildings or outdoor equipment, could in turn further effect localised snow/ice accumulation and ablation patterns. It is intended to minimise this possibility by regular shovelling and grading of built-up snow. With regard to melt, the structural soundness of the ice as a platform for buildings, vehicles and equipment will be regularly checked to avoid any the type of loss scenarios noted above. Containers at storage sites will likely cause a direct impact on snow ablation and accumulation in the form of snow drifts and melt pools. The possible indirect impacts will be on soil moisture and vegetation dynamics. Storage of camps would be short term and the effects would be localised.

Under normal operating conditions, the project's activities are not expected to have more than a minor or transitory effect on flora and fauna, water quality or the terrestrial environment, and therefore secondary impacts on natural systems are not anticipated. However, in the unlikely event of a catastrophic event such as a major fuel spill (fuel being the only potentially harmful substance which will be stored in large quantities) entering the marine environment (almost impossible at an ice shelf site), directly impacted water, soils or biota could in turn affect predator species etc, although given the relatively limited quantities on site even these effects would be quite localised. In the highly fluctuating sea-ice influenced marine environment, the effects of even a major spill would probably be short-lived.

5.6 Cumulative impacts

Cumulative impacts may occur over time and should be assessed by looking at other human activities occurring in the proposed locations. All activities should be considered including those that have taken place in the past, those occurring in the present and those expected to take place in the future. Information on most country's science programmes for the future is not readily accessible, especially for planned future activities by national programmes. One objective of circulating this Draft CEE is so that such information can be made known. Cumulative impacts and those of this proposal on them may then be assessed more completely for the Final CEE.

Past and present activities and their impacts were reviewed in Section 3.2.6. The table below (Table 25) gives some impression of the scale of past use of Granite Harbour and New Harbour, providing details of New Zealand parties up to the present day. Legacies of the past activities include visible signs of terrestrial surface disturbance (e.g. vehicle tracks in the New Harbour area), casing remnants and in some cases drill fluid (diesel) contamination from past drilling, and built structures. By storing camp and drilling equipment at sites already marked by vehicle use and/or drill rig storage, ANDRILL will to some extent be exacerbating the existing surface impacts. However, planned remedial action post-storage means that the effects are unlikely to be as long lasting as in the past, and it is considered preferable to use these impacted sites than to pose risks to a more pristine site.

Table 25 Duration and size of New Zealand field parties to Granite and New Harbours, as recorded in New Zealand's Environmental Database.

Site	Days	No. people	Person days
Granite Harbour	135	135	471
New Harbour	248	169	1524

There is likely to be other, smaller research events taking place at several of the locations and within a give season these will add to the possibility of cumulative impacts, such as more serious disturbance of seal or bird individuals on vehicle routes or near activity sites, or the skua colony at Cape Roberts. While there is no central coordination of various field events, it is possible that each national programme participating in ANDRILL could advise events active at or near ANDRILL sites of the precautions being taken by ANDRILL (e.g. any restrictions on vehicle use, personnel movement etc). Ongoing use of the sites by small research groups is anticipated for the foreseeable future, but at the present time no specific long term cumulative impact issues have been identified.

Transport of all personnel and equipment to Antarctica will rely on existing transport systems within the joint logistics pool operated by the US, New Zealand and Italy. ANDRILL's logistical requirements will therefore contribute to the emissions of aircraft and ships travelling to and from Antarctica, although no significant impact on the number of flights or voyages is expected. Emissions from aircraft have previously been considered and approved under US environmental legislation.

Initial staging of equipment and personnel through Scott Base may also add to existing impacts, such as physical disturbance at storage areas and minor local air contamination from vehicles and generators.

Emissions from vehicles and generators may spread into the atmosphere over the Antarctic circle through atmospheric circulation. The expected amounts of CO_2 are not large in comparison to other significant Antarctic activities and the duration of emissions will be short – two to four months of the year. On their own, the impact of these emissions on the atmosphere is negligible, but on a cumulative basis, combined with past, present and future emissions from around the world, they may contribute to global climate change.

5.7 Identification of unavoidable impacts

The proposed ANDRILL project and the activities such as transportation of equipment, camp and drilling activities, and storage of the camps will all have impacts on the Antarctic environment but most of the impacts will be local and temporary. All activities on the fast ice will cause minor short-term physical disturbance of the ice surface and exhaust emissions into the air above it. The campsite would have minor local and transient impacts on lower trophic levels of the marine system.

The measures described in Section 4.2 and 4.3 and earlier sections of this Draft CEE are designed to reduce or avoid adverse impacts of the proposal. Provided they are strictly adhered to most impacts should be small and/or unlikely. Despite the planning described in the CEE, there are still likely to be some adverse impacts, due to human error, oversight or accidents.

Perhaps most significant identifiable unavoidable impacts of the proposed activity will be local damage from drill cuttings and biodegradable mud to the seafloor and the drill hole itself. Cemented steel casings would be left in place in the seafloor sediment. Grey water will also be discharged at the locations or filtered through to the marine environment causing localised impacts before dispersal.

The transportation of equipment, material and personnel in the ANDRILL: McMurdo Portfolio Project will have unavoidable impacts on the snow/ice, atmospheric and marine environments of Antarctica, but these impacts will be local and temporary.

At time of writing no practicable alternative to these impacts had been identified.

6. MITIGATION OF IMPACTS AND MONITORING

A number of measures have been outlined within this Draft CEE as ways to minimise environmental impacts, including monitoring, which will detect and minimise unforeseen impacts. In summary these measures are:,

- the selection of environmentally and operationally sound options during planning, which will operate reliably and safely in the face of Antarctic conditions;
- further fieldwork at the four locations - to identify exact drill and storage sites, fill information gaps and clarify uncertainties, and test equipment e.g. the HWD;
- the development and implementation of operational monitoring and control measures for the operational phases to avoid or minimise environmental impacts;
- the establishment of reliable environmental monitoring programmes and procedures to verify actual impacts;
- contingency plans for mitigation of adverse effects of potential incidents.

Together these measures form the best possible method of ensuring that the adverse environmental effects of the project are minor in comparison to its benefits.

6.1 General Planning

General planning of the proposed activity is particularly important for selection of options which are environmentally sound, pragmatic, technically safe and reliable in the extreme Antarctic conditions. The nature and significance of various impacts can be reduced through careful consideration of different options available for activities. Decisions on fuel containment, storage locations, grey water disposal, human waste disposal and water supply have yet to be finalised and several options have been presented in this Draft CEE. Each option will be researched further and when decisions are made the disregarded options will be moved to the alternatives section of the Draft CEE (Section 2.5). The length of the proposed activity is such that technological advances made over this period may also affect the way activities are conducted. Any changes to the activities proposed in the Final CEE will only be carried out with the approval of the New Zealand EARP, and will be notified to the ATCPs in accordance with Resolution XXI-2 (1997).

6.2 Further fieldwork

Further fieldwork will be take place at all locations after circulation of the Draft CEE, to fill gaps in information and to advance understanding of the environment at each of the locations. Seismic work has been proposed for MSV and MIS in the 2003/04 season. Site visits will be conducted at all locations, providing more detailed information on the initial environments and better understand potential impacts on them, identifying of potential storage areas, and gathering more general information about each location. The gaps identified in this Draft CEE will be filled with information as it becomes available and results from fieldwork will be included in the Final CEE. Further fieldwork and site visits will enable comprehensive short and long term monitoring of environmental impacts of the proposed activity.

6.3 Control measures / Operational monitoring measures

Development and implementation of control measures for the operational phases, including logistic support operations, will help to avoid or minimise environmental impacts. Environmental impacts will almost certainly be greater if no controls are put in place regarding fuel storage and handling, spill containment and clean up, waste management, and vegetation and skua protection in storage areas.

Development of these control measures is based on the earlier drilling projects including the CRP (Keys, 1984; Waterhouse 2001) and CIROS (Logan et al., 1984), existing Antarctica New Zealand operating procedures, and Antarctic Treaty requirements.

Control measures will cover operations of the storage area, transport and other logistics including camp sites, drilling and safety issues. Operational and safety plans will be prepared by Antarctica New Zealand as the project manager in conjunction with other specialists. These will follow the circulation of the Final CEE and final approval of the project.

6.3.1 Traverse routes

- Flagged routes will be established from MCM/SB across the fast ice to Granite Harbour and New Harbour. Established flagged roads are in place for SMIS and MIS but routes will be flagged whenever the traverse leaves the established routes. The flags will be removed at the end of the project.
- Satellite imagery and on site assessments will be used to decide whether it is safe to proceed with planned activities each season. Cracks in the fast ice and crevasses in the ice shelfwill be examined carefully for ice thickness and bridged where necessary.
- Measures for vehicle operations in the Antarctica New Zealand Operations Manual and the drilling project plan would be adhered to so that the chance of vehicle accident or loss, and disturbance to biota such as seals and penguins will be minimised.
- Traverse routes will be checked for seals. If seals are sighted close to the route, deviations will be made where it is safe to do so.

6.3.2 Camp sites and storage areas

6.3.2.1. General control measures

- Daily weather forecasts and any storm warnings will be obtained from McMurdo Station and Scott Base. Daily weather observations should also be taken and recorded in standard formats.
- Fire safety controls are to be developed and listed in the Operations Plan.

