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SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

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SCAR Antarctic Offshore Stratigraphy Project (ANTOSTRAT)

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(SCAR) Antarctic Offshore Stratigraphy Project (ANTOSTRAT)

Report of a Workshop on

GEOLOGICAL STUDIES TO MODEL ANTARCTIC PALEOENVIRONMENTS OVER THE PAST 100 MILLION YEARS.

Wellington, New Zealand

10-11 July, 1999

Compiled by

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EXECUTIVE SUMMARY

The Antarctic Offshore Stratigraphy Subcommittee (ANTOSTRAT) convened a workshop in conjunction with the 8th International Symposium on Antarctic Earth Science in July 1999 in Wellington, New Zealand, to follow up recommendations for future research made by a previous SCAR ANTOSTRAT Workshop on Antarctic Late Phanerozoic Earth Sysem Science held in Hobart, Australia in 1997. Over 40 researchers from 12 countries attended and participated in the discussions.

Objectives:

To identify specific actions needed by the earth science community for geological studies to model Antarctic paleoenvironments over the past 100 million years.

Workshop recommendations:

The workshop recommend that the future research effort should focus on three particular time periods of the climate history - early Cenozoic glaciation, middle Miocene ice build-up, and Plio-Pleistocene glacial/interglacials. Geological data are urgently needed, and will be used to constrain new paleoclimatic models. The focus should be on collection and analysis of ground-truth geologic information from around Antarctica and its continental margin.

Implementation strategies:

A key contribution in acquiring new geologic information will come from continued ANTOSTRAT coordination efforts in promoting and justifying further ODP drilling. However, to complement ODP results and to get better access to the ice-proximal geologic record, the workshop considers shallow drilling (up to 100 m pentration) on the continental shelf and upper slope as the principal ANTOSTRAT strategy for the coming decade.

Shallow drilling can be implemented by two principal approaches – ship based drilling and drilling from land fast ice. Drilling from a ship can be with a mobile rig mounted on an Antarctic research- or supply-vessel, or by a contracted dedicated drilling vessel. A multi-vessel approach will promote wider participation and enhance capabilities. Drilling from land-fast sea ice could be shallow penetration with a small system or extended penetration with the proven Cape Roberts type system. Shallow- penetration systems should be encouraged to promote wide participation and enhance capabilities.

Milestones:

The workshop set a goal of having the first shallow-drilling campaign in the field and cutting core before the Spring of 2003.

INTRODUCTION

The Antarctic Offshore Stratigraphy Subcommittee (ANTOSTRAT) works under the auspices of the SCAR Joint Working Groups on Geology and Solid Earth Geophysics (Fig. 1) to help promote acquisition and coordination of geoscience data needed to conduct paleoenvironmental studies related to Antarctic glacial history (Fig. 2). In July 1997, ANTOSTRAT at the request of SCAR convened a workshop in Hobart, Australia to

