Future Antarctic geological drilling: Discussion paper on ANDRILL and beyond

P. J. Barrett,[1,2] P. -N. Webb,[1,3] D. Futterer,[1,4] C. Ghezzo,[1,5] M. R. A. Thomson,[1,6] A. R. Pyne,[2] and F. R. Rack[7]

[1]Member, ANDRILL Science Advisory Panel
[2]Antarctic Research Centre, Victoria University of Wellington, P. O. Box 600, Wellington, New Zealand. (peter.barrett@vuw.ac.nz, alex.pyne@vuw.ac.nz)
[3]Department of Geological Sciences, The Ohio State University, 155 South Oval Mall Columbus, OH 43210-1398, USA. (webb.3@osu.edu)
[4]Alfred Wegener Institute for Polar and Marine Research – AWI, P.O.Box 12 01 61 D-27515 Bremerhaven, Germany. (Dieter.Fuetterer@awi.de)
[5]Dipartimento di Scienze della Terra, Universita' di Siena, Via del Laterino 8, 53100 Siena, Italy. (ghezzo@unisi.it)
[6]Stone House, Thornton Rust, Leyburn, North Yorkshire DL8 3AW, UK (m.thomson@stone-house.demon.co.uk)
[7]ANDRILL Science Management Office, 125C Bessey Hall, University of Nebraska-Lincoln, Lincoln, NE 68588-0341, USA. (frack2@unl.edu)

Summary Geological drilling technology developed over the last quarter century has provided access to critical knowledge on the climatic and tectonic history of the Victoria Land margin of Antarctica, giving us a new understanding of the history and behaviour of the Antarctic ice sheet in this region over the last 34 million years. The challenge now is to develop a framework within the Antarctic science and logistics communities and other relevant groups for further projects to extend this technology to other areas both around the Antarctic margin and into the interior. This paper reviews some of the issues and offers a way forward.

Citation: Barrett, P.J., P.-N. Webb, D. Fűtterer, C. Ghezzo, M.R.A.Thomson, A.R. Pyne and F.R. Rack (2007), Future Antarctic geological drilling: Discussion paper on ANDRILL and beyond: *in* Antarctica: A Keystone in a Changing World – Online Proceedings of the 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-File Report 2007-1047, Extended Abstract 139, 4 p.

Introduction

The ANDRILL (ANtarctic geological DRILLing) Program late in 2006 drilled through the McMurdo Ice Shelf and 900 m of water to core 1285 m of Neogene strata (Naish et al., this volume). This has demonstrated the technical and scientific capability of drilling through ice shelves for new knowledge and understanding of the past behaviour of the Antarctic ice sheet. Here we provide some background and suggestions for further gains to be made by this approach. Recent research indicates large uncertainties in the likely future behaviour of the Antarctic ice sheet (AGSC, submitted) in response to global warming. The evidence is now "unequivocal" and the rising trend largely a consequence of increasing human activity (IPCC 2007). The timely development of clear scientific objectives for appropriately selected and adequately surveyed new sites for drilling is now important.

Background

Geological drilling on the Antarctic continent grew out of the Dry Valley Drilling Project (DVDP) in the early 1970s (McGinnis, 1981). By this time the late Paleozoic and early Mesozoic history was known in some detail through outcrop studies of the Beacon Supergroup and Ferrar Group (390-180 Ma) but the Cenozoic was largely unknown. DVDP was initiated to recover a record of its Cenozoic history from the valley fill using a "slim-hole" drilling system to core to depths of ~300 m. About the same time the first leg of the Deep Sea Drilling Project to the Antarctic margin drilled in the Ross Sea to show that the Antarctic ice sheet was initiated at least 25 million years ago, 10 times older than any previous estimate (Hayes et al., 1975). This led to a series of projects to core strata in the sedimentary basin seaward of the McMurdo Dry Valleys, culminating with the Cape Roberts Project (1997-99), which obtained a record of climate, sea level and tectonic history from 34 to 17 million years ago (Cowie et al., 2002; Davey et al., 2002). The technical and logistics knowledge and experience gained from these projects (Pyne, 2002) have now been applied successfully to ANDRILL, and with last season's experience form a sound basis for future drilling.

Current status

The initial expedition of the ANDRILL Program has now been successfully completed (Naish et al., this volume). The hot-water drilling system melted and maintained a 60-cm-wide access hole through an 85-m-thick McMurdo Ice Shelf for a period of 58 days. Some difficulties were encountered in coring the soft sediment just below the sea floor due to the need to emplace the sea riser within one tidal cycle, but from 20 m below sea floor (bsf) to 1285 m bsf coring was continuous, with a recovery rate of 99%.

