Confidential

2008 Review
of
Contract - C05X0410 ANDRILL

Partnered by the Foundation for Research Science and Technology and the Institute of Geological and Nuclear Sciences Limited (GNS Science)

Expert Review Panel	Prof. John Hay (Chair)
	Prof. William Howard
	Prof. Thomas Crowley
	Prof. Nick McCave
Report Date	June 10, 2008
Report Version	**FINAL Report**
Final Report signed on behalf of Review Panel	

Contents

Important Notice

This Report has been prepared by an independent Expert Panel comprising Prof. John Hay, Prof. Will Howard, Prof. Tom Crowley and Prof. Nick McCave, at the request of The Foundation for Research, Science and Technology (FRST) and the Institute of Geological and Nuclear Sciences Limited (GNS Science). Except where otherwise noted or apparent, all information used in the preparation of the Report was supplied by FRST and GNS Science. The Expert Panel was not asked to verify independently the accuracy of the information provided and accordingly provides no guarantees as to information accuracy or sufficiency. In particular, information supplied to the Expert Panel includes statements, opinions, estimates, assumptions, projections and analyses made by others that may or may not prove correct. Where information supplied has been inadequate, the Expert Panel has sought further information, but cannot be certain that all pertinent information has been provided.

Accordingly, while the statements, views, analyses, estimates and projections contained in this Report have been developed with great care, no representations are made by the Expert Panel or its respective members, as to the accuracy or completeness of such statements, views, analyses, estimates and projections. In particular, no representation is made that the development and commercialisation of projects reviewed will be successful.

Executive Summary

Background and Overall Objectives

FRST and the Institute of Geological and Nuclear Sciences Limited (GNS Science) have jointly commissioned this Science Review of contract C05X0410. The Review has been conducted by an independent expert panel in accordance with the agreed Terms of Reference.

The focus of the Review was on the following key criteria:

- Science Quality
- Technology
- Leadership
- International Linkages and Relationships
- Outreach
- Economic Impact
- Science Infrastructure
- Future Plans
- Overall assessment

Findings

The Review Panel reached a number of conclusions and therefore this document includes a number of recommendations for the consideration of FRST and GNS Science.

This mid-term review of the ANDRILL/New Zealand Research Project was prepared by an independent Expert Panel comprising Prof. John Hay, Prof. Will Howard, Prof. Tom Crowley and Prof. Nick McCave at the request of The Foundation for Research, Science and Technology (FRST) and the Institute of Geological and Nuclear Sciences Limited (GNS Science).

The goal of ANDRILL/New Zealand is to obtain a proximal record of Antarctic Ice Sheet behaviour from the time of formation of the East Antarctic Ice Sheet (EAIS) about 40 Ma (million years ago) to the present. In the 2006/7 and 2007/8 seasons this goal was addressed, in part, by drilling two boreholes– one on the western edge of the Ross/McMurdo Ice Shelf (termed MIS), and the other on sea ice in the Southern McMurdo Sound (termed SMS).

Both of these efforts were highly successful in terms of percent of core recovered (98%), and depth (below seabed) of core drilled (>1100 m in both cases) – the two deepest holes ever drilled on the Antarctic continental margin. The technological success of the drilling program is due to a dazzling array of technological solutions to the problems of drilling on thin sea ice and thick ice shelves. These areas are difficult, if not impossible, to reach with ship-based or traditional land-based drilling rigs, making the ANDRILL capabilities unique. The high quality of the cores enabled a suite of interpretations that easily reach the highest international benchmarks of scientific merit.

Most prominent of the scientific findings is the discovery of repeated intervals of warm and cold oscillations from about 1.7-5.0 million years ago in the western Ross Sea. These can be interpreted in terms of waxing and waning of the West Antarctic Ice Sheet (WAIS). If this interpretation can be verified through future work, it could imply an unexpected sensitivity of the WAIS that would have very significant implications for global warming impacts (see Science Quality section). Melting of this ice sheet can contribute up to 6 m of global sea-level rise.

Such information is of high value to the international community, as the magnitude of sea level due to anthropogenic greenhouse gas increases represents perhaps the largest uncertainty of the recently published Fourth Assessment Report of the Intergovernmental Panel for Climate Change (IPCC). A

whole suite of additional measurements and analyses are now underway to improve chronology and quantify the magnitude and timing of (especially) warmer marine intrusions.

Other findings include:

- ANDRILL/NZ scientists, technicians, engineers and administrators have played a leading role in ANDRILL's international efforts.

- In the SMS project ANDRILL overcame several of the down-hole logging problems encountered during the MIS project; there was also a successful hydro-fracture experiment in SMS, the first ever in Antarctica; however, significant challenges do remain for future logging, especially with respect to operating from platforms on a fast-moving ice shelves.

- ANDRILL/NZ has contributed to capacity-building in terms of attracting and retaining very well qualified scientists and students to New Zealand institutions.

- Overall, ANDRILL outreach efforts are exceptional, but it was difficult to evaluate the value of the outreach efforts of ANDRILL/NZ.

- ANDRILL/NZ has acted as a catalyst for the development of analytical facilities such as the magnetics lab at Otago University, the physical-properties logging capability at Otago University, and the laser-ablation trace-metal facility at Victoria University of Wellington (VUW).