6.3.2.2. Project personnel control measures

Personnel numbers at the locations will create pressures on the environment throughout the project. Direct impacts on the environment will be created through a multitude of activities including transport and emissions, energy requirements, waste created, fuel consumed, and foot traffic. Personnel numbers will include people directly involved with the project, including drillers, support staff and scientists, as well as other, usually short term visitors. Visitors may involve scientists, environmental staff, Scott Base staff on maintenance visits, an array of people from the different countries involved, distinguished visitors, and media. Wherever possible, visitors not essential to operations will be scheduled when there is spare capacity in the camp facilities. Numbers will be monitored and if necessary a personnel limit will be set for the support camp. Personnel will wish to recreate, and any environmentally sensitive areas will be clearly communicated to all participants as off-limits. Any recreational trips off-site will only be conducted with the permission of the Project Manager, in small groups and with appropriate supervision and controls in place.

- All ANDRILL personnel numbers will be recorded.
- Visitor numbers will be recorded including those from other events in the area.

6.3.2.3. Storage sites

Potential storage areas will be identified, taking into account past human impacts at these locations.

- Where possible the camp, drill rig and equipment will be pushed up onto the land rather than towed, to limit vehicle tracks on the soils. Vehicles will then reverse back down the same tracks rather than turning around on the land.
- The camp, drill rig and equipment will be towed off early in the season when snow cover can provide protection to the soils beneath.
- Helicopter landing sites will be designated in the storage areas should helicopter support be needed here.
- Personnel movements at Cape Roberts will be restricted as much as possible to the flat storage area and essential routes, to avoid disturbance to skuas and vegetation. The maps used during CRP, showing acceptable routes and restricted areas, will be used to brief personnel and displayed during the storage activities.
- Any guy wires or other structures which could pose a risk to flying skuas will be flagged for visibility.

6.3.2.4. Waste

Control measures for human waste disposal will be dependent on the final decision of how best to dispose of waste. Some control measures are generic to all options and these are listed below.

- No untreated human waste or any other solid wastes will be disposed of in ice-free areas.
- There will be one person in charge of toilet maintenance and management.
- All waste will be handled and disposed of a manner consistent with the Protocol and existing Antarctica NZ procedures.
- Solid waste will be securely stored in an ISO container and not exposed to wind. The sites will be regularly checked for any small items of waste dropped, and any found collected.

6.3.2.5. Fuel

- Personnel will be trained in specific fuel transfer procedures and cautioned to use the utmost care for safety reasons and to avoid spillage.
- Detailed records will be kept of fuel consumption. Accidents and leaks will be identified very quickly if accurate up-to-date records are kept.
- All fuel storage, whether in drums or tanks, will have secondary containment. The fuel tanks will either be designed with secondary containment or the ISO20 containers holding the tanks will be modified to provide secondary containment. Drums will have trays or heavy duty tarpaulins to provide containment.
- Specific areas will be designated for the storage of fuel. Fuel containers will be colour coded to eliminate confusion.
- Specific areas will be designated for re-fuelling at the camps and these will have some form of catchment underneath the refuelling area. Refuelling stations will contain absorbent mats, shovels etc.
- A system for melting out contaminants from snow following leaks or spills will be considered. Such a system will allow for the contaminated snow to be melted and the

resulting fuel burnt *in situ*, which will reduce the difficulties of storage and transportation of large amounts of contaminated snow back to Scott Base and eventually New Zealand.

- A supply of empty drums will be kept at the camps for the collection of hydrocarbons or other contaminants, should spills occur. Contaminants or contaminated media (snow, ice or soil) will be taken to SB for disposal in NZ.
- Daily visual checks will be conducted of all fuel storage areas at the support camps and drill sites.
- Weekly inspections of the fuel handling procedures including use of drip trays and absorbent mats when refuelling.
- If spills or leaks are detected, immediate clean-up action will take place. Estimated volume and depth of penetration involved will be calculated and areas will be excavated accordingly.
- Hydraulic lines and connections will be checked regularly and that remedial action taken as soon as possible if leaks or damaged lines and connections are discovered.

6.3.3 Drilling operations

- All drilling will be carried out by fully trained drilling crews working under trained, qualified and certified drilling supervisors and crew bosses. Many of the personnel have experience from previous Antarctic drilling projects.
- Drilling procedures will be in accordance with normal standards of safety and good practice.
- Pressure control will be monitored (see Section 2.4.2.9). High density kill mud will be available on-site at all times and pressure control diversion equipment will be installed. Fluid diversion lines will be set up exiting away from the drill platform.
- Fast ice monitoring will be conducted regularly. Fast ice thickness, temperature, depression, movement and extent will all be monitored. Ice thickness will also be monitored at active crack systems. Ice thickness will be monitored initially on a fortnightly basis but more frequently as hole depth and the season progress; ice depression will be also monitored initially fortnightly and then more frequently, e.g. as necessary during increases in ice loading. Horizontal ice movement will initially be monitored on a fortnightly basis but more frequently as hole depth and season progress; ice extent will be initially monitored on a monthly basis or during or immediately after major storms; vertical ice movement due to wave propagation through the ice would be monitored if deemed necessary.
- Checks will be made immediately prior to any explosives use for seals within a 500m radius. No detonation will take place unless the area is clear.

6.4 Impact monitoring and audit approach

The ANDRILL project will involve a number of stages including the construction and set up, operational, and decommissioning stages. Compliance monitoring will be carried out for each of these stages and adherence of the project's activities to the final CEE and any approved changes will be recorded. In addition, environmental impact monitoring at the different locations aims to detect unforeseen impacts and verify predicted impacts.

Detailed, site specific monitoring programmes will be developed for each location. Monitoring at locations later in the programme will build on experience learnt from earlier locations. The monitoring programme will be reviewed and modified as deemed necessary.

Key environmental indicators have been developed around expected and potential impacts for the proposed activity, and are identified below based on the information from Section 4.

6.4.1.1. Fuel spills and accidents;

Experience from several locations in Antarctica has shown that fuel spills move very quickly vertically through the snow pack, and apart from a small area of contaminated surface snow are difficult to clean up. At the ice shelf locations, fuel spills will move vertically through the snow until they reach an impermeable layer of ice where it will spread horizontally in an ever-widening circle until the state of equilibrium is reached (Oerter, 2000). This could be at depths of 80 m or so.

- Records of exact location and extent and nature of the spill and clean up action will be completed.

The CRP showed that contrary to early predictions it was not fuel spills that were an environmental problem but hydraulic spills – two of which occurred when vehicle hydraulic lines failed without warning. Pressurised fluid is released very rapidly, and in both incidents most of the vehicles' hydraulic oil was dumped on the ground before the problem was discovered. Hydraulic leaks are common in low Antarctic temperatures due to the perishing effect on rubber.

Lubricating oils have a high viscosity at low ambient temperatures and leach into the snow at a fairly slow rate. The snow and temperatures as well as the intensity of the fluid leakage will influence the extent to which the contaminated volume expands.

- The size, location, type, cause (if known) and remedial action of all spills or leaks greater than one litre will be recorded.

6.4.1.2. Waste disposal

Waste disposal sites will be monitored to check that there is no significant build up of material or algal or other growth at the grey water and brine outlets.

- Regular visual and metered checks of the RO brine and grey water discharge pipes.
- Inspection by remote-control video camera of the RO and grey water outlet area (if grey water is discharged directly into the sea).
- Periodic collection of water samples from beneath the ice in the vicinity of the grey water outlet and visual assessment for obvious signs of contamination. Nutrient analysis of the screened grey water will take place when the screening systems are set up.

6.4.1.3. Storage areas

The monitoring used for storage areas will follow the monitoring methods used at Cape Roberts for the CRP. Other storage areas will be mapped out in a similar fashion (Figure 21).

- Surface disturbance from storage will be visually assessed using criteria in an assessment form (Campbell 1993; Table 26). Monitoring will continue for at least two seasons after storage has taken place.

Table 26 Assessment Form: Intensity and Extent of Terrestrial Environmental Impacts (Campbell 1993)

Impact Assessment Criteria	Severity and Extent of Impacts			
	High (max impacts)	Medium	Low	Negligible (min impacts)
Disturbed surface stones	Abundant > 25	Many/few 25-10	Few < 10	None visible
Stone impressions	Fresh, sharp edged	Distinct, slightly rounded	Shallow indentations	None visible
Boot imprints	Fresh	Indistinct	Just visible	None visible
Visibly disturbed area	> 100 sq m	100- 20 sq m	20-5 sq m	< 5 sq m
Surface colour difference	Strong contrast	Moderate contrast	Weak contrast	None visible
Surface impressions	Very fresh	Distinct	Weakly visible	None visible
Ground tracking	Strongly defined	Moderately defined	Weakly defined	Not visible
Extent of ground tracking	> 100 metres of tracking	< 100 metres length	< 10 metres length	No tracks visible
Foreign objects	Many	Some	Few	None
Fuel spills	Very obvious	Visible	Faintly distinguished	None
Biological disturbance	> 5 sq m	5-1 sq m	< 1 sq m	None visible
Disturbance intensity	Disturbed and very obvious	Clearly visible disturbance	Weakly distinguished	Disturbance not visible
Extent of recovery of previously occupied sites	No recovery observable. Impacts fresh and obvious.	Impacts still clearly visible. Signs of recovery observable.	Impacts faintly visible. Recovery almost complete.	Fully recovered. No impacts visible.