Preparations for drilling included a planning phase, with the development and submission of a proposal (2001-2004) (Harwood et al., 2003; ANDRILL, 2003), site survey programs for gathering both scientific and technical data to support the proposal and design the drilling strategy (2002-2006) (Naish et al., 2005; Harwood et al., 2006) and a development and testing phase of similar length (2004-2007) for the new technology. The latter included a new drilling system based on a top-driven UDR 1200 rig, and with extensive electronic surveillance and management, with a sea riser that could handle daily tidal currents of up to 20 cm/sec in 900 m of water, ice moving 25 m laterally during the duration of drilling, and a purpose-built hot-water drilling system for maintaining the access hole.

Preparations for drilling MIS included an access route over the ice shelf and a packed snow pad for the 85 tonne

drilling system constructed in the 12 months prior to drilling. Preparations for drilling the Southern McMurdo Sound (SMS) site in late 2007 for the mid-Miocene climate transition have proceeded in parallel with those for the McMurdo Ice Shelf (MIS) site, though the site characteristics are somewhat different, the latter probably being on 8m thick multiyear sea ice in 480 m of water, ~55 km by "road" across the sea ice. The shorter (60 day) "drilling window", due to sea-ice conditions, effectively limits the target depth to approximately 1000 m below the sea floor.

Future targets

The McMurdo Ice Shelf and Southern McMurdo Sound sites will together prove the concept and operational capability of the ANDRILL system in moderately thick ice. They also provide, along with the Cape Roberts record, a continuous stratigraphic record of climate and tectonic history for the last 34 Ma off the Victoria Land margin of Antarctica (Fig. 1). The figure also shows the significance of these records for earth's projected climate in the near future.

This is primarily a record of the East Antarctic Ice Sheet, though influenced somewhat by the Transantarctic Mountains barrier, and in the case of the McMurdo Ice Shelf site by the West Antarctic Ice Sheet. A survey following the success of the Cape Roberts Project attracted 25 one-page proposals, over half of them coming from outside the McMurdo region (Fig. 2). Below we outline some considerations for new prospective sites for geological drilling on the Antarctic continent beyond the McMurdo region, bearing in mind the necessarily long planning time for the scientific proposal and acceptance process, site surveys and logistics/drilling planning and delivery.

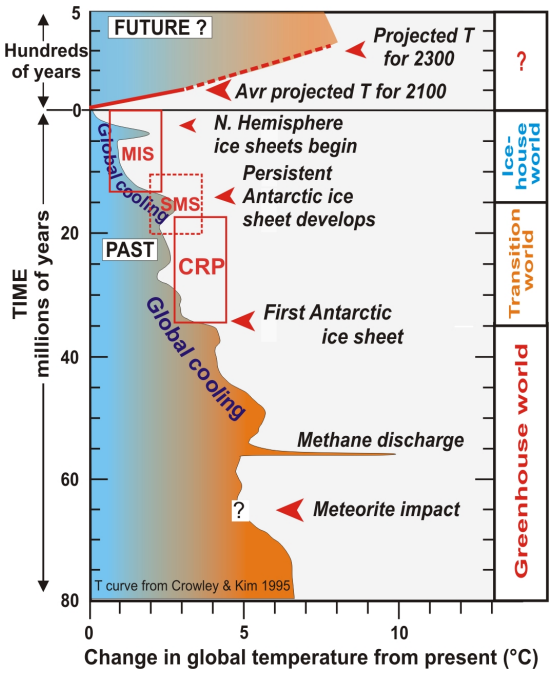

Figure 1. Global average temperature through Cenozoic time, showing the intervals covered by CRP and ANDRILL MIS records, and expected from the ANDRILL SMS drillhole (dashed box). The temperature curve of Crowley and Kim (1995) is modified to show the effect of the methane discharge at 56 Ma (Zachos et al., 2003) and the early Pliocene warming (Ravelo et al., 2004) (from AGCS, in review).

Compelling science

Each new site should address a major question (or two) of widespread interest that will provide new knowledge and understanding of some significant period in Antarctic climate history or insight into the behaviour of some aspect of the Antarctic ice cover.