- There is some modest direct economic benefit to New Zealand, on the order of $US 5 M.; there is also potential for spin-off applications relevant to the superb developments in drilling technology. However, this aspect would require significant additional effort from the relevant New Zealand university and government organizations.

In general, the panel endorses the future plans of ANDRILL, which include drilling on the Coulman High. This effort would provide greater insight into the history of the Ross Ice Shelf and the WAIS during interval 5-20 Ma and also the "greenhouse world" of about 40 Ma. Another possible site would be the eastern Ross Ice Shelf, which would provide insight into more recent movements of the WAIS and test earlier inferences of a variable WAIS. Significant technical innovations would be required for the latter effort because of the fast-moving nature of the ice shelf (possibly as fast as 750m/y).

The panel recommends additional management support in two areas: (1) augmentation of the technical side of the drilling operation in order to provide both backup for the (sole) drill systems designer/manager and enable parallel drilling operations (if desired); and (2) addition of a possibly full-time manager (such as Assistant to the Director of the Antarctic Research Centre) whose duties would include assisting in the oversight and management of operations, interfacing with international groups, and supporting knowledge and technology transfer with respect to developments in the newly-approved Scientific Drilling Office (SDO) at Victoria University of Wellington. This and other specific technical recommendations are listed on the following page.

In terms of both *quality* and *quantity* the Panel rates the overall performance of ANDRILL/NZ as Very Strong, signalling little room or need for improvement. In the words of Chris Mace, Director of the Sir Peter Blake Foundation, "In a connected world, people are New Zealand's advantage. In New Zealand, there is no better example of this than in science, and within that there is no better example than ANDRILL/NZ".

RECOMMENDATIONS

A. Science Outcomes

- Build on the excellent work to date by improving still further the alignment between the paleoclimate-related activities (e.g. analysis of the cores, research collaboration, education and outreach) and the predictive studies being undertaken by climate and other modelers, and by taking appropriate actions to facilitate inclusion of the collective findings into the IPCC processes, including being used to improve IPCC projections, particularly in relation to sea-level rise and the sensitivity of the WAIS.

- Contribute the technical and scientific capabilities of ANDRILL/NZ to proposing and implementing a research project that would provide critically important new information and understanding by:
  - drilling in the Ross Sea sedimentary structure known as the Coulman High, as this would provide greater insight into the history of the Ross Ice Shelf and the WAIS during the Miocene, Pliocene and the "greenhouse world" of the Paleogene, while noting that the drilling effort would require major technological innovations due to the fast moving ice shelf (as great as 750m/y); and
  - drilling in Pine Island Bay, the advantage of this site is its remoteness from influences of the EAIS and proximity to a major and fast icestream coming from the WAIS.

- Take actions to capture the significant added value that could come from including one or two additional members of the ANDRILL consortium in future scientific and related activities.

- Reflect and act on the potential for further scientific and related policy benefits that would arise from building additional analytical capacity in areas where New Zealand is already strong, such as in the organic geochemistry of biomarkers

- In terms of the research-based public outreach activities, develop and track indicators of their impact within New Zealand.

B. Drilling Activities, Technology Development and Application, and Project Management

- Identify and implement changes in technology and operations that would build on the excellent experience and advances gained to date in order to achieve:
  - even more consistent down-hole logging of boreholes; and
  - improved measurement of down-hole physical properties.

- Address the vulnerability of the human resource base, arising in part from excessive reliance on key individuals.

- Reflect on the observation that management of ANDRILL/NZ activities appears to be stretched too thin, and consider a recommendation of additional management support.

- Serious consideration be given to broadening the mandate and capacity of the Scientific Drilling Office (SDO) based at Victoria University of Wellington (VUW) to that of an international centre for drilling in polar and other remote regions.

- Consideration be given to capturing the considerable additional benefit which could flow from additional nourishing of spin-off applications; consideration should be given to formalizing this effort, perhaps in the recently established SDO. This would require additional staff in the SDO.

ANDRILL Programme:

1. Science Quality

The goal of ANDRILL/New Zealand is to obtain a proximal record of Antarctic Ice Sheet behaviour, from the time of formation of the modern East Antarctic Ice Sheet (EAIS) about 40 Ma (million years ago) up to the present. In the first two years of the five year programme this goal was addressed by drilling two boreholes in successive years – one on the western edge of the Ross/McMurdo Ice Shelf (termed MIS), the other on sea ice in the Southern McMurdo Sound (termed SMS).

Both of these efforts were highly successful in terms of percent of core recovered (98%) and length of core drilled (>1100 m in both cases) – the two longest holes ever drilled on the Antarctic continental margin. For obvious reasons, analyses of the MIS core have progressed to a more advanced stage; results from the second hole (SMS) primarily confirmed successful completion of the goal of obtaining a Pliocene-Miocene section that not only overlaps, but extends, the higher resolution recovery of Pleistocene-Pliocene records from the first core (MIS).