- Visual assessment plots to check for disturbance to vegetation will be created from established photo points (see Figure 21 for Cape Roberts).

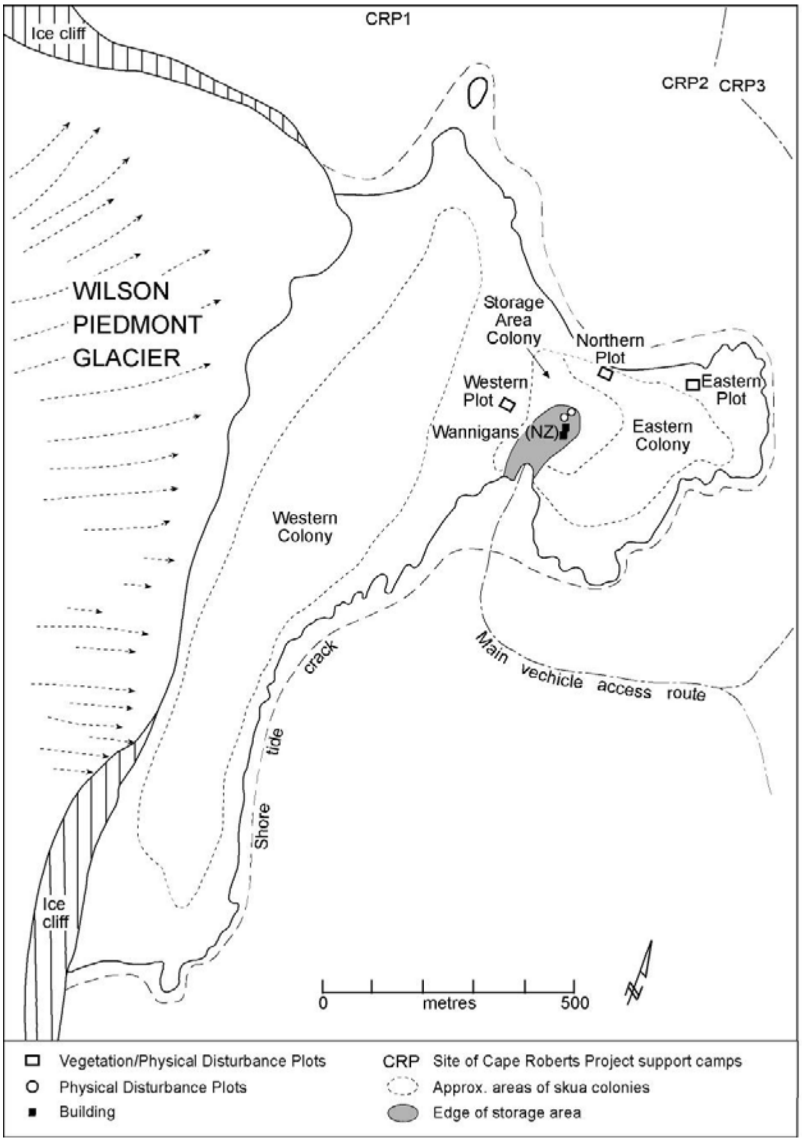

Figure 21 **Location of the storage area, vegetation plots, disturbance plots, the approximate extent of skua colonies and existing buildings on Cape Roberts**

- Vegetation conditions will be described, in particular noting any obvious human disturbance.
- Photo monitoring will be carried out for all of the storage areas.
- Changes in the number of skua and the location of the breeding pairs at the Cape Roberts storage area will be recorded before the camp is stored (end of November/beginning of December) and again after it has been stored (January).
- If any fuels are stored, melt water and soil samples from within the storage area will be taken and analysed for hydrocarbon contamination.
- All storage site monitoring which identified an impact during storage will be continued for two years after removal of equipment.

6.4.1.4. Benthic community species and abundance around drill holes

Monitoring of the sea floor around the drill holes is necessary to check for disturbance.

- The drill hole will be videoed initially as the sea floor is about to be entered, at least once during drilling and after drilling has ceased at the hole. Benthic communities visible in the immediate vicinity of the drill holes will be examined to determine extent and degree of damage.

6.4.2 Levels of impacts

Key parameters for environmental monitoring have been set for the proposed activity. Levels of impact and their acceptable limits have been set where known (Table 27). Natural variability and limits of resilience may be difficult to measure and therefore make defining unacceptable limits hard to define. If the limits in the table below are exceeded in any one season then the project managers will be required to review operations and procedures to ensure compliance with the Operations Plan. If all procedures are being followed and the impacts continue at that level, then expert advice is to be sought and abandonment of activities may have to be considered. However, it is not expected that any of the environmental limits will be exceeded.

Table 27 summarises the environmental monitoring requirements of this Draft CEE and includes key parameters, environmental limits, timing and responsibilities.

Table 27 Summary of Key Monitoring Parameters and Environmental limits

Parameter	Limit	Timing	Responsibility
Fuel handling and spillage	200 litres per spill and 300 litres total per season	Daily and weekly inspections	Project Manager
Waste handling and management	No significant build up at grey water/brine outlet	Daily and weekly inspections (water samples)	Project Manager
Benthic communities at drill site	No disturbance more than 3 m beyond the hole.	Before, during and after drilling operation	Drill Site manager
Skua populations	None set.	Beginning of December and again in January.	Project Manager and Environmental Manager/Officer
Surface disturbance at storage sites including vegetation disturbance	No > than new number here m^2 of disturbed surface at the storage area.	After storage phase. Repeat for two years after storage removed.	Environmental Manager/Officer
Soil contamination at storage sites	Spills/contamination not to exceed limits for fuels. Less than 100 TPH.	After storage phase.	Environmental Manager/Officer

Note: No environmental limits have been set for skua populations at any of the sites but records of the numbers of skua will be recorded.

6.4.3 Environmental reporting

Monitoring will need to be carried out systematically. The responsibility and roles for the person(s) carrying out monitoring will be clearly defined. The camp manager is to inspect storage and refuelling sites on a regular basis, to ensure that equipment is in good condition and that all precautions have been taken to prevent fuel and lubricant spills.

A member of the EARP, a representative of a non-governmental environmental organisation or another suitably qualified independent person (perhaps from another Antarctic Programme) may be invited to conduct an independent audit on the proposed activity. The objective of such an inspection would be to verify its compliance with the control and monitoring measures (e.g. those set out in the Final CEE), with Treaty regulations (including the scientific intent of the drilling project itself) and with other measures designed to safeguard the environment.

6.5 Contingency planning

Contingency plans will be prepared for mitigation of adverse effects of potential accidents and will ensure a quick, coordinated and effective response to accidents. Plans will be developed for all conceivable accidents to mitigate, as far as possible, potentially serious consequences for the environment and for human safety.

The contents of the contingency plans will define responsibilities and reporting networks, lines of authority, methods to minimise potential damage, and outline the main decisions which need to be made. They will provide information and identify resources available to deal with the accident.

Contingency plans for the project will be fully developed by Antarctica New Zealand prior to the start of the operational phases. They will be prepared consistent with the COMNAP guidelines for emergency plans and may need to be updated prior to each season. Copies of the contingency plan and other operational and safety plans will be kept at the drill sites and camp sites for ready reference. The contingency plans will be summarised and will be an Annex to the Final CEE.

Potential dangers that need consideration are fuel spills; fire; helicopter crash; vehicle accidents; fast ice breakout (or movement more rapid than anticipated); gas under pressure; drill rig problems (e.g. dropping the drill string); and escape of hydrocarbons or formation fluids.

Subsequent decisions will aim at:

- preventing the spread of toxic materials to sensitive areas and biota, as identified in this Draft CEE
- containment
- cleanup
- return of contaminated materials and waste to the camp site and MCM/SB.

The Project Leader should assume initial authority for dealing with accidents in the vicinity of the drill site and camp, assigning responsibility for immediate response to the Science Manager, Drilling Supervisor or Camp Manager as appropriate. Accidents nearer MCM/SB or involving aircraft would be immediately reported to MCM/SB where appropriate personal will assume overall responsibility.

Any necessary resources of the project and MCM/SB should be made available to deal with emergency situations. Final lists of project vehicles, people and equipment should be contained in the operations and safety plans. Emergency equipment, including first aid gear, fire fighting and rescue equipment and materials, stocks of inert absorbent material and implements for mopping up spills need to be kept at the camp site. Key personal need to be trained in the use of this equipment to ensure the most rapid effective response.

7. GAPS IN KNOWLEDGE AND UNCERTAINTIES

7.1 Information Gaps

Fieldwork carried out in the 2002/03 season will continue to fill information gaps in this Draft CEE (Table 28). At the time of writing this Draft CEE, hot water drilling was being conducted on the McMurdo Ice Shelf. Water current measurements and the character of sedimentation beneath the ice shelves is being explored. Further fieldwork and seismic investigations will be taking place over the next few seasons and results will be incorporated in the Final CEE.