Adequate prior knowledge

Thickness and movement of the ice platform, the water depth, and current speeds are all key operational constraints, though having a secure platform to drill from is perhaps the most critical to establish at the outset. High quality seismic data are important both for stratigraphic context and geophysical/geological models outlining the record expected from the drillhole. Whether the data are obtained from ships, sea-ice or ice shelf traverses the lines are time-consuming and expensive, contingent on environmental conditions at the time of shooting, and are likely to require more than one season. Site surveys require planning and funding several years before a drilling proposal is submitted.

Gaining community support and credibility

Through the Cape Roberts Project and the ANDRILL Program there is now a wide body of experience in Antarctic geological drilling, though almost entirely gained from drilling in the McMurdo region. Significant expertise has also gathered recently around SHALDRIL, for ship-based drilling of shallow targets on the Antarctic continental shelf, with experience thus far in the Weddell Sea and Antarctic Peninsula. The Ocean Drilling Program (ODP and its successor IODP) has also been significant both in advising and in providing experience for scientists in marine geological records and global paleoclimate issues. We also look to the progress of the Antarctic glaciological community in extracting climate history on annual to decadal scales back almost a million years. Future ANDRILL projects will gain strength if they can help address issues that are also seen to be important by these communities.

Directions

Here we consider two directions in which the ANDRILL Program might develop either separately or simultaneously. One is the original ANDRILL concept of drilling portfolios being developed for each section of the Antarctic margin (ANDRILL, 2003; Fig. 2). This is well founded from our knowledge that the Antarctic ice sheet responds to climate and sea-level forcing at different times and rates in different sectors (and even differently within West Antarctica). To understand fully the AIS response to climate change we need histories from all sectors.

The other direction is to move from drilling the margin to drilling towards the interior of the continent to recover new data from inner shelf and platform basins on the past behaviour of ice shelves and ultimately from sub-glacial lakes. The goal here would be to seek histories of all aspects of environmental change in the Antarctic interior, for which we are currently dependent entirely on ice sheet modelling (and extrapolating from margin records). In addition to climate-related objectives, this direction also provides new knowledge of tectonics and of biology from extreme environments (SALE; Wilson, 2007). The current ANDRILL technology could most likely be adapted for interior ice shelf drilling. A larger drilling system would be needed for sub-glacial lake drilling, but most of the same principles would apply.