Initial analyses indicate that the principal findings from the McMurdo Ice Shelf (MIS) core will be:

(1) Approximately 12 glacial-interglacial fluctuations from ~1.8-2.9 (Ma) that have been interpreted to indicate a highly variable West Antarctic Ice Sheet (WAIS);

(2) progressively more glacial conditions in the Pleistocene, with a notable exception of unusual warmth in marine isotope stage 31 (~1.1 Ma);

(3) an early-mid Pliocene section with comparable recovery of glacial and nonglacial sections; from top to bottom there is a primarily glacial interval from ~2.9-3.3 Ma, below which is a hiatus and then a thick (~50 m) diatomaceous nonglacial interval from about 4.2-4.6 Ma, a primarily glacial interval from about 4.6-4.9 Ma, and then another nonglacial interval from 4.9-5.2 Ma.

(4) Intervals of laminated diatomaceous sediments that may provide windows into higher frequency climate variability near the Antarctic margin.

A whole suite of additional measurements and analyses are now underway to improve chronology and quantify the magnitude of (especially) warmer marine intrusions.

Efforts are underway to include a modelling component of ANDRILL, effected primarily through interactions with U.S. colleagues. Initial work in this area seems promising but the panel cautions that a healthy dose of scepticism needs to be entertained with respect to model representations of ice-sheet forcing mechanism. For example, modelling results indicate that Stage 31 warming could be due to the unusual orbital configuration at this time, but the sensitivity of the models to orbital forcing should be tested by running them with similar orbital geometries. Caveats such as these need to be kept in mind in order to maximize fruitful interactions between observations and modellers.

The panel gives the highest rating to the quality of science already completed and judges the preliminary findings of a highly variable WAIS of first-order scientific importance. ANDRILL results are relevant to understanding one of the two (the other being Greenland) ice sheet regions susceptible to melting due to rising greenhouse gas concentrations.

1.1 ***What is the quality of the research with respect to New Zealand and international benchmarks?***

- The highest international standards have been achieved – the sheer quality of the core enables a suite of interpretations that easily reach the highest international benchmarks

1.2 ***What important new knowledge is the programme likely to deliver?***

- Preliminary findings of a variable WAIS are of primary scientific importance because of the heightened worldwide interest in terms of its relevance to future sea-level changes. The Panel urges the ANDRILL team to consider as broad a range of processes as possible, in addition to carbon dioxide levels, to explain WAIS evolution. This might include establishment of geomorphic anchor points such as Mt. Erebus.
- Additional findings about the long-term history of Antarctic glaciation in the Pliocene may sharpen overall understanding of the behaviour of the ice sheet and its relation to global climate change.
- Ongoing work quantifying the magnitude of warming in the western Ross Sea during nonglacial intervals will enable better understanding of the relationship between ice sheet retreat and surface warming.

1.3 ***In what ways is the research relevant to New Zealand and global environmental change issues?***

- ANDRILL research provides valuable climate perspectives on sea-level changes that could occur in the future.
- Such information is also very important to the international community as exemplified in the the IPCC Fourth Assessment Report (IPCC AR4) which includes consideration of past and future sea-level changes.

1.4 ***Other:***

- The magnificent coring effort and the importance of the scientific findings strengthen international appreciation of New Zealand science.

The panel scored this criterion: **5**, ***Very Strong Performance****, with little room for improvement*.

2. Technology

2.1 ***How well has the technological side of the project responded to the science needs?***

- The key to the success of ANDRILL (and indeed any project based on coring) is the recovery of complete, continuous sections of core material. In this respect, the technology deployed in support of ANDRILL has been outstandingly successful. Recovery of material representing 98% of drilled depth is most unusual for drilling through coarse-grained material at sea. (ANDRILL is, of course, a marine coring programme using ice support for the drilling rig, rather than a ship).

2.2 ***What aspects of the technology are "leading edge" internationally?***

- The list of innovative components that has delivered this success is a dazzling array of technological solutions to the problems of drilling on thin sea ice and thick ice shelves. These include:
  - Support for a drilling rig by way of inflatable airbags under the ice,
  - Compensation for a complicated tidal regime with tidal range of up to 1.5m,
  - Deployment and maintenance of up to 1,000 m of riser from the sea-bed to the drill floor,
  - Enclosure of the drilling structure, providing environmental control,
  - Hot water drilling of a hole through the ice shelf coupled with reaming systems to keep the hole open, and
  - Coupling these advances with a relatively standard commercial drilling rig (i.e., avoiding unnecessary re-invention of the "wheel").
- The above list comprises unique capability at the cutting edge of drilling technology in extreme environments.
- The achievement of the above, while also maintaining a clean environment at the rig site both during and after drilling, is rare and highly commendable.

2.3 ***What aspects of the technology might contribute more broadly to enhancing polar research capability?***

- The list of six items above has been developed over the past two decades, especially in the Cape Roberts Project and ANDRILL. This technology would be applicable to drilling Arctic margins, e.g. off Siberia, Canada and other Arctic sites with seasonal fast ice cover.
- Ocean drilling programmes have struggled to recover soft sediments of sand size and coarser. Lessons from ANDRILL, where recovery was outstanding, may be more broadly applicable, particularly if a riser can be deployed.
- The hot-water drilling capabilities developed for ANDRILL may have applications in areas of science other than geological drilling, e.g. oceanography (deployment of under-ice instruments) and glaciology, and, in the distant future, drilling through ice-cover on moons such as Europa.