Table 28 Gaps in the proposed activity.

Gaps	Specifics	Survey work	Implications
Lack of information about the marine environment underneath the ice shelf.	Benthic communities unknown.	Video.	It will not be possible to identify impacts if benthic communities are not identified.
	Bathymetry and currents unknown.	Further measurements will be conducted at various locations.	Currents will affect drilling itself and also dispersion rates of brine and waste returned to the marine environment.
Lack of information at potential storage sites.	Vegetation, surface structure, fauna.	Site surveys will be conducted. A photographic record will be kept of potential sites.	Details of locations of vegetation or other significant features of geomorphology or soil biology, are necessary to develop site specific procedures for storage activities and to determine impacts.

7.2 Uncertainties in this Draft CEE

Uncertainties exist for this proposal because of the scope of this project. It will take place over a ten-year time span and it is expected that there will be many changes in this time and that more information will become available.

At this stage of planning there still remain several uncertainties in the proposal (Table 29). These uncertainties include exact transport methods, timetables, quantities of fuel and other consumables, waste disposal methods, water supply techniques and final details of the drilling system and camp site composition. These uncertainties will become better known with ongoing planning.

Table 29 Uncertainties within this Draft CEE.

Activity	Location	Options	Uncertainties
Personnel	All	*Option 1*	Up to a minimum 31
		Option 2	Up to maximum 41.
Water supply	Sea ice	*Option 1*	RO unit
		Option 2	Snow melter
	Ice shelf	*Option 1*	RO unit through ice shelf
		Option 2	RO unit to well in ice shelf
		Option 3	Snow melter
Waste	All	*Option 1*	Treatment on-site. Must decide on a system.
		Option 2	Removal from location. Probably only viable for MIS because of proximity to SB or MCM.
Grey water	Sea ice	*Option 1*	Disposed through sea ice.
		Option 2	Disposed into sea ice bulbs.
	Ice shelf	*Option 1*	Disposal into sub ice well.
		Option 2	Disposal through the ice shelf into the sea
		Option 3	A tanker to remove grey water from sites.
Fuel containment	All	*Option 1*	Bulk fuel tanks
		Option 2	Drums
Generators	All	*Option 1*	Both generators run at same time. Another generator at the drill site and one there as backup.
		Option 2	Purchase of a more powerful generator.
Storage areas	New Harbour	*Option 1*	Decommissioned Commonwealth camp
		Option 2	At a beach to the south of Cape Bernacchi
	McMurdo Ice Shelf	*Option 1*	Stored as set up on ice shelf.
		Option 2	Towed back to Scott Base
	Southern McMurdo Ice Shelf	*Option 1*	On land at Black Island

		Option 2	Stored in the near of Black Island on ice shelf
		Option 3	Towed back to Scott Base.
	Mackay Sea Valley	*Option 1*	Cape Roberts
		Option 2	Wilson Piedmont Glacier
		Option 3	Marble Point

Natural uncertainties such as sea ice conditions and weather conditions from season to season cannot be known too far in advance. These will be built in as part of the assessment programme before the drilling starts each season and the best assessments possible will be made.

8. REMEDIATION

At the conclusion of activities at each site, every effort will be made to remove all equipment. In the event of any items being irretrievable (e.g. due to freezing in), the nature and location will be carefully recorded for further future attempts at removal.

A thorough and detailed search of the snow or soil surface will be made to collect any small items of waste or equipment.

Snow/ice will be graded to restore as much as possible the surface. Compacted soil at storage sites will be raked where appropriate to accelerate the natural restoration of structure. Environmental impact monitoring at the terrestrial storage sites will continue for two years after all equipment is removed, to assess site recovery.

9. CONCLUSIONS

This Draft CEE has presented information outlining the scientific significance of the proposed ANDRILL McMurdo Sound Portfolio, and described how the proposal would or could affect the environment.

The measures described in Section 5 are designed to reduce or avoid adverse impacts of the proposal. Provided they are strictly adhered to most of the impacts should be small and/or unlikely. Monitoring and further planning has been identified which would mitigate such effects and ensure compliance with the protective measures.

The most significant unavoidable impacts of the proposed activity will be local damage to benthic communities at the drill sites due to return of drill cuttings and release of biodegradable mud to the seafloor and to the drill hole itself. Cemented steel casings would be left in place on the seafloor sediment. All activities on the fast ice would cause minor short-term physical disturbances of the ice surface and exhaust emissions into the air. The campsites and drill sites would have minor local and transient impacts on some trophic levels to the marine ecosystem.

Major accidents including escape of hydrocarbons or other sedimentary fluids would have much more significant effects but are unlikely. Current and future planning and operational procedures will make the occurrence of such accidents almost impossible.

Information gaps and uncertainties have also been identified. Further fieldwork and procedural development will take place to address these gaps and uncertainties where possible. It is also hoped that feedback on this Draft CEE may reduce uncertainties regarding potential effects, based on the experience and expertise of reviewers. The duration of this project and the possible development in technologies over this period mean that there may be changes in the future to this document, and any such will be assessed by the appropriate level of EIA and notified to the Consultative Parties.

Overall, this Draft CEE predicts that probable environmental effects of the proposed activity will be minor and short term, and that more major impacts which are possible can be avoided or mitigated. The level of impact predicted is considered acceptable given the significant scientific advantages of drilling the ANDRILL McMurdo Sound Portfolio.

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11. APPENDICES

11.1 Appendix I

ANDRILL Management Structure

ANDRILL is supported by two committees: the ANDRILL International Steering Committee and the ANDRILL Operations Management Group.

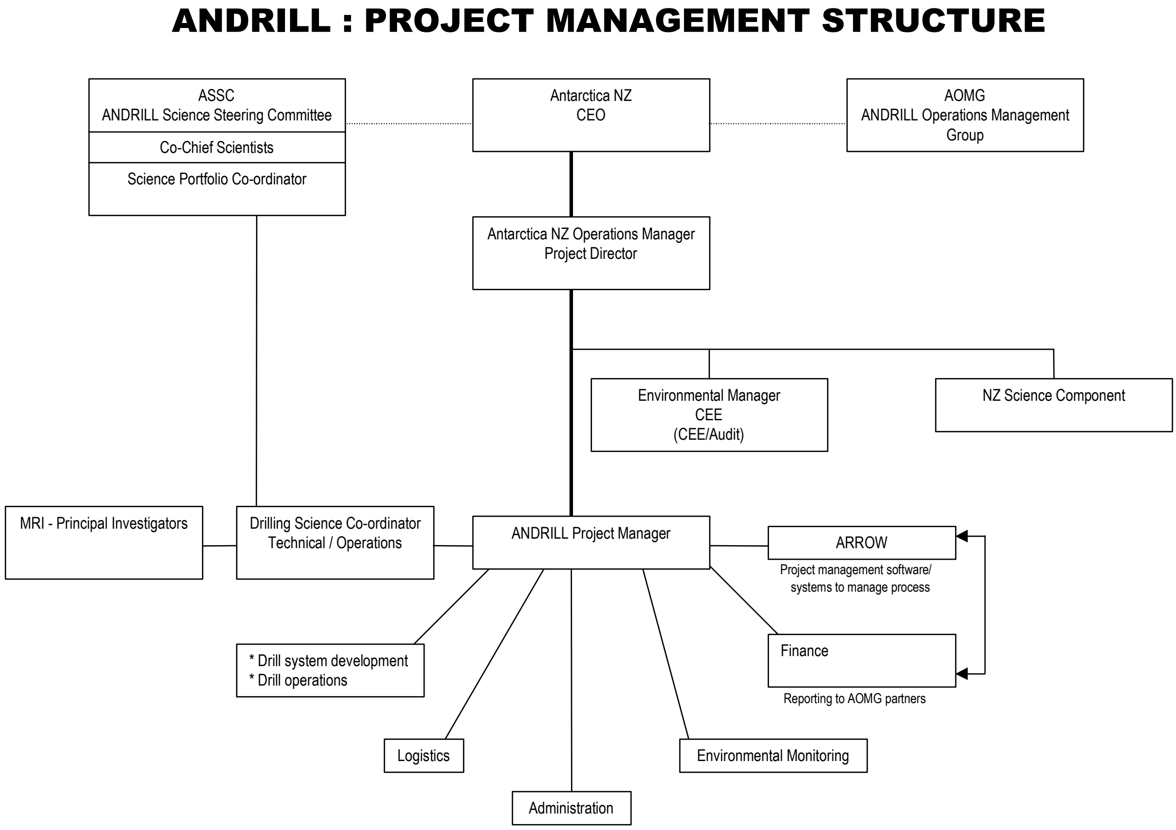


Figure 1. ANDRILL Management Structure

The ANDRILL International Steering Committee

At a final Cape Roberts project Workshop in Columbus, Ohio, September 2000, a steering committee (the **ANDRILL International Steering Committee**, or ASC) was convened from the main proponents of drilling projects and national representatives, to advance the scientific and logistical planning for this project. This committee is responsible for managing the scientific programme of the McMurdo Sound Portfolio. Decision-making of the ASC is by consensus.