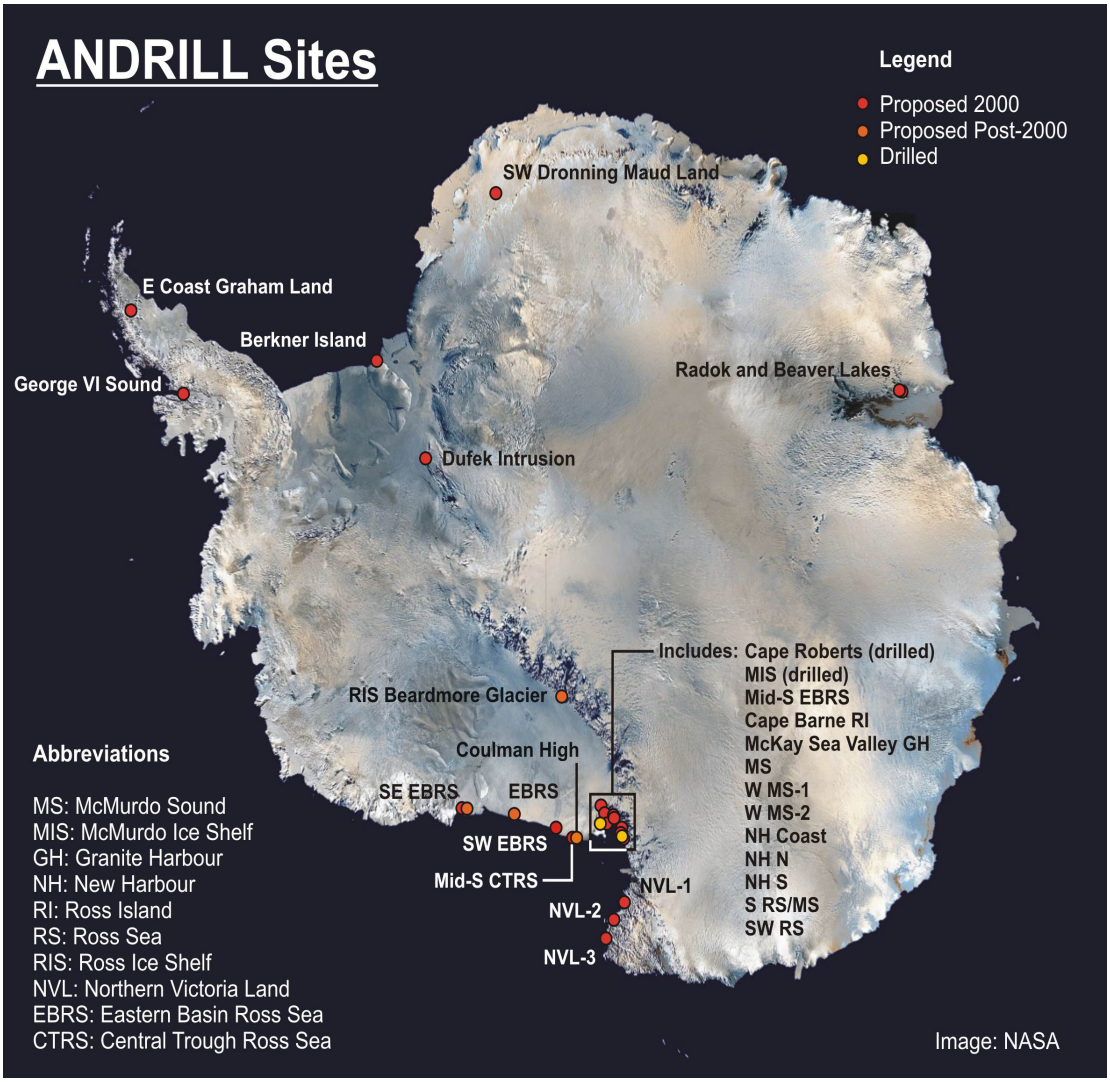

Figure 2. Map of Antarctica showing sites of prospective drilling locations based on proposals received in 2000 for future ANDRILL targets by Mike Thomson and Peter Barrett, with more recent prospects added for the Ross Sea (EBRS, CTRS, Decesari et al., 2002) and Beardmore Glacier (Wilson, 2007).

Organization, planning and timelines

The ANDRILL Science Management Office (SMO) was set up at the University of Nebraska to oversee the planning and management of ANDRILL science for the first two sites funded for drilling and also to assist with further planning activities (see www.andrill.org). The ANDRILL Program is also guided by a community-based ANDRILL Science Committee (ASC) with representation from interested countries – currently, Germany, Italy, New Zealand, UK and USA. The current drilling operation is managed by AntarcticaNZ (Project Manager Jim Cowie), with drill system development and management by Alex Pyne, Victoria University of Wellington. There remain significant knowledge gaps in the Antarctic region, for example, a high resolution Holocene record from around the Antarctic margin, time breaks of 1-3 million years in both ANDRILL and CRP records, and the transition from the Eocene "greenhouse" world into the subsequent "icehouse" world, and plans are well developed for addressing these through further drilling (Decesari et al. 2002; ANDRILL 2003).

The workshop scheduled to follow this symposium on September 1, 2007, provides an opportunity for exploring the broad interests and current capabilities of the Antarctic earth sciences community for planning further sustained drilling activities to address the big problems in Antarctic ice sheet behaviour and related science.

We envisage a process following the discussion involving:

- the development of a broad management structure for Antarctic geological drilling with links between ANDRILL, SHALDRILL, IODP, FASTDRILL, SALE and EPICA,
- a call for brief (one–page per site) expressions of interest, including a simple check list of basic information that will serve as the starting-point for developing full drilling proposals,
- the establishment of a process that leads to the development of a Science Plan outlining the community consensus for Antarctic scientific drilling targets, strategies and technology needs, and
- plans for a workshop to present the strategies and requirements to address the most promising drilling targets.

With regard to timelines, a proposal to drill from the Ross Ice Shelf east of Ross Island (Decesari et al. 2002) to seek a physical record from the Antarctic margin for the transition from Eocene "greenhouse" to Oligocene "ice house" world is in an advanced state of preparation. Key site survey data were obtained from a ship-based seismic survey in 2000, but because further sub-shelf data are required, as well as funding approval, the earliest this project can be drilled is probably 2010-11. This example indicates the importance of beginning the planning process as soon as possible.

Acknowledgments. We thank the national Antarctic programs of the United States of America, New Zealand, Italy, Germany, Australia, United Kingdom, The Netherlands and Japan, who have supported Antarctic margin drilling for over three decades, and the scientists, administrators, logistics support personnel and drillers who made it happen. We also thank co-editor Tim Naish for useful comment.