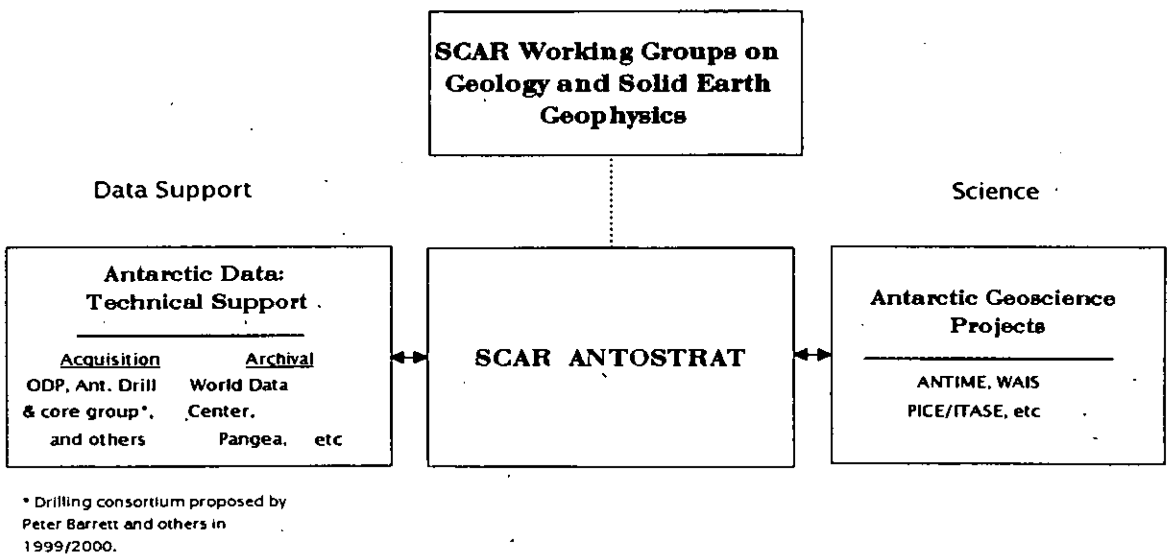
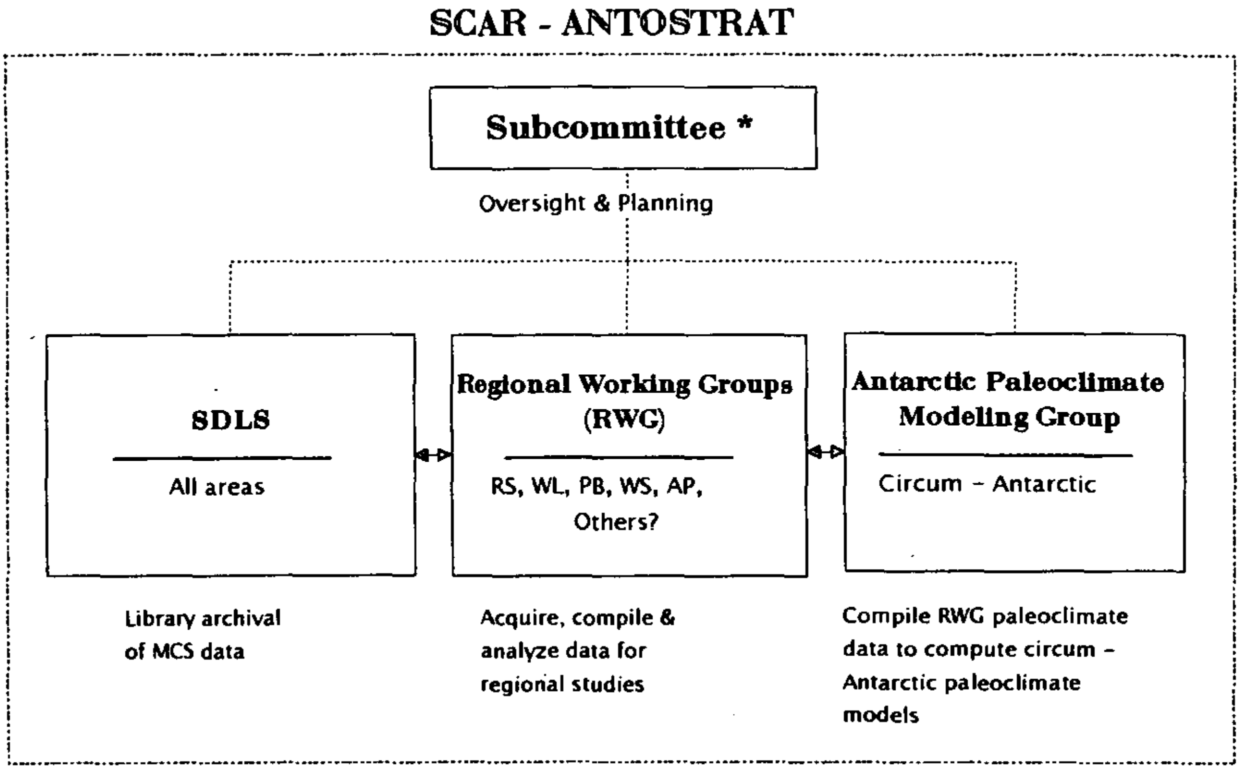


Figure 1. The framework for SCAR ANTOSTRAT and its role in promoting acquisition and coordination of marine geoscience data needed for Antarctic paleoclimate studies.



* The ANTOSTRAT subcommittee is an advisory body only, with no jurisdiction over national Antarctic Programs. Its primary fuction is to coordinate the activities of ANTOSTRAT, as outlined in SCAR Report #16, and to facilitate and promote earth science studies.

Figure 2. Activities of the SCAR ANTOSTRAT Subcommittee.

outline important topics and priorities for the next decade of geoscience research in Antarctica. The result were published in *SCAR Report* no. 16 (Webb and Cooper, 1999). A consensus statement from the workshop emphasized the need for acquiring geologic samples via coring and drilling in support of paleoenvironmental studies. To implement this consensus statement, ANTOSTRAT convened another workshop in conjunction with the 8th International Symposium on Antarctic Earth Sciences in Wellington, New Zealand, July 1999. This report outlines the discussions and recommendations of the Wellington workshop.