The ANDRILL consortium currently comprises five countries - the United States of America, Italy, Germany, the United Kingdom, and New Zealand, each of which has a member on the ASC. Other countries may join in the future e.g. Japan.

Table 1. The ANDRILL Steering Committee (ASC) members (as at December 2002)

Name	Country	Position
Frank Niesson	Germany	
Fabio Florindo	Italy	New Harbour proponent
Jane Francis	United Kingdom	
Tim Naish	New Zealand	Convenor; McMurdo Ice Shelf proponent, Environmental Representative
David Harwood	United States of America	New Harbour proponent; Treasurer
Ross Powell	United States of America	Secretary; Mackay Sea Valley proponent
Gary Wilson	United Kingdom	Southern McMurdo Ice Shelf proponent

The ASC is responsible for the facilitation of proposal preparation and promotion of international collaboration of the science team. They manage the process of science staff selection, the prioritisation of drilling sites, and approve sample requests and project sampling strategy, in conjunction with the Co-chief Scientists, to resolve issues of overlapping science interests. The ASC controls the balance of national science participation and national science funding contribution. The ASC will advertise the drilling projects and invite applications from interest scientists. The SMO will organise the post-drilling workshops, coordinate the production of Initial Report and Science Report volumes, liase with Crary Lab staff to support the needs of scientists and on ice and aid in the dissemination of information.

The ASC has held four meetings to date covering a range of issues from documenting the rationale and plan for future Antarctic margin drilling under the McMurdo Sound Portfolio, to developing a Science and Logistics Implementation Plan (SLIP).

The ASC is aided by an **Advisory Committee,** which includes one member from each ANDRILL nation. The ASC is supported by the **ANDRILL Science Management Office** (SMO), located at the University of Nebraska-Lincoln. The SMO is the office to the ANDRILL **Staff Scientist**.

The ASC is the main point of control in both scientific planning and the logistics organisation. In science operations, planning should proceed through the ASC, but a science project leader will need to be appointed by the committee, for coordinating science activity in Antarctica. Antarctica New Zealand are the designated ANDRILL Project Operators.

The ANDRILL Operations Management Group (AOMG)

The ASC liases with the AOMG to describe science needs and develop the drilling schedule. The AOMG comprises the National Antarctic Operators from all ANDRILL member nations, and will be convened by the head of the **Operations Management Office** (OMO). The ASC established the ANDRILL Operations Management Group (AOMG) in Shanghai, China, July 2002. This group is responsible for the operational planning for the core recovery phase of the project. They will delegate the details of logistical, operational and drilling planning functions to the Project Manager (see below).

Operations and Logistics
Project Operator
The AOMG will oversee the ANDRILL **Project Operator,** Antarctica New Zealand, (the New Zealand Antarctic Institute) and the physical delivery of the project. The expertise developed by Antarctica New Zealand in providing project management, logistics and drilling support to the CRP has been recognised through this invitation. The responsibilities of the Project Operator would be similar to those responsibilities Antarctica New Zealand undertook with respect to the CRP. This will included responsibility for:

- Operations and environmental management, drilling, environmental requirements, logistics support plan, statutory approval requirements, risk assessment, safety requirements, procurement, implementation, and close out.
- Chairing the Project Management Team comprising Antarctica New Zealand, and the drilling, science and technical services providers. The Project Management Team will provide for co-ordination of Project plan development, drilling and operations support, and liaison with the Project science office.
- Convening the ANDRILL Operations Management Group (AOMG) comprising nominated operations representatives of each ANDRILL participating country. The AOMG in conjunction with the ASC would agree the contribution to the Project by each participating country, develop a Project Memorandum of Understanding, and provide oversight of the Project operations.

A major difference to the CRP model of project operation (Cowie, 2002) is that a separate drilling office will be set up to oversee the development of drilling technology, deployment, and actual drilling. Another difference is that ANDRILL has established a science management office at the University of Nebraska, Lincoln (UNL). The office is funded by UNL. It includes offices, conference facilities and will house a consortium secretary and staff scientist (to be employed by UNL but approved by ASC).

Project Manager
A **Project Manager,** has been appointed by the ANDRILL Project Operator. The Project Manager will confirm the project plan, and develop a memorandum of understanding for signature of the project parties prior to the project start. They are responsible for the organising and shipping of equipment and maintaining financial control on the project budget, and for logistics, environmental control and safety.

Drilling Manager
Responsible for the running of the drilling team in Antarctica

Science Support Manager
Responsible for environmental monitoring and core processing. Interacts with the Staff Scientist to address the Co-Chief Scientists and on-ice scientists needs and concerns.

Science
Portfolio Coordinator
Responsible for record-keeping and long-resident memory for the project. The Project Coordinator may interact with national agencies, along with National Representatives, to promote ANDRILL. This position is important to maintain continuity through the duration of the portfolio.

Co-Chief Scientists
Co-chief Scientists are appointed by the ASC and will likely include Proponents and National Representatives who develop site prospectus, and work to implement the project goals. It is anticipated that the Co-chief scientists will alternate between the lab and drill camp throughout the drilling season. The Co-chief scientists are responsible to the ASC for the

development of the scientific aspects of the projects and ensuring the successful implementation of the science plan. During the drilling phase, decisions on science operation and drilling strategy are the responsibility of the Co-chief scientists (based on advice from the drilling manager).

Crary Laboratory Science Leader
Responsible for US scientists housed in the Crary Lab and responsible for the coordination of research by the lab-based scientists, and for the coordination, production of information to the Staff Scientist who will distribute it on the on-ice scientists at the lab and camp, and also to off-ice science staff.

Staff Scientist
The chief responsibility of the Staff Scientist is to facilitate the production of scientific output at all levels, through enhanced communication and coordination among on-ice and off-ice scientists and with the positions identified above. The Staff Scientist will provide continuity between the four projects through the support and direction provided to the Co-chief scientist in the implementation and completion of the science plan.

11.2 Appendix II

Geophysical Survey Programme

Table 1. Three year collaborative programme of geophysical surveys in the McMurdo Sound area for ANDRILL.

Year	Funded	Survey	Location
2001/2002	Germany, New Zealand, USA, UK	Sea ice seismic survey (*Completed*)	New Harbour - 20 line km along two lines of seismic reflection data.
		Shelf ice seismic survey (*Completed*	Windless Bight - 20 line km along a single line on the McMurdo Ice Shelf between Black Island and Minna Bluff.
		Gravity, magnetics and GPS survey (*Completed*	New Harbour, McMurdo Ice Shelf (between Ross and White Islands), Southern McMurdo Ice Shelf (between Black Island and Minna Bluff, Mount Discovery and Brown Peninsula)
		Aeromagnetic survey (*Completed*	McMurdo Ice Shelf, Southern McMurdo Ice Shelf (between Ross Island, Minna Bluff and Brown Peninsula encompassing the area over White and Brown Peninsula).
		Shipboard site survey (*Not completed due to heavy ice conditions*)	Mackay Sea Valley
2002/2003	Italy, New Zealand, USA, UK	Shelf ice seismic survey	McMurdo Ice Shelf, Southern McMurdo Ice Shelf 40 line km of seismic data in three lines on the McMurdo Ice Shelf, two lines between Ross and White Islands, and one line between Black Island and Minna Bluff, Mount Discovery and Brown Peninsula.
		Shipboard site survey	MacKay Sea Valley, New Harbour
		Airborne Geophysics	New Harbour
		Sub-ice shelf oceanographic and sedimentary survey	McMurdo Ice Shelf
		Site Surveys	Programme of hot water drilling and piston coring beneath the Ross Ice Shelf in between Ross and White islands.
2003/2004	Pending funding	Shipboard seismic survey	Southern McMurdo Ice Shelf