2.4 ***Other:***

- Logging of drill holes is an important component of the complete recording of geological data. The ANDRILL work to date is highly commendable in this regard. It is difficult log holes that progressively narrow downwards, such as in the case of ANDRILL. The Panel notes that several of the down-hole logging problems encountered during MIS were overcome for the second year SMS project. There was also a successful hydro-fracture experiment in SMS, the first ever in Antarctica. But significant challenges do remain for future logging from "fast-moving ice shelves". Achievement of more consistent logging of holes will provide an important contribution to documenting down-hole physical properties, tying core properties to seismic information, and

helping to fill-in any coring gaps. The Panel recognises the difficulty of logging narrow holes in unstable material. Thus acquisition of good logs will always be a bonus, but never a certainty.

- The most important component of ANDRILL/NZ that will contribute to further enhancement of New Zealand's (and international) polar research capability is the human resource base. But this is rather fragile. Alex Pyne, ANDRILL Drilling Science Coordinator, may not be irreplaceable, but the future of New Zealand's polar palaeoclimate capability would be more secure if it did not rest in large part on the shoulders of one man.

The panel scored this criterion: **5**, ***Very Strong Performance****, with little room for improvement*.

3. Leadership

3.1 ***To what extent has the programme developed existing and new leadership capability?***

- New Zealand scientists and administrators have played a prominent role in ANDRILL's international efforts. This is large part due to the importance ANDRILL/NZ has placed on succession planning. The programme was influential in attracting Gary Wilson back to New Zealand. It provided an environment which allowed him to develop and demonstrate strong science leadership, both in relation to ANDRILL activities and more widely within New Zealand and international science and administration. Gary chairs the McMurdo Sound ANDRILL Science Implementation Committee (M-ASIC). He has shown exceptional skill, especially while negotiating an agreement between the four countries participating in ANDRILL. Similarly, Tim Naish returned to New Zealand, where he has been able to develop and demonstrate high credibility and visibility as a science leader, again both within ANDRILL and more broadly. International recognition of this has come in the form of the US Society for Sedimentary Geology awarding Tim Naish the James Lee Wilson Award for 2008.Tim is Co-Chief Scientist of ANDRILL's McMurdo Ice Shelf Project and chairs the ANDRILL Science Committee. He is also Director of the Antarctic Research Centre at VUW.
- It is highly unusual to have individuals from a relatively small country occupy such senior positions in an international science initiative. This, and the continuity of these appointments, emphasises the high international regard for New Zealand Antarctic science leadership.
- ANDRILL provided Peter Barrett with the opportunity to hand over drilling-based research leadership to others, freeing him to apply his leadership skills at a higher level, across science and policy, again within New Zealand and internationally.
- In terms of senior leadership in international operations management for ANDRILL, Jim Cowie is the ANDRILL Project Manager while Alex Pyne is the ANDRILL Drilling Science Coordinator. Both are building on experience gained through New Zealand contributions to the Cape Roberts Project (CRP) and earlier projects. Alex is especially highly-regarded in the design of specialised drilling equipment, logistics management, in-field project management and ice drilling. He was recently appointed to the technical advisory panel of the Integrated Ocean Drilling Project (IODP). Careful consideration needs to be given to ensuring that the accumulated expertise and experience of Alex and Jim remains accessible to ANDRILL.

3.2 ***How has the science leadership been demonstrated and recognised at international level?***

- ANDRILL recognised the important scientific benefits of retrieving cores proximal to the Antarctic ice sheets, with the choice of drilling locations and subsequent interpretation of the findings being guided by extensive surveys and modelling. This science strategy drove numerous technological advances. Moreover, it took on even greater importance with the growing international attention on the past and future stability of the Antarctic ice sheets, as highlighted in IPCC AR4.
- Thus ANDRILL is contributing not only fundamental knowledge about the glacial history of Antarctica, but it is also providing understanding that is critical to developing climate change policies at the international level. It is delivering information on ice extent, temperature of the Ross Sea and implications for the Ross Ice Shelf and West Antarctic Ice Sheet (WAIS) system

under the warmer conditions expected to result from elevated atmospheric CO2 concentrations. The drill core records of past natural climate cycles, especially during periods of higher CO2, can be used to calibrate climate models, allowing more rigorous characterization of possible future changes. The recovered core has the potential to place important constraints on the ocean and atmospheric temperatures, sea levels and other parameters associated with past ice shelf collapse and ice sheet retreat. Any models which seek to explain the evolution of the Antarctic cryosphere will have to take ANDRILL's core records into account.

- The first comprehensive environmental evaluation under the Antarctic Treaty System was undertaken during preparations for the CRP. It established best practice, to international acclaim, and was replicated for the ANDRILL project.

3.3 ***How has the technical leadership been demonstrated and recognised at international level?***

- The previous section has highlighted the substantial technological innovation attributable to ANDRILL, including the first geological drilling from an ice shelf platform, first combination of ice hot-water drilling and geological drilling, and the deepest geological borehole and longest geological rock core recovered in Antarctica. This has resulted in international recognition of New Zealand as a leader in the development of on-ice drill rig technology, including both engineering and management, with potential spin-offs to the commercial sector.