OBJECTIVES

The objectives of the workshop were to outline and detail specific actions needed by the earth science community to compile and further acquire the geological information needed to begin a new generation of modeling efforts for the Late Phanerozoic Antarctic Earth System. The approach would build on the present Antarctic Offshore Stratigraphy (ANTOSTRAT) circum-Antarctic Working Group format. It would direct efforts toward incorporating all circum-Antarctic geologic information, acquired by the entire spectrum of geologic sampling techniques, into models that depict the evolution Antarctic paleoenvironments.

1. Develop a specific implementation plan for restructuring ANTOSTRAT to achieve the desired objectives of:
   - collecting and analyzing ground-truth data from around Antarctica (onshore and off-shore); and
   - creating a folio of paleoclimate maps of Antarctica for selected time intervals.
2. Conceive, discuss and initiate several specific cooperative projects, in addition to the ongoing efforts with ODP and Cape Roberts, that
   - are needed;
   - are of interest to more than 1 National Programme;
   - are feasible and would be accomplished within 3 years.
3. Create the written materials needed to write a short workshop report to document how ANTOSTRAT will proceed and what cooperative projects would be promoted.

ANTOSTRAT BACKGROUND
(A Cooper)

The Antarctic Offshore Stratigraphy (ANTOSTRAT) Subcommittee, which functions under the Joint Working Groups on Geology and Solid Earth Geophysics, was implemented at the SCAR XXV meeting in Concepcion, Chile, 27–31 July 1998. The work of the subcommittee continues the cordination efforts of its predecessor ANTOSTRAT Steering Committee (for the ANTOSTRAT Project), formerly under the Cenozoic Group of Specialists. The subcommittee focus is on coordinating new broad science initiatives related to coring and drilling, to assist Antarctic geoscience studies (Fig. 1).

Currently, ANTOSTRAT is involved with the following projects (Fig. 3):

Ocean Drilling: Promoting a circum-Antarctic drilling effort with the Ocean Drilling Program to decipher Cenozoic Antarctic glacial history. The first ANTOSTRAT proposed leg was drilled last year along the Antarctic Peninsula. The second leg is scheduled for January 2000 in Prydz Bay region. And, proposal for ODP drilling in the offshore Wilkes Land and Ross Sea and Weddell Sea areas are currently under consideration.

Cape Roberts Drilling: Assisting a major international drilling effort from fast sea ice in McMurdo Sound (Ross Sea) to study glacial history and structural evolution of the Transantarctic Mountains.

Shallow Drilling and Coring: Promoting and helping to coordinate multinational programs focussed on acquiring geologic samples by shallow drilling and coring (i.e., <100 meters below sea floor) of the Antarctic continental margin. Such operations would use research vessels of National Programs, contract vessels, and dedicated drilling platforms, and would operate principally on the continental shelf and upper continental slope around around Antarctica in places where high-resolution seismic surveys are possible.