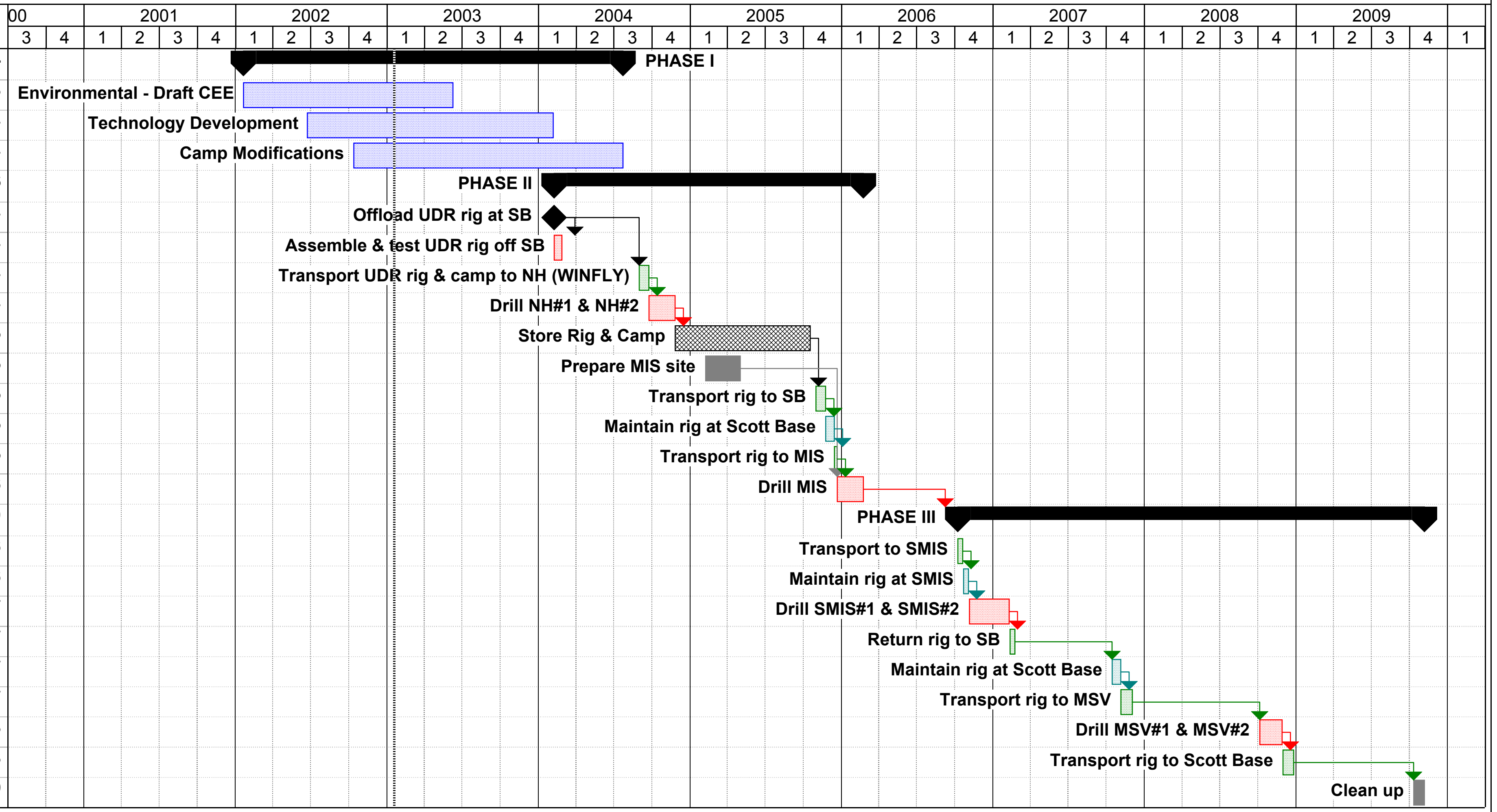
		Sub-ice shelf oceanographic and sedimentary survey	Southern McMurdo Ice Shelf

11.3 Appendix III

Timeline for the ANDRILL project

ANDRILL TIMETABLE

ID	Task Name	Duration	Start	Finish
1	***PHASE I***	**131 wks**	**Mon 21/01/02**	**Fri 23/07/04**
2	Environmental - Draft CEE	72.2 wks	Mon 21/01/02	Mon 9/06/03
3	Technology Development	85 wks	Mon 24/06/02	Fri 6/02/04
4	Camp Modifications	93 wks	Mon 14/10/02	Fri 23/07/04
5	***PHASE II***	**106.7 wks**	**Mon 9/02/04**	**Thu 23/02/06**
6	Offload UDR rig at SB	0 days	Mon 9/02/04	Mon 9/02/04
7	Assemble & test UDR rig off SB	3 wks	Mon 9/02/04	Fri 27/02/04
8	Transport UDR rig & camp to NH (WINFLY)	3.5 wks	Wed 1/09/04	Fri 24/09/04
9	Drill NH#1 & NH#2	9 wks	Fri 24/09/04	Fri 26/11/04
10	Store Rig & Camp	11.6 mons	Fri 26/11/04	Tue 18/10/05
11	Prepare MIS site	3 mons	Tue 8/02/05	Mon 2/05/05
12	Transport rig to SB	3.5 wks	Tue 1/11/05	Thu 24/11/05
13	Maintain rig at Scott Base	3 wks	Thu 24/11/05	Thu 15/12/05
14	Transport rig to MIS	1 wk	Thu 15/12/05	Thu 22/12/05
15	Drill MIS	9 wks	Thu 22/12/05	Thu 23/02/06
16	***PHASE III***	**161 wks**	**Mon 9/10/06**	**Fri 6/11/09**
17	Transport to SMIS	2 wks	Mon 9/10/06	Fri 20/10/06
18	Maintain rig at SMIS	2 wks	Mon 23/10/06	Fri 3/11/06
19	Drill SMIS#1 & SMIS#2	14 wks	Mon 6/11/06	Fri 9/02/07
20	Return rig to SB	2 wks	Mon 12/02/07	Fri 23/02/07
21	Maintain rig at Scott Base	3 wks	Tue 16/10/07	Mon 5/11/07
22	Transport rig to MSV	4 wks	Tue 6/11/07	Mon 3/12/07
23	Drill MSV#1 & MSV#2	8 wks	Mon 6/10/08	Fri 28/11/08
24	Transport rig to Scott Base	4 wks	Mon 1/12/08	Fri 26/12/08
25	Clean up	4 wks	Mon 12/10/09	Fri 6/11/09



11.4 Appendix IV

Hot Water Drilling Operation

Subsidiary components include: a submersible pump for retrieving water from a sub-surface well where no natural surface water supply is readily available (in particular in Antarctica); a low pressure circulation pump for purging of the system in order to avoid breakages due to freezing; inlet and outlet manifolds for distribution of the water through the banks of pumps and heaters; a capstan stand or derrick for guiding the hose down the hole; a range of sensors and monitors for control of system integrity such as flow meters, temperature and pressure gauges, well head indicators, load cells and depth counters; and an enormous array of interconnecting hoses, fittings, adaptors, and general surface plumbing to link the entire system together.

Hot water drill operation

Firstly, a surface supply of water (at least 8000 litres) is prepared by melting large amounts of readily available snow in a portable tank. This is used to drill a pilot hole down to a depth beyond the upper porous layers, where the snow is then sufficiently impervious to allow pooling of water in the bottom of the hole. A conical spray nozzle may be fitted during this operation to obtain a suitable diameter hole in the upper snow layers. A large sub-surface reservoir is then melted out at this depth. The submersible pump can then be lowered into this pool of water, some of which can be pumped back to the surface storage tank for further recirculation.

The drill tower is shifted a small distance, usually less than a metre, and the main hole is drilled down to the sub-surface reservoir depth. Continued supply of hot water expands this cavity until it merges with that from the pilot hole to form a single large sub-surface reservoir, from which water pumped down the main hole can be recirculated back to the surface for further use. Little or no extra snow needs to be melted from this point on.

The main borehole is then continued down past the sub-surface reservoir, generally using a solid steam jet nozzle, as turbulent mixing in the now water-filled borehole distributes the heat evenly to produce a uniform cylindrical cavity.

For hot water drilling through ice shelf to the ocean below it is important to maintain the hole as near to vertical as possible. This allows for ease of retrieval when instruments are lowered through the hole on winching cables later on. It is also important to avoid necking at the base. This can be caused by ocean currents sweeping the hot water away from the hole upon the initial breakthrough, and can be prevented by holding the drilling head near the base for several minutes to ensure a good cavity is melted out there.

11.5 Appendix V

Riser Options

Steel Riser. A "conventional approach" to the development for a riser would be a screw jointed steel casing such as a "standard" oil field production tubing, and may be a possible alternative for the deep water/ice shelf sites. The use of a flush jointed slim-hole casing (HWT) may be possible in the shallow water situation or possibly deep water with extremely low current velocities but this too would have to be modelled. The use of non-standard tubing (ie. the re-machined CRP riser) could limit the ability to replace consumed components in good time and should be considered carefully. A steel riser is strong but unfortunately heavy and would require buoyancy when deployed from the sea ice platform that has a limited load bearing capacity. CRP has pioneered both riser flotation for tensioning and the sea ice platform support with sub-ice buoyancy so this consideration is probably now less important. The drill rig or an "add on system" would be required to deploy the total weight of riser in an ice shelf hole.

The CRP 5" diameter sea riser casing and buoyancy system could potentially be used only for shallow water targets from a sea ice platform. The existing pipe has been inspected for straightness, internally drifted and the joints crack by magnflux. New sea floor embedment tools, modelled on a concentric casing system are required to reuse this riser casing.

This casing would need to be replaced for deep-water operations but the rigid and inflatable buoyancy systems would be applicable for sea ice deployments. Both the HWT slim hole drill string (in deep water low current sites) and a 5.5" or 6" robust oil field tubular should be considered for further engineering studies. The additional use of a liner pipe may be required for the larger tubular to support rotation of the HQ size drill string if a HWT casing is hung off at the sea floor to minimise the total riser weight. A near neutrally buoyant polyethylene liner for the riser casing was suggested to reduce loading on a sea ice platform and to enable the use of the existing CRP riser buoyancy and tensioning system.

The deployment of a new riser could be carried out in a similar way to the CRP riser for sea ice operation by anchoring the riser into the sea floor using a concentric casing system. A larger diameter riser, with and internal HWT casing could use of a PQ casing advancer to drill further into the sea floor thereby increasing the flexibility of the system.

The ability to deploy a riser through the ice shelf is a key consideration and a major feature of the project. Two different approaches have been considered for tidal compensation, the prevention of freezing of drill fluid within the riser and recovery (unfreezing) of the riser.