3.4 ***How has the management leadership been demonstrated and recognised at international level?***

- As noted above, New Zealand participants in ANDRILL have taken lead roles in its multi-national management structure. Despite some difficult challenges during the establishment phase, the management system put in place has proven to be highly successful. As a result, it is well regarded by all parties. Assistance was taken from experts to form the management plan, which evolved to its current form from a nominal starting point. The management procedures are considered to require little modification for the next phase of ANDRILL, should it proceed. They are also seen as having high replication potential for other international science programmes.
- Excellent examples of management leadership are the production and successful implementation of the Scientific Logistics Implementation Plan and the Operations Plan. These address the complexity of ANDRILL by helping to develop understanding and establish a cooperative spirit, without being overly prescriptive.

3.5 ***Other:***

- The Panel is somewhat concerned that the management of ANDRILL/NZ activities appear to be stretched too thin. If any other responsibilities are added to the present arrangements (e.g., increased interactions with the IODP, multiple simultaneous ANDRILL field operations), problems could arise with respect to either the effectiveness of coordination and/or the success of field operations. The Panel recommends both augmentation of the technical drilling staff and additional management support. With respect to the latter, one possible avenue would be establishment of a full-time manager (such as Assistant to the Director of the Antarctic Research Centre). The responsibilities of this person could also include knowledge and technology transfer with respect to the Scientific Drilling Office (SDO) (see Section 6).

The panel scored this criterion: **5**, ***Very Strong Performance****, with little room for improvement*.

4. International Linkages and Relationships

4.1 ***To what extent have the programme and people involved, achieved international linkages of importance?***

- As the founding and leading members of the ANDRILL consortium, New Zealand scientists have established the significant linkages that have allowed the ANDRILL project to be internationally funded and supported. The larger, international ANDRILL programme has somewhat limited membership (4 countries), compared to the total of 28 Antarctic Treaty nations. The links, especially with the USA, who provide 50% project funding, are excellent. The leadership role being assumed by Italian scientists also testifies to good links there. German scientists from the Alfred Wegener Institute in Bremerhaven are enthusiastic participants. There is room within the structure to accommodate one or two more members of the consortium in the future. Increased membership would allow benefits such as greater frequency of drilling operations.
- There are also strong and growing links between ANDRILL and other international programs such as the IODP and the International Continental Drilling Program (ICDP). These links are well worth ANDRILL nurturing, while maintaining focus on its core strengths and capabilities.

4.2 ***How has the programme contributed to New Zealand strategic Antarctic and climate change relationships****?*

- As a result of this work, New Zealand is able to sit at any Antarctic negotiation secure in the knowledge that it has a strong overall technological position and clear leadership in significant areas of scientific investigation of the continent. New Zealand can thus speak with an authoritative voice.
- The stability and future behaviour of the WAIS looms large in most discussions of the impacts of global climate change on sea level. Understanding of the Antarctic sea-ice-atmosphere system will permit better modelling and will allow New Zealand representatives to influence the views of the international community on impacts of Antarctic variability on climate change and its global impacts.
- The cooperation between a major CRI (GNS) and three of New Zealand's leading universities is both noteworthy and commendable. We consider this a very strong performance.

The panel scored this criterion: **4**, ***Strong Performance****, room for improvement in a few areas*.

5. Outreach

5.1 ***What have the outreach activities achieved through scientific publications, newspapers, radio, television, film, websites and education in terms of:***

a) quantity? The panel scored this question: **5**,
***Very Strong Performance**, with little room for improvement*.

b) quality? The panel scored this question: **5**,
***Very Strong Performance**, with little room for improvement*.

c) impact? The panel scored this question: **4**,
***Strong Performance**, room for improvement in a few areas*

- Considerable information related to ANDRILL's education outreach programme was made available to the Panel, but it was mainly presented from the perspective of the US-based ANDRILL programme office and the United Kingdom (UK)-based International Polar Year (IPY) programme. The Panel received little information related to the education programme within New Zealand. As the focus of the review was on ANDRILL/NZ, evidence based on more specific reporting and tracking of national education outcomes would have been helpful. For example, the Panel was provided with a list of schools in Italy which participated in the ANDRILL outreach programme, but not with a similar list for New Zealand. Similarly, the Panel was not provided with assessments from New Zealand teachers who participated in ANDRILL and was thus unable to assess the impact ANDRILL/NZ's outreach and education programme at the national level.
- ANDRILL as a whole has done an outstanding and innovative job in designing and implementing an outreach programme. Staff have raised the profile of the project in a wide variety of media, and across a wide range of countries. In particular, they have utilised a number of innovative digital media outlets for sharing the ANDRILL story with the public and the education sector. These include webcasts, Podcasts, and streaming video and audio content. Another strong point of the outreach programme is the direct involvement of teachers in the project, particularly taking teachers into the field. Targeting teachers for education outreach is an effective way to reach a large number of students.
- In terms of both quality and quantity the Panel rates the performance of ANDRILL/NZ as Very Strong. In terms of both media coverage and education in New Zealand, the programme has probably had more visibility than any other science programme. However, as noted above and relative to the overall project, little specific evidence to support this perception was made available to the Panel. Information on public lectures and similar activities was provided, but similar information for other outreach activities was lacking.
- While the impact of outreach activities is not as easy to measure, and indeed may not be fully known for several years, particularly in the area of education outreach, the Panel recommends appropriate effort be given to tracking such impacts, at least through to the end of the current project funding period.
- Specifically in terms of the public outreach it would also be useful to track some indicators of the impact within New Zealand, including hits and downloads on the relevant websites from within New Zealand, numbers of attendees to public lectures and museum exhibits.
- It would also be useful to have evidence of the impact of public outreach efforts in non-ANDRILL member countries. Most of the evidence presented related to impacts within the ANDRILL member countries.
- Related to Point 4.1 above, it would be useful to target outreach activities to both the public and the scientific communities of countries not currently participating in ANDRILL, but whom ANDRILL would like to attract to the project in future.