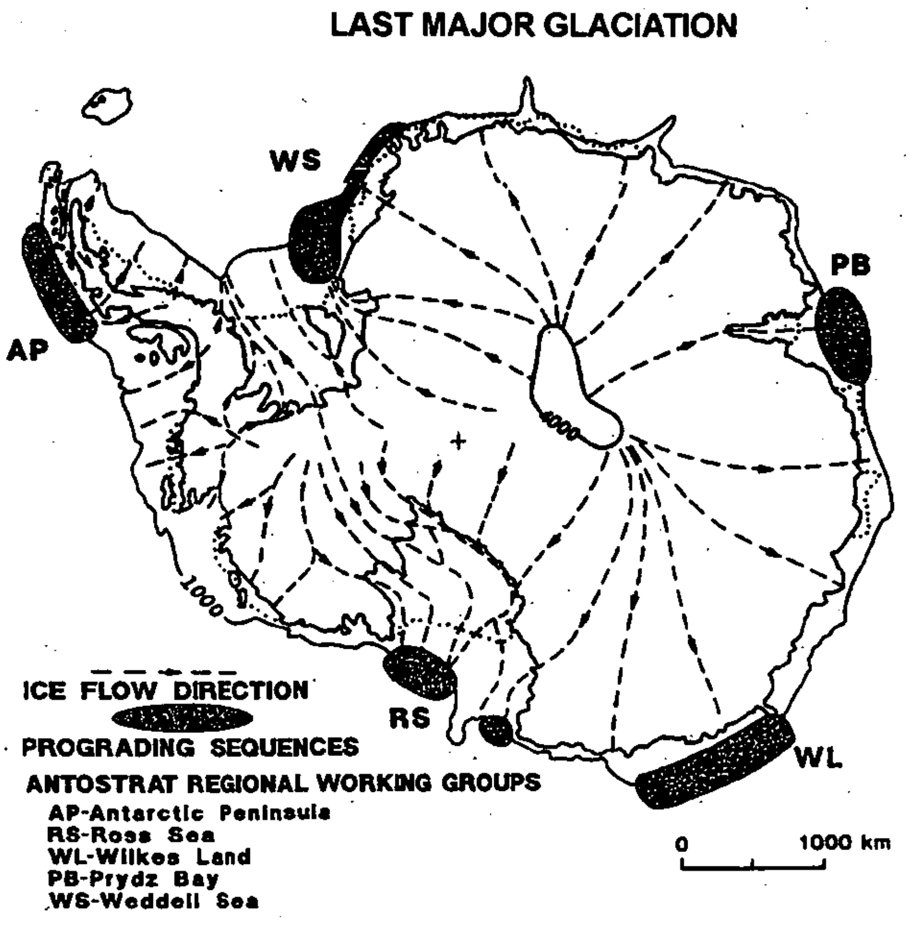


Figure 3. Map showing the five areas around Antarctica where ANTOSTRAT activities are focused. These parts of the circum-Antarctic continental margin contain major Cenozoic prograding sequences which lie at the end of inferred former ice streams.

Paleoclimate Models for Antarctica: Initiating and implementing an international effort to acquire and use existing geologic sample information to establish a suite of paleoclimatic models for Antarctica. The models will depict the varied climatic conditions at critical times during the past 130 million years, to better understand the climatic evolution during Recent times.

Antarctic Seismic Data library (SDLS): Continuing SDLS activities. The SDLS, in existence since 1991 (ATCM Recommendation XVI-12), has 12 branches in 10 countries and provides open access to Antarctic multichannel seismic data. The library system will be assessed at a SDLS workshop in Wellington, in July 1999, to suggest policy and technology changes (e.g. data access via the World Wide Web) that will improve the utility of the SDLS to the research community.

SUMMARY STATEMENTS

Input needs for Antarctic paleoclimate modelling (B Oglesby)

The major goal of any physically based modeling effort is to serve as a test of our understanding of how some observed or reconstructed phenomena came to be. Paleoclimate modeling can be used to help examine and "test" ideas and assumptions about geologically relevant forcings, feedbacks and reconstructions. The climate modelers want the geologic data in order to pose the problems and provide boundary conditions, and then to validate their models, while the geologists want the model results to guide and then validate their reconstruction. *(Note – a climate model is a hypothesis, therefore it CANNOT be used to formally "test" another hypothses, e.g., proposed paleoclimatic hypothesis. One can only see if the model is consistent with the postulated hypothesis).*

Two basic types of climate simulations can be done with the General Circulation Model (GCM):

1 A "true" simulation is an attempt to simulate all aspects of a given period of time, and requires all appropriate boundary conditions and necessary forcings imposed as correctly as possible for the specific point in time investigated. The farther back in time one goes, the harder it is to adequately fulfill these requriements.

2 In sensitivity, or process studies, one looks at, in a mechanistic way, some aspect of the climate system (eg, response to changing CO_2; ice sheet instability). Having all boundary conditions and forcings exactly right is less important here.

Demonstrated needs that must be met in order to perform paleoclimate modeling studies in a statisfactory manner include:

i) Global and regional paleogeography, paleotopography and paleobathymetry are needed as accurately as possible for model boundary conditions.

ii) Information on "external" forcings is also needed, such as broad estimates of atmospheric CO_2 and changes in solar luminosity, etc.

iii) Detailed site reconstructions are needed for subsequent evaluation and interpretations of model simulations.

Paleoclimate models can play a key role in helping to syntesize and integrate our understanding of major Antarctic climatic and glacial events and can also suggest correspondences and inconsistencies in the interpretation of these events from the geologic record. Model results can also be used as a guide to where future geologic data needs are greatest.