- One is to maintain "warm water" around the riser in the ice shelf hole by a combination of intermittent reaming with the hot water drill and heated drill fluid circulation. Tidal compensation and riser tensioning can then be achieved with a hydraulic system at the surface.
- An alternative is to allow the riser to freeze into the ice shelf and compensate for tidal movement with a tensioned slip joint either in the water column or at the sea floor. This is likely to be a more complicated system and at this stage is not preferred.

These approaches and their associated problems require further detailed analysis including thermal modelling of the ice hole drilling and maintenance combined with and heating requirements for drill fluid circulation before the ice shelf riser system can be developed. Site investigation data that is vital for these studies include: lateral sea ice and ice shelf movement, water column currents, tidal range and sea floor sediment characteristics (shear strength) and possibly sea floor video. Engineering studies like those undertaken for the modified CRP riser will be necessary to finalise the riser concept and design.

Plastic Riser. A less conventional riser could be manufactured from plastic pipe and would primarily be applicable to the deep-water sites. The Norwegian Company, Geo Drilling, has developed and operates a plastic riser. Some consideration towards developing a plastic riser was also given by CRP personnel (ref. Hollaway). The advantage of a plastic riser is that it is nearly neutrally buoyant in sea water and so would not load the sea ice significantly during deployment and the lowering system including the drill rig mast would not have to be as robust as for a steel system. Both the Geo Drilling riser and the CRP plastic concept require wire cable and a heavy sea floor template to provide tension and strength to the riser. The handling system for this concept would therefore include a large winch. This option is unlikely to be suitable for ice shelf deployment because of the large diameter sea floor template, external cables and an upset jointing on the casing system that will be subject to refreezing within the body of the ice shelf.

Composite. Exotic materials such as fibreglass/epoxy, Kevlar/epoxy or Carbonfibre/epoxy pipe may be suitable for a sea riser casing for casing. Centron make a fibreglass epoxy casing that is externally upset on pin and box to retain strength in the pipe. This material will have a lower heat transfer than steel, which may be an advantage, in particular for an ice shelf deployment where the cold ice will have a tendency to cool (and freeze?) the drilling fluids. However, epoxy tubulars are between 12-30% the tensile strength of comparable steel casing therefore it is possible that an external steel cable for strength and sea floor template like the plastic options will be required to support the riser in an water column situation. The cost of these materials is likely to be higher than steel or plastic options.

Video monitoring of the riser and sea floor was carried out during Cape Roberts drilling operations. This was particularly valuable during the process of riser embedment and subsequent anchoring with cement grout. A similar procedure is recommended for the future but will require further technical development for Ice Shelf operations where an additional hole may be required for a slim video system and other instrumentation.

The steel riser option may allow direct drilling and anchoring of the riser into the sea floor. This method was pioneered by CRP and was successful but the technique can still be substantially improved with some different tooling and by considering a casing that can be rotated in the water column.

The design of the riser should also consider flexibility in size of chosen casing to allow the internal use of a further drill string HWL for soft sediment sampling and to case off the upper unconsolidated sea floor section. A liner tubing may be required to substitute for HWL casing to allow the use of the smaller HQ string within the casing. This liner may be made of plastic and could also improve the thermal performance of the riser when deployed through the ice shelf.

11.6 Appendix VI

Human waste disposal techniques options table.

NATURAL GAS OR PROPANE INCINERATING TOILET - **Storburn International Inc.**				
EXPERIENCE	**USAGE**	**OPERATIONAL and MAINTENANCE REQ.**	**COST & DIMENSIONS**	**ENERGY**
General: **US – EPA tested.** **Ash = 2.23% of waste treated.** Seem to be preferred model in Antarctica. Currently designing a unit which runs on diesel fuel. "Usenburn"	8-10 people in an 8-10 hour day. 40-60 uses before incineration.	• Propane tanks should be kept heated when used in sub-zero conditions. • Anti-foam sachets • Empty ashpan. • Burning cycle takes from 4-6 hours.	• 17¾" x 31¼" • Approx. 170 lbs • US$2650 (Propane) • US$2680 (Natural gas) + antifoam etc	• 100 lb. propane gas cylinder will burn approx. 600 uses (10 capacity loads) • More efficient to burn full loads. • Propane tanks must also be heated.
Feedback				
USAP – (Storburn) Lake Hoare (10 year old units)	• 10 – 15 people • Burn every 30 uses • Toilets housed. Small box behind to keep propane warm in. • Slow to start in October but by November tanks stay warm and easier to light. • Problem – Difficulty with maintenance. Very time consuming to access the parts that frequently need replacing. • 2 units for 15 people. When 15 in camp then one unit in the burn cycle everyday. • Temperamental, difficult to repair in the field. • Best with one operator. • Vastly reduce amount of waste leaving the field. • Much safer and easier to handle sterile ashes. • One 100 lb propane tank will last 60 hours (15x 4 hour burns) • Full chamber requires a 4 hour firing. • Odour from first hour of burning but diminishes in the second hour.			

BAS (Storburn) Fossil Bluff (2000) 1 unit Sky Blu (2001) 1 unit	• 6 - 8 people • Burn overnight for 6 hours • Large, bulky and heavy (especially with propane tanks) so only used for permanent summer camps. • Have worked well so far. • Recommend that good for small permanent summer stations. • At Fossil Bluff the Storburn can cope with up to 6-10 people on station. • Burns carried out overnight when people are asleep for approximately 6 hours. • After burning there is a sterilised brown solid mass and ash at bottom of bowl. This is drummed up and taken to Rothera for shipment out. • Houses constructed for the Storburn unit. • No bad odour problems. BAS are interested in the Usenburn (the diesel unit) as if it can run off aviation gas it would be optimal as Fossil Bluff and Sky-Blu act as refuelling sites for the Twin Otter aircraft. BAS will wait until the unit has passed all the appropriate US and Canadian safety regulations before researching this unit further.
AAD Used incinerating toilets in stations in 1980s/early 1990s. Recently installed at Heard Island	• Units appear to work fine. • Problems setting up the unit at Heard Island

ELECTRIC INCINERATING TOILET – Incinolet				
EXPERIENCE	**USAGE**	**OPERATIONAL and MAINTENANCE REQ.**	**COST & DIMENSIONS**	**ENERGY**
General:	4-8 persons	• Incinerate after each use. Can use while incinerating. • Paper bowl liner for every use. • Empty ashpan regularly – perhaps twice a week. • General cleaning and maintenance	• US$1500 to US$2000 • Width 15" • Height 21" • Depth 24" • Weight 85-95 lbs	• 208 volts • 3600 watts • 17.5 amps • 100 cfm blower capacity
Feedback				
French Polar Institute (Incinolet)	• Up to 10 people • Burn 2.5 hours instead of 90 minutes because cycle interrupted because they travel during the day and have to turn it off. • Do not urinate in the toilet because of odour reasons. • Empty ashpan every three days. • Each year return it to Australia for maintenance and repair. • 3 kW incinerator • Easy to install and reliable.			

INCINERATING TOILET – Mikalet (Kerosene)				
EXPERIENCE	USAGE	**OPERATIONAL and MAINTENANCE REQ.**	**COST & DIMENSIONS**	**ENERGY**
Japanese Syowa Station (5 years) **(Mikalet)**	• Up to 50 people	• Disposes 25 l/per hour • Easy maintenance • No odours	• Width 720 mm • Depth 2100 mm • Height 1510 mm • Weight 650 kg	• AC 100V 50 Hz or 60 Hz • 380 W • Kerosene (JIS kerosene No. 1) 10 l/per hour

Feedback	
Syowa Station	• Have three Mikalet toilets installed at the station. Two outside the lodge and one inside it. • Need to burn after every use. • Burn cycle last about 7 minutes per use. Can use whilst in operation. Burner will stop automatically when the temperature inside the tank reaches the set value.

COMPOSTING TOILETS				
EXPERIENCE	**USAGE**	**OPERATIONAL and MAINTENANCE REQ.**	**COST & DIMENSIONS**	**ENERGY**
Rota-Loo **Greenpeace -** Cape Evans	950 model – up to 8 people. Maxi Rota-Loo – commercial use	• Requires peat moss and constant warmth. • Emptying of chambers. • Disposal of compost.	• AUD$2500 – AUD$4000	
Sun-Mar		• Peatmoss added manually at rate of one cupful per person per day. • Should be kept at a minimum temperature of 13-15 °C • Can be left to freeze. Will act as a holding tank until reheated. • Compost needs to be aerated and mixed every third day by turning drum handle. • Extraction will need to be freq. in commercial scale setting.	• US$899 • Available in New Zealand.	• The units require electricity to power the fan (25 watts continuous) and a heating element which is thermostatically controlled. • Can install a 12 volt fan, draws 1.9 watts.