Based on information provided,
the Panel scored this overall criterion: **4**, ***Strong Performance**, room for improvement in a few areas*.

6. Economic Impact

Because the primary purpose of the project was not aimed at producing a result of immediate economic benefit, the economic impacts of the project are more restricted than for some other projects. Nevertheless there are two major areas where the impact can be quantified – some immediate net benefits to the Christchurch region and the longer-term potential for spin-off applications of drilling technology.

6.1 ***What economic benefits has the programme produced for New Zealand from its operations?***

- The total cost of the ANDRILL project to New Zealand was about $US 2.3 M. The Panel understands that, in comparison, about 50% of the total international cost (i.e., $US 4.6 M) flowed into New Zealand (primarily to the Christchurch region) in the process of implementing the drilling operation. Assuming a standard multiplier of 2-3 as the benefits of this investment diffuse through the economy, a reasonable estimate of the net direct economic impact to New Zealand might be in the order of $US 5.0 M).

- By way of further comparison, a recent study[1] indicates that the direct contribution of Antarctic-related activities is almost $NZ 88.0 M per annum to the Canterbury economy and at least $NZ 133 M annually to the New Zealand economy
- The innovative drilling methods developed for the coring system should also have some economic benefit. Anecdotal evidence suggests this is already the case. But it is not clear under the present circumstances whether it is possible to patent such capabilities, in part because of international project funding (particularly from the U.S. National Science Foundation) provided to the project (see below).

6.2 ***Other***

- International agreements cover implementation of the ANDRILL project. These are yielding mutual benefit to the partners. New Zealand has taken the lead in technological developments, with appropriate involvement of commercial drilling and engineering companies. Even without commercialisation of the New Zealand-based advances in drilling and other technologies, the entire project has benefited immeasurably from these developments. Moreover, as noted above, New Zealand has benefited financially from investments the international partners have made in New Zealand.
- Although a number of key technological advances have been made in New Zealand, assigning ownership of the intellectual property (IP) is complex, as the programme involves several institutions in New Zealand, and several countries, all making financial and in-kind (staff, logistics, etc.) contributions to the ANDRILL project. While it might seem obvious that New Zealand should reap commercial benefit from the technological developments, the IP ownership needs careful negotiation. For example, consideration should be given to the entire New Zealand IP component being vested in a single entity, such as the new SDO based at VUW. The office could also promote appropriate spin-off applications.
- The Panel's ratings for this section have been influenced favourably by the recognition that few 'pure' science programmes deliver any immediate economic benefit.

The panel scored this criterion: **4**, ***Strong Performance****, room for improvement in a few areas*.

[1] Saunders et al., 2007: Contribution of Antarctic-related Activities to the Canterbury and New Zealand Economies.

7. Science Infrastructure

7.1 ***How has the programme contributed to the development of research infrastructure?***

a) **In New Zealand**

- ANDRILL/NZ has contributed strongly to infrastructure development. A major highlight is the drilling facility itself which is, and will likely continue to be, a major technological infrastructure resource for New Zealand and other countries. Similarly, ANDRILL has acted as a catalyst for the development for other analytical facilities such as the magnetics laboratory at Otago University, the physical-properties logging capability at Otago University, and the laser-ablation trace-metal facility at VUW. ANDRILL also provides a focus for other supporting scientific capabilities such seismic profiling and interpretation, over-ice geophysics, and oceanography.
- A particular strength of ANDRILL/NZ is its contribution to capacity-building in terms of attracting and retaining scientists and students to New Zealand institutions. ANDRILL is a flagship programme; an important unifying project which brings together a large number of scientists within New Zealand (including universities and government science agencies) to focus on a shared objective.

b) **Internationally**

- In a similar way the establishment of a formal SDO will provide a framework for maintaining and sustaining human and technological infrastructure. The SDO will also be a way of strengthening and sustaining New Zealand's leadership position in Antarctic scientific drilling.

7.2 ***Other:***

- Even in areas where New Zealand is already strong, such as micropalaeontology, seismic stratigraphy, paleomagnetism, and geophycis, there is likely to be a need and opportunity for capacity building. . The ANDRILL/NZ community might also consider the project as an opportunity for building capability in areas where New Zealand has historically had less strength, such as in organic geochemistry.
- All the infrastructure developments which ANDRILL/NZ has calalysed will have applications and benefits beyond ANDRILL, into other areas of earth science, and potentially into the more applied aspects of environmental science.

The panel scored this criterion: **4**, ***Strong Performance****, room for improvement in a few areas*.