References

AGSC (submitted), State of the Antarctic and Southern Ocean Climate System (SASOCS), Rev. Geophys.

ANDRILL (2003), Investigating Antarctica's role in Cenozoic global environmental change, International Science Proposal, ANDRILL Contribution No. 2, ANDRILL Science Management Office, University of Nebraska-Lincoln, C1-41 (Project Description).

Cowie, J.C. (ed.) (2002), Cape Roberts project - Final Report 1995-2001, Antarctica New Zealand Miscellaneous Series 8, 134 pp.

Davey, F.J., P.J. Barrett, M.B. Cita, J.J.M. van der Meer, F. Tessensohn, M.R.A. Thomson, P.-N. Webb, K.J. Woolfe (2002), Drilling for Antarctic Cenozoic Climate and Tectonic History at Cape Roberts, Southwestern Ross Sea, EOS, Trans. AGU, 82, 585, 589, 590.

Cape Roberts Science Team (1998), Initial Report on CRP-3, Terra Antartica, 5, 1-187.

Crowley, T.J., K. Kim (1995), Comparison of long-term greenhouse projections with the geologic record, Geophysical Research Letters, 22, 933-936.

Decesari, R C, Luyendyk, B P, Bartek, L R, Sorlien, C C, Wilson, D S, Diebold, J B. (2004), Ice shelf drill sites proposed to study Pre-Late Oligocene climate and tectonic history, Coulman High, Southwestern Ross Sea, Antarctica. EOS Trans. AGU, 85, Fall Meet. Suppl., Abstract T11A-1244.

Harwood, D.M., F. Florindo, R.H. Levy, C.R. Fielding, S.F. Pekar, M.A. Speece, and SMS Science Team (2006), Southern McMurdo Sound Project Scientific Prospectus, ANDRILL contribution No. 5, Science Management Office, University of Nebraska-Lincoln, 29 pp.

Hayes, D.E. , L.A. Frakes (Eds.) (1975), Initial Reports of the Deep Sea Drilling Project, 28, U. S. Government Printing Office, 1012 pp.

IPCC (2007), Climate Change 2007: The Physical Basis, edited by S.Solomon, D.Qin, M..Manning, M.M.K.Averyt, M.M.B.Tignor, H.L.Miller, Jr., Z.Chen. www.ipcc.ch .

McGinnis, L.D. (1981), Dry Valley Drilling Project, Amer. Geophys. U. Antarctic Research Series, 33, 465 pp.

Naish, T.R., R.D. Powell, P.J. Barrett, H. Horgan, G.B. Dunbar, G.S. Wilson, R. Levy, N. Robinson, L. Carter, A.R. Pyne, F. Neissen, S. Bannister, N. Balfour, D. Damaske, S.A. Henrys, P.R. Kyle, T. Wilson (2005), McMurdo Ice Shelf Project Scientific Prospectus, ANDRILL contribution No. 4, Science Management Office, University of Nebraska-Lincoln, 21 pp.

Naish, T.R., Powell, R.D., Henrys, S.A., Wilson, G.S., Krissek, L.A., Niessen, F., Pompilio, M., Scherer, R., Talarico, F., Levy, R.H., Pyne, A.R. and the ANDRILL-MIS Science team (this volume), New insights into Late Neogene climate history of Antarctica: Initial results from the ANDRILL McMurdo Ice Shelf Project.

Ravelo, A.C., D.H. Andreasen, L. Mitchell, A.O. Lyle, M.W. Wara (2004), Regional climate shifts caused by gradual global cooling in the Pliocene epoch, Nature, 429, 263-267.

Wilson, T. (2007), Post-Gondwana and active tectonics, in TransAntarctic Mountains TRANsition Zone (TAM TRANZ Project): Multidisciplinary Research in the Central and Southern Transantarctic Mountains, edited by Elliot, D.H., W.B. Lyons, L.R. Everett, Miscellaneous Series 430, Byrd Polar Research Center, The Ohio State University, Columbus, OH., 99 pp.

Zachos, J.C., M.W. Wara, S. Bohaty, M.L. Delaney, M.R. Petrizzo, A. Brill, T.J. Bralower, I. Premoli-Silva (2003), A transient rise in tropical sea surface temperature during the Paleocene-Eocene Thermal Maximum, Science, 302, 1551-54.