ANTOSTRAT data management with the information system PANGEA (H Grobe and D Fuetterer)

The information system PANGAEA (Network for Geological and Environmental Data) is aimed at archiving and distributing data from solid earth, climate variability and marine environmental research. Long term storage of data in a relational data base and access for the scientific community via World Wide Web, is ensured. The system is able to store analytical data together with any related meta-information. The client/server network allows complex retrievals with a web client as well as easy access on any combination of data and metadata through a web address (http://www.pangaea.de)

PANGAEA is offered to the ANTOSTRAT project to be used as a tool for archiving data in a consistent form, for distributing and sharing data through the Internet, and as a scientific tool for the extraction and interpretation of comprehensive data sets. Password protection to share unpublished data between working groups is possible. Technical operation and support is done by the Alfred Wegener Institute for Polar and Marine Research, Germany. Collection, quality control and import of data has to be maintained by a scientific data curator, to be defined by the project.

PANGAEA has stored the meta-data of most of the marine sediment cores from the Southern Ocean (3.400 cores south of 60 degrees South), all marine geological data provided by the Alfred Wegener Institute, data of the Cape Roberts, CIROS and MSSTS cores, some ODP data from high southern latitude sites, and data from investigation of Antarctic lakes, 17,000 data sets in total.

Ocean Drilling Programme (P F Barker)

The review process of the Ocean Drilling Programme (ODP) responds to individual proposals and can approve drilling anywhere in the world to address important geoscience problems. Successful proposals are an independent measure of the quality and global relevance of this part of Antarctic geoscience.

Building on the preceeding data compilation effort, a package of five ANTOSTRAT proposals were first submitted at the end of 1994 for drilling on the circum-antarctic continental margin (Antarctic Peninsula, Prydz Bay, Wilkes Land, eastern Ross Sea and Weddell Sea, see figure 3). It was argued that it would be necessary to drill 3 or 4 of these to determine the main features of ice sheet history. Individual proposals have been through repeated review and revision since then, and the overall strategy was endorsed and refined by an ODP Detailed Planning group in 1996. Since then, the first leg (ODP 178) off the Antarctic Peninsula was successfully drilled in February 1998, and ODP leg 188 in Prydz Bay was completed in April 2000. The other three proposals remain under review. A significant development was the decision to drill in Prydz Bay without a chartered ice support vessel.

An ANTOSTRAT workshop was held in Siena in May 1998, mainly to pass on the lessons of Antarctic Peninsula and Cape Roberts drilling to other ANTOSTRAT proponents, and to consider future strategy (Barker and Cooper, 1998; Barker *et al.*, 1998). The Wilkes Land and Ross Sea proponents submitted Addenda for the March 1999 deadline. All three proposals were considered by the ODP Environmental Science Steering and Evaluation Panel (ESSEP) in May 1999. The Weddell Sea proposal was ranked higher than the others as it had been amalgamated with one seeking to sample Lower Cretaceous black shales and the underlying ocean floor at the advice of the ODP Detailed Planning Group. Cancellation of an early 1999 Italian/ Australian site survey cruise contributed to lower ranking of the Wilkes Land proposal. The Ross Sea region is adequately surveyed already, but the panel is concerned with general philosphy and internal consistency of the proposal.

In general the ANTOSTRAT approach for Antarctic margin drilling by ODP survives, and is recognized by the ODP science structure. The views of the members of ODP panels attending this workshop were very welcome. The ANTOSTRAT proposals benefit at present from a wish by ODP to complete some of the multi-leg drilling problems embarked upon, before end–2003. A probable passage of the ship as inferred from a preliminary review of other ODP proposals suggests that the best opportunity to drill Wilkes Land and/or Ross Sea (possibly as 2 mini-legs or a super-leg) is in early 2001, and the best chance for Weddell Sea may be in early 2002.

Cape Roberts drilling (P Barrett)

The project was developed in 1993 from earlier drilling on the fast ice in McMurdo Sound, Antarctica. The aim was to investigate the early history of the East Antarctic ice sheet and the West Antarctic Rift System by drilling off Cape Roberts (77.0°S, 163.7°E). We have now almost completely drilled the western margin of the Victoria Land Basin, a sedimentary succession 1500 m thick and dating from 34 to 17 Ma. In 1997 CRP-1 had drilled only 148 m before terminating when fast ice near the rig blew out in a storm. However, in 1998 CRP-2 and 2A drilled to 624 m, including 31 m overlap with CRP-1, and in 1999 CRP-3 drilled to 939 m with underlap estimated to be at most a few tens of m. CRP-3 also drilled, at 823 mbsf, into the floor of the Victoria Land Basin (Beacon sandstone).