8. Future Plans

8.1 ***What new opportunities and directions are coming out of the work of this programme?***

- The emerging scientific understanding and the numerous technological innovations are highlighting both the need, and the opportunity, to collect additional cores that will provide complementary information. Future plans might well address the following key research questions:

  - What are the key sedimentary signatures for relevant environmental conditions and the state of the ice sheets, ice shelves and sea ice?
  - What is the history of the Ross Ice Shelf?
  - What are the sensitivities and key thresholds of the Ross Ice Shelf/WAIS system to external forcing; what are these key forcing agents?
  - What are the relative roles and responses of the WAIS and EAIS, including scale, threshold, vulnerability and other relevant considerations?
  - What are the strength and nature of the linkages between Antarctica and the global climate system, including sea level and ocean circulation?

- The Panel heard a variety of views on what could constitute realistic plans to address these or related research questions. The Panel had a minor concern that a broad consensus had not been reached within at least the ANDRILL/NZ team. It appeared that many of the views had been formulated somewhat hurriedly immediately prior to and during the review.
- Many of the above research questions could be addressed, in part, by drilling in the Ross Sea sedimentary structure known as the Coulman High. In particular, this would provide greater insight into the history of the Ross Ice Shelf and the WAIS during the Miocene, Pliocene and the "greenhouse world" of the Paleogene. The drilling effort would require major technological innovations due to the fast moving ice shelf (as great as 750m/y)
- The Panel urges that consideration also be given to drilling in Pine Island Bay, the site of another major outlet glacier of the WAIS. The advantage of this site is its remoteness from influences of the EAIS and proximity to a major and fast icestream coming from the WAIS. The UK is likely to be interested in drilling-based research in this area.
- Through these and other initiatives, the SDO has the potential to become the international centre of expertise for on-ice geological drilling.

8.2 ***How are these new opportunities aligned with national & international Antarctic & climate change research strategies?***

- ANDRILL is the only operation for Antarctic near shore drilling and ANDRILL/NZ is the principal source for the technical expertise in order to fulfil this function. The research goals of the ANDRILL programme are directly aligned with the Science Research Programme of the Scientific Committee on Antarctic Research (SCAR) and particularly with its programme on Antarctic Climate Evolution (ACE). The scientific goal of ACE, to which ANDRILL is a major contributor, is to continue the study of Antarctic climate and glacial history through palaeoclimate and ice sheet modelling studies, purposefully integrated with geological investigations of the proxy record of ancient Antarctic climates and ice sheets. Tim Naish and Gary Wilson are members of the Executive Committee of ACE and the former is Chair of the Pleistocene Subcommittee. ANDRILL is an official SCAR programme. It is also a sanctioned IPY project. ANDRILL is a major component of the IPY education and outreach campaign.
- ANDRILL is also closely aligned with the Past Global Changes Programme (PAGES) of the International Geosphere Biosphere Programme (IGBP). The emphasis of PAGES is to compare Arctic and Antarctic Quaternary climate records in order to better understand interhemispheric global climate dynamics. Tim Naish and Julie Brigham-Grette (Chair of the PAGES SSC) are convening a workshop and presentation session on Quaternary bipolar climate connections at the International Geological Congress in Oslo in August.

- ANDRILL's palaeoclimate results, and especially the new constraints on Antarctic ice sheet behaviour during past intervals of elevated temperature and CO_2, are directly relevant to the IPCC's palaeoclimate assessments. Members of the ANDRILL/NZ team are collaborating with their international partners and with members of the IPCC to help ensure that these ANDRILL findings, including the modelling results, will be available to those undertaking the assessment for the fifth report of the IPCC.
- ANDRILL is also closely aligned with the FRST portfolio Understanding and Adapting to Global Environmental Change (GLO) and especially with the target outcome of establishing the characteristics, causes and consequences of global change and variability. Investments in the GLO portfolio are intended to contribute to improved wellbeing for New Zealanders by informing decision making relating to global environmental processes and change. This includes investment in New Zealand-specific and internationally linked research, science and technology, which will help New Zealand to: (i) reduce its vulnerability to global and regional variation and change; (ii) develop more effective adaptation and risk management strategies; (iii) be confident of its position when negotiating international agreements and implementing policies in New Zealand that stand scrutiny internationally; and (iv) be a positive influence internationally and support sustainable resource development. ANDRILL will contribute to these outcomes by: (i) providing baseline data, models and knowledge for use by a wide range of users, including other research programmes, policy analysts for international negotiations, central and local government for mitigation and adaptation; (ii) provide capability that will support greater integration of information and knowledge across other research programmes and portfolios; and (iii) provide baseline data and models to improve predictive capability across a range of disciplines and environments, and verification of existing information for national purposes and international obligations.

8.3 ***How are programme participants contributing to future planning?***

- The ANDRILL/NZ participants are playing a leading role in establishing the future work programmes proposals and scientific strategies for ANDRILL.

The panel scored this criterion: **4**, ***Strong Performance****, room for improvement in a few areas*.

9. Overall Assessment

9.1 ***What is the overall assessment of the programme?***

- In terms of both quality and quantity the Panel rates the overall performance of ANDRILL/NZ as Very Strong, signalling little room or need for improvement. In the words of Chris Mace, Director of the Sir Peter Blake Foundation, "In a connected world, people are New Zealand's advantage. In New Zealand, there is no better example of this than in science, and within that there is no better example than ANDRILL/NZ".