CHEMICAL TOILETS				
EXPERIENCE	**USAGE**	**OPERATIONAL and MAINTENANCE REQ.**	**COST & DIMENSIONS**	**Notes**
Bioloo		• Has to be stored, handled, transported and heated. • Sodium hydroxide	• Small (≤ 6 people) $2390 • Large (≤50 people) $2750	• Chemical release into Antarctic environment not desirable.
CURRENT PRACTICE				
Antarctica New Zealand	Transported back from the field	• Handling issues mean that waste from the field is returned to NZ rather than being pumped into the Scott Base system.	• $1.75 per kg • 1.8 litres of waste per person per day. • 45 people x 60 days • $3645.00 estimated annual cost of sterilisation	
TANKER				
USAP tanker for Willy's commissioned	Run with flush toilets. Would have to handle approx. 15 litres per day.	• Could act as a heated holding tank. • Heated (2Kw heaters). • 250 mm polystyrene insulators (or housed in insulated container) • Sledge mounted	• Fuel tanker for Scott base cost $85,000 (excluding vehicle)	• Size dependent on number in camp. May need two tanks - one for storage while one in transport mode back to base. • Some locations for ANDRILL will be too far away for a tanker e.g. Granite Harbour & probably New Harbour • Design specs requested from USAP.
DISPOSAL INTO THE SEA ICE OR THE ICE SHELF				
Cape Roberts project at Granite Harbour	• Put into small bulbs. • 360 litres per bulb • 45 people x 60 days x 1.8 litres of waste = 13.5 bulbs in a season.			
South Pole Station	• Bulbs – hold 7.6 million litres of wastewater and last 5-6 years.			

Willies Field	• Wastewater discharged into a snow pit. • Snow melted by wastewater provides some dilution. • Estimate approx. 19 000 litres/day. • Will start trucking waste back from Willie's Field to incorporate into new system.

11.7 Appendix VII

Previous Drilling Projects in the Ross Sea region

Deep Sea Drilling Project 1973
In 1973 four holes (DSDP 270, 271, 272 and 273) were drilled in the continental shelf from the drillship *Glomar Challenger* as part of Leg 28 of the international Deep Sea Drilling Project (DSDP). The drilling represented a quantum leap in knowledge of Antarctic glacial history, showing that extensive glaciation began at least 25 million years ago. Since that time glacial action and marine sedimentation has deposited a sedimentary sequence up to 7 km thick over part of the Ross Sea continental shelf.

Dry Valleys Drilling Project 1974
Drilling from fast ice in the southwestern Ross Sea began in 1975 with the final hole of the Dry Valley Drilling Project (DVDP). DVDP 15 was drilled approximately 12 km offshore (southeast) of Marble Point in 122 m of water and penetrated 64.4 m into the sea floor with 52 percent recovery. The Longyear 44 rig supplied for DVDP was used for this hole and Longyear supplied a sea riser system specifically for this offshore site. The sea riser design was based primarily on Longyear's lake ice drilling experience in Canada and consisted of PW casing weighted with collars on the sea floor and tensioned with floats.

New Zealand Drilling 1979-86
In 1979 the McMurdo Sound Sediment and Tectonic Studies (MSSTS 1) drilled 12 km NNE of Butter Point in 196 m of water, penetrating 230 m into the sea floor with 44 percent core recovery. The same drill rig and sea casing system was used as in the DVDP. Drilling equipment and fuel were staged near Cape Bernacchi from the preceding summer (1978/79) at the ice free promontory known as "Rig Point" 26 km from the drill site. MSSTS1 provided a record of five glacial events from 25 to 30 Ma ago, when grounded ice advanced beyond the edge of the Transantarctic Mountains and covered this drill site. These were periods when ice was much more extensive in the McMurdo Sound Region (Barrett, 1991).

In 1984 the Cenozoic Investigations in the western Ross Sea project (CIROS) drilled the CIROS 2 hole in the Ferrar Fjord in 211m of water to target (basement) at 166 m with 67 percent core recovery. A support camp established for the CIROS programme was located about 15 km away at Butter Point, on Bowers Piedmont Glacier in an equilibrium line - where accumulation and ablation are in balance. This hole was again drilled using the same rig as with DVDP15 and MSSTS1.

CIROS 1 was drilled offshore in 1986, 12 km northeast of Butter Point in 197.52 m of water penetrating 702 m into the sea floor with 98 percent recovery of the cored interval (27-702 m). A full mud programme, primarily to improve core recovery, was used for this hole, as the old DVDP rig was used once again. New sea riser floats of greater strength were constructed for the 5 inch API sea casing on this hole and the HW casing advanced and cemented 27 m into the sea floor. This hole was terminated at 702 m in fractured formation with mud loss and because the physical limits of the rig were being approached. The success of CIROS 1 more than any other previous hole demonstrated the potential of drilling on the fast sea ice platform with a diamond coring rig to obtain a high core recovery of quality core. The frequency of ice sheet growth and decay is best shown in the 700 m of continuous core from the CIROS-1 drillhole through strata beneath McMurdo Sound. The strata was deposited from 36 to about 22 million years ago and show variations in sediment characteristics reflecting both variation in extent of ice, and of sea level change of the order of tens. Four glacial periods (times when ice was more extensive than today and sea level was depressed) are recognised between 30 and 25 million years ago, each with a duration of no more than about 1 million years but possibly much less (dating is not precise enough to preclude shorter durations).

Cape Roberts Project 1997-1999

The most recent drilling programme, the Cape Roberts Project, completed three holes between 1997 and 1999. Cape Roberts is located 125 km northwest of McMurdo Station/Scott Base in the SW Ross Sea. A total of over 1500 m of sediment core was recovered from the three sites equal to over 8000 kg of core with a combined 95 percent recovery rate. The first site (CRP1) began drilling in October 1997, and a bottom hole depth of 147 m below the sea floor was reached with an 86 percent core recovery rate before the hole was terminated permanently due to storm induced unstable sea ice conditions. The second site (CRP2) drilling was drilled in October and November of 1998, and reached a bottom hole depth of 625 m below the sea floor with a 94 percent core recovery rate. The third site (CRP3) was drilled between October and November of 1999, when drilling reached 939 m below the sea floor with a high 97 percent core recovery rate.

The cores recovered from the Cape Roberts Project provide a record of the period from 17 to 34 Ma ago and show:

- this sector of East Antarctica had a sub-polar climate with tundra-like vegetation from 34 to 24 Ma. During this time temperate glaciers from the mountains and possibly an inland ice sheet were regularly releasing ice bergs to the Ross Sea;
- the period from 24 to 17 Ma was cooler with periods of more extensive grounded ice;
- the present phase of volcanism in the McMurdo Sound region began around 24 Ma;
- the Transantarctic Mountains had achieved most of their present height by 34 Ma; and
- most subsidence in the Victoria Land basin took place from 34 to 17 Ma ago.

All of these drilling programmes underwent some form of environmental impact assessment (ref Parker??). For the CRP, the highest level of environmental impact assessment within the Antarctic Treaty system of the time, a Comprehensive Environmental Evaluation (CEE), was undertaken on the project in 1993. The Final CEE (Keys, 1994) was the basis for annual environmental reviews throughout. A final environmental report was produced in 2001 (Waterhouse 2001) and a final project report in 2002 (Cowie, 2002).

Table 1. Drill holes of the Ross continental shelf and coastal Victoria Land from which Cenozoic strata have been recovered.

Hole	Year	Latitude	Longitude	Elevation (sea floor depth) (m)	Penetration (m)	Percent recovered	Oldest sediment
DSDP 270	1973	77°26.48'S	178°30.19'W	-634	422.5*	62.4	late Oligocene
DSDP 271	1973	76°43.27'S	175°02.86'W	-554	265.0	5.8	Pliocene
DSDP 272	1973	77°07.62'S	176°45.61'W	-629	443.0	36.6	early Miocene
DSDP 273 & 273A	1973	74°32.29'S	174°37.57'E	-495	346.5	24.1	early Miocene
DVDP10	1974	77°34.72'S	163°30.70'E	+2.8	185.9	83.4	early Pliocene
DVDP11	1974	77°35.40'S	163°24.67'E	+80	328.0	94.1	late Miocene
DVDP12	1974	77°38.37'S	162°51.22'E	+75	166*		Pliocene
DVDP15	1975	77°26.65'S	164°29.93'E	-122	65	52.0	?Pliocene-Pleistocene
MSSTS-1	1979	77°33.43'S	163°23.21'E	-195	229.6	56.1	late Oligocene
CIROS-2	1984	77°41'S	163°32'E	-211	168.1	67.0	early Pliocene
CIROS-1	1986	77°04.91'S	164°29.93'E	-197	702.1	98.0	early Oligocene
CRP-1	1997	77.008°S	163.755°E	-153.5	147.69	86	early Miocene
CRP-2/2a	1998	77.006°S	163.719°E	-177.94	624.15	95 (below -45.97m)	earliest Oligocene
CRP-3	1999					98	

Current Drilling Programmes

ANDRILL objectives have strong synergies with other projects working on the Antarctic margin, such as Shallow Drilling Project (SHALDRIL), and Antarctic Ice Margin Evolution (ANTIME). The results from drill sites targeting the last million years will be of interest to ice-coring projects in the interior, European Project for Ice Coring in Antarctica (EPICA), Subglacial Antarctic Lake Exploration (SALE) (Lacy et al., 2002). The discoveries from this work will also be of interest to modelers wanting to understand past behaviour of climate and ice sheets.