The Cape Roberts Project is a cooperative venture between scientists, administrators and Antarctic support personnel from 7 countries - Australia, Britain, Germany, Italy, Netherlands, New Zealand and the United States of America. The key to the operation was the 55 tonne drilling system, set up 13 to 16 km offshore in early October on fast sea ice. The fast ice typically forms between April and June, and then thickens to around 2 m by early October. Water depths ranged from 153 m to 295 m. Once established, the rig operated 24 hours a day for around 5 weeks. Average core recovery for the 1680 m drilled was 95%.

The cores provide a record for the period from 17 to 34 Ma ago and show that:

- this sector of East Antarctica had a sub-polar climate with a low woodland vegetation (*Nothofagidites* and podocarps) from 34 to 25 Ma. During this time mountain glaciers and possibly inland ice sheets were releasing icebergs to the Ross Sea,
- the period from 25 to 17 Ma was cooler, allowing a low growing sparse tundra on the adjacent mountains, along with periods of more extensive grounded ice, and that
- the Transantarctic Mountains had achieved most of their present height by 34 Ma, whereas most subsidence in the adjacent Victoria Land Basin took place from 34 to 17 Ma ago.

Detailed results from individual drill holes are being published as issues of the journal *Terra Antartica* with the following dates: CRP- 1 Initial Report (1998) & Scientific Report (1998), CRP-2/2A Initial Report (1999) & Scientific Report (in press) and CRP-3 Initial Report (in press) and Scientific Report (in preparation). Core logs on a scale of 1:20 and scanned core box images are published as supplements to the Initial Reports. Information can also be found at:

http://www.geo.vuw.ac.nz/croberts/

Hole	CRP-1 (1997)	CRP-2/2A (1998)	CRP-3 (1999)
Location	77.008° S; 163.755° E	77.006° S; 163.719° E	77.011° S; 163.640° E
Distance east of Cape Roberts	16.0 km	14.2 km	11.8 km
Sea ice thickness in October	1.6 m	2.0 m	2.0 m
First core	17-Oct	16-Oct	9-Oct
Last core – terminated by storm	24-Oct	25-Nov	19-Nov
Water depth	153 m	178 m	295 m
Depth to top of first core	15 mbsf	5 mbsf	2 mbsf
Quaternary & ?Pliocene strata	28 m	22 m	0
E Miocene & Oligocene strata	105 m	597 m	821 m
Basement			116 m
TOTAL DEPTH BSF	148 mbsf	624 mbsf	939 mbsf
Recovery (avr – 95%)	86%	94%	97%
Downhole logging	Nil	340/540/620 m	910-920 m
Stratigraphical overlap between holes	31 m overlap between CRP-1 and -2	Gap of m to 10s of m between CRP-2A and –3	

Table 1. Drilling statistics for the Cape Roberts holes

Marine shallow drilling (Y Kristoffersen)

Marine shallow drilling will supplement and extend the information obtained by the ODP drill sites on the circum-antarctic continental margin. Increased penetration beyond the conventional gravity- and piston-core sampling is a pre-requisite to new advances in our knowledge of ice sheet history from the continental shelf sediments. This requires shallow drilling (<100 m sub-bottom). A glacially eroded shelf often expose truncated sediment sequences at the sea floor, and provide access to a geological record which range from younger sediments at the shelf edge to successively older strata towards land or an ice shelf.

There are several approaches to geological sampling by shallow drilling:

- drilling from landfast sea ice;
- use mobile systems adapted to research and support vessels;
- use of ice strengthened dedicated drilling vessels.

Shallow drilling in Antarctica beginning with the Dry Valley Drilling Project (1970-75), progressed offshore to drill from a sea ice platform during the MSSTS and CIROS projects and more recently with drilling off Cape Roberts reaching a record 939 mbsf. at a water depth of 295 m. Marine shallow drilling from over the stern of a research vessel using a light mining rig with riser was first attempted during the 1995/96 season on the Weddell shelf. The string had reached 16 mbsf with 18% recovery when the site had to be abandoned due to a change in the ice situation. The greatest operational flexibility is provided by a remotely operated rock drill deployed from a research vessel. In early 1998, a remotely operated rock drill capable of taking up to 5 m long cores was used in shelf areas of the northern Antarctic Peninsula. There, 77 rock drills were attempted, and 26 of these were successful in recovering rockhead (mostly less 1 m., one 1.4 m and one 2.5 m long). Most of the rest recovered "mixed pebbles", i.e. loose ice-rafted debris. Two were empty. Although, the results obtained to date by mobile systems deployed from research vessels are modest when compared to the achievments of drilling from fast ice, it should be pointed out that the resource requirements for these two different approaches are significantly different.

Drilling from landfast sea ice can be carried out as operations ranging from the dimensions of the very successful Cape Roberts Project which involved more than 40 tons of equipment at the rig site to more modest light undertakings with, say of the order of 5–10 tons. The circum-Antarctic margin localities offer a multitude of partially sheltered bays where the sea ice remains intact until late in the season, and offer safe working conditions. If priority geological targets lie in these areas, then small self contained drilling operations may be employed on landfast sea ice, and serviced by a vessel operating in the general area during the 1–3 week drilling period.

Small mobile systems such as a rock drill lowered to the sea floor and remotely operated from a research vessel have been successfully used on European shelves for decades. However, core length is limited to 5 meters, and diamicton is a particularly challenging lithology. The

Antarctic continental margin offer a number of sites where consolidated rocks are exposed at the sea floor where a rock drill would be an excellent reconnaissance tool.

Use of mobile light mining rigs used over the side or the stern of Antarctic research vessels have been shown to be feasible, but we still need to refine equipment and operating procedures. Also, experience suggests that for drilling within drifting sea ice fields on the Antarctic shelf, a moon pool is not necessarily required to provide protection. A drill string over the side may be adequately protected by a simple guard below the water line, thereby reducing the technical challenge to one of determining how best to secure the guard.

An ice strengthened dedicated drilling vessel would be the ideal tool to pursue shallow drilling, but only few are commercially available. The cost of a one month leg in Antarctica would be similar to that of the logistics costs for the Cape Roberts project.

The Antarctic continental margin is a challenging environment for any endeavour to obtain scientific data. It is therefore important to recognize that the knowledge of weather patterns, sea ice conditions, temperature ranges specific to priority geological target areas reside with the scientists themselves and not with outside "experts" (e.g., commercial contractors). As demonstrated by the success of drilling from fast sea ice and also to some degree by light over-the-side rigs, scientific progress requires that the scientists take initiative in defining the practical solutions.

Dredging/coring (A Maldonado)

The continental slope around Antarctica is incised by canyons eroded by dense, fast flowing turbidity currents fed by sediments brought to the shelf edge by grounded ice.

The canyon wall may expose extensive stratigraphic sections as in the case of the Jurassic through Holocene section in Wegener Canyon, southeastern Weddell Sea. Scarps generated by tectonic displacements are particularly abundant in the Antarctic Peninsula region. These opportunities for stratigraphic access have not been attacked by any systematic dredging or coring campains with the exception of the Wegener canyon. A classical example of a place to undertake such a systematic project is the southeastern Weddell Sea, to demonstrate the potential for stratigraphic information from a suite of offset cores where no drill sites are available. Several of the modern Antarctic research vessels have multi-beam swath mapping systems which greatly improve target definition and make such systematic operations possible.

It is strongly recommended that coring and/or dredging campains are undertaken to obtain samples in stratigraphic transects to facilitate composite sections, particularly in areas where ice conditions do not encourage a drilling effort. Problems relevant to ANTOSTRAT objectives that can be addressed by coring and dredging campains include:

- lithology and age of depositional sequences;
- temporal and spatial variations in terrestrial and biogenic sediment input along
- a margin, and identification of erosional events;

all of which would help define a proxy for ice sheet history in the region.

Under-ice drilling (R Scherer)

Direct access to 98% of Antarctica's geology requires drilling through glacial ice. The interior includes numerous sedimentary basins, many of which undoubtedly contain stratigraphic evidence cental to ANTOSTRAT goals. To date, no *in situ* rocks have been recovered from beneath the Antarctic ice sheets. Surficial examples of the glacigenic drape have been recovered from several regions in the interior Ross Embayment, from beneath the Ross Ice Shelf and West Antarctic Ice Sheet. These glacial sediments contain recycled traces of strata of various ages, derived from West Antarctic interior basins. Drilling within these basins is clearly within the ANTOSTRAT goals.

Recovery of geological materials from beneath the ice sheet requires development of some new technologies or significant modification of existing technologies. Hot-water drilling provides relatively easy access through grounded ice of less than 1500 m thickness, especially in West Antarctica, where atmospheric temperatures are relatively moderate. Larger rigs can be constructed for melting access holes through thicker ice and/or higher surface elevation ice. Deploying rock drills through hot-water holes is feasible, though off-the-shelf technologies require modification for operation through limited diameter boreholes, and freeze-up prevention.

Floating ice shelves provide the easiest platform for sub-ice drilling. many different types of drill rigs could be deployed. Large access holes can be opened and maintained, as demonstrated 20 years ago by the Ross Ice Shelf Project. This project included a modest sediment recovery component with 53 short (ca. 1 m) gravity cores from the southern Ross Ice Shelf. Perhaps the biggest down-side to the use of ice shelves as drilling platforms is the difficulites of site survey. Standard seismic methods may suffer severe echo problems when passing through the ice/water column/rock interfaces.

Deep stratigraphic drilling beneath glacial ice can only be done where there is little or no basal sliding. Ideal locations would be ice divides overlying sedimentary basins, though ice here may be very thick.

Technical targets for sub-ice rcovery of geologic materials, each requiring unique drilling strategies, include:

- Deep sub-ice drilling into consolidated strata or bedrock
- Recovery of unconsolidated subglacial sediments
- Recovery of frozen sediment
- Recovery of undisturbed, waterlain subglacial materials associated with a zone of dynamic ice-bed interaction

Broad thematic goals for sub-ice drilling include crustal studies with sampling of basement rocks, volcanic provinces and opportunity for heat-flow measurements; paleoclimatic studies focussing on early glaciations and Late Neogene ice sheet minima; glaciological processes or life in extreme environments i.e. subglacial lakes and subvolcanic vents.

Several specific targets relevant to ANTOSTRAT goals were identified during the workshop:

High priority sites for crustal studies

- Gamburtsev Mountains: The age of these mountains is identified as critical to modeling ice sheet history
- West Antarctic interior volcanic province: Active volcanos within the interior of West Antarctica have been hypothesized based on geophysical surveys. Active volcanism beneath a marine ice sheet may impact significanlty on its stability, and represents a "wild-card" that is currently not included in WAIS modeling. Drilling is needed to test the existence of active volcanism.

High priority sites for interior paleoclimate studies:

- West Antarctic interior basins: These are known to contain thick sedimentary sequences. Subglacial tills include a mix of fossil ages, including Pleistocene diatoms, indicating Pleistocene collapse of the WAIS.
- Wilkes Land basins: May or may not contain a significant sedimentary sequence. If *in situ* Pliocene sediments are recovered, then a long-standing debate will have been settled. The absence of such sediments, however does not disprove the theory.

Glaciological and biological processes operating beneath glacial ice are both important to ANTOSTRAT goals, but are considered ancillary. Understanding sedimentary processes beneath the ice sheet, notably the mechanism of sedimentary erosion, transport, and redeposition as till packets of recognizable geometry, is particularly important to the ANTOSTRAT agenda, but these specific goals may be better addressed by active glaciology programs. ANTOSTRAT endorses such efforts.

Lake coring (I. Goodwin)

Antarctic lacustrine sediments have provided a broad range of paleoenvironmental data suitable as input for modelling purposes. The themes and data include:

- Holocene relative sea-level change, marine transgressions/regressions;
- Quaternary glacial fluctuations;
- Late Pleistocene/Holocene climate including:
  Lake water balance-precipitation, evaporation, aridity, seasonal temperature;
- Environmental characteristics including:
  Salinity and salt precipitation
  Biological productivity
  Carbonate precipitation
  Stable isotope composition
  Source of lakewater, precipitation, groundwater, meltwater
  Catchment evolution, landscape weathering
- High resolution paleoclimate proxy data suitable for direct comparison with ice core data.

Lacustrine water bodies range from small shallow tarns and ponds to deep lake basins in ice free areas around Antarctica. Lakes are principally located in the coastal zone of East Antarctica and in the northern Antarctic Peninsula, and offshore islands.

The challenge for lacustrine paleoenvironmental studies is the retrieval of long cores spanning at least the Holocene, and the older Quaternary in some locations, like Radok Lake and Beaver Lake in the Prince Charles Mountains, the Dry Valley lakes and the lakes in Schirmacher and Untersee Oases, in Dronning Maud Land. Antarctic Peninsula lakes potentially contain very high resolution paleoenvironmental records. Robust proxies require further