The panel scored the overall assessment: **5**, ***Very Strong Performance****, with little room for improvement*.

Appendices

Appendix 1: Purpose and Conduct of Review

Purpose of Review

1. The Foundation for Research Science and Technology together with the Institute of Geological and Nuclear Science Limited has undertaken a Science Review of the ANDRILL contract C05X0410.
2. The purpose of the Review was to assess the quality of the scientific and technical work supported by the contract and to make relevant recommendations.
3. The overall objectives for the review were specified in the Terms of Reference.

The Review Panel and the Review Meetings

The independent expert Review Panel selected by FRST and GNS Science comprised:

- Prof. John Hay
- Prof. William Howard
- Prof. Thomas Crowley
- Prof. Nick McCave

The Review Panel attended presentations and conducted interviews at meetings in GNS Science facility in Lower Hutt on April 1 to April 3, 2008.

Paul Sanders from The Foundation of Research Science and Technology acted as co-ordinator throughout the review, with responsibility to ensure that the process was appropriate, fair and equitable. Ruth Berry (FRST Strategic Manager) attended some of the review meetings. The FRST personnel were not members of the Review Panel and did not contribute to the writing of the report.

Appendix 2: Documents and Source Information

Documents from FRST and GNS Science provided and considered in this review included:

1. **FRST Background Material**
   - 1.1 Introduction
   - 1.2 Agenda
   - 1.3 Terms of Reference – question set
   - 1.4 Current contract
   - 1.5 2006/7 Achievement Report
   - 1.6 2006/7 FRST-Business Manager Assessment Report
   - 1.7 FRST Environment Fund and GLO (Global) portfolio information
   - 1.8 Index page hyper links – ANDRILL programme on internet

2. **ANDRILL Programme Background Material**
   - 2.1 Programme Summary Statement
   - 2.2 Purpose of the Documentation
   - 2.3 Table of Contents
   - 2.4 Programme for FRST ANDRILL Programme Review
   - 2.5 Key Personnel
   - 2.6 Terms of Reference
   - 2.7 History of Antarctic Margin Geological Drilling
   - 2.8 ANDRILL Programme: Background and Overview
   - 2.9 Programme outputs
   - 2.10 Scientific Highlights
   - 2.11 Drilling and Technical Achievements
   - 2.12 Future Directions
   - 2.13 Appendix I. ANDRILL FRST Programme Contract & 2007 Annual Report
   - 2.14 Appendix II. ANDRILL Scientific Project Prospectuses
   - 2.15 Appendix III. Scientific Logistics and Implementation Plan for the ANDRILL McMurdo Ice Shelf Project
   - 2.16 Appendix IV. ANDRILL Programme Overview Publications
   - 2.17 Appendix V. ANDRILL Programme Media Guide
   - 2.18 Presentation – copies of PowerPoint slides

Appendix 3: Review Participants and Attendees

Attendees at the presentations at GNS Science, Lower Hutt on April 1 and April 2, 2008 and the sessions on March 31 and April 3, 2008 were;

Name	Position and Oganisation
GNS Science Management	
Robin Falconer	Group Manager – Research
Louise Harrington	
James Crampton	Programme Manager – Global Change
FRST ANDRILL Programme Investigators	
Tim Naish	Programme Leader, GNS Science, VUW
Gary Wilson	University of Otago
Peter Barrett	Victoria University
Lionel Carter	Victoria University
Margaret Harper	Victoria University
Mike Hannah	Victoria University
David Bibby	Victoria University
Robert McKay	Victoria University
Rosie Cody	Victoria University
Lisa Johnston	University of Otago
Andrew Clifford	University of Otago
Alan Cooper	University of Otago
Alan Aitken	University of Otago
Christian Ohneiser	University of Otago
Rory Gamble	University of Otago
Bryan Storey	University of Canterbury
Greg Browne	GNS Science
Brad Field	GNS Science
Ian Raine	GNS Science
Percy Strong	GNS Science
Chris Hollis	GNS Science
Julian Thomson	GNS Science
Stuart Henrys	GNS Science

Name	Position and Oganisation

Antarctica New Zealand (Project Operator)

Jim Cowie	ANDRILL Project Manager
Dean Peterson	Science Strategy Manager

Victoria University Scientific Drilling Office

Alex Pyne	Drill Systems Manager,
Tamsin Falconer	Drill Systems Support Co-ordinator

Invited Guests

Robert DeConto – by phone	ANDRILL Climate Modelling University of Massachusetts
James Kennett – by phone	Professor of Marine Geology UC Santa Barbara
Ulrich Harms – by phone	ICDP Executive Secretary GFZ – Potsdam
Chris Mace	Trustee Sir Peter Blake Foundation
Robert Dunbar – by phone	Prof Environmental Earth System Science, Stanford
Frank Rack	US ANDRILL Executive Manager University of Lincoln - Nebraska
Simon Lamb	Climate Change Communications Fellow Oxford/VUW
Jeff Ashby	Webster Drilling
Rhian Salmon – by phone	IPY Office, Education and Outreach BAS Cambridge
Martin Manning	Prof of Climate Change, VUW

FRST Representatives

Ruth Berry	Strategy Manager
Robert Matheson	Business Manager
Anna de Raadt	Business Manager
Paul Sanders	External Review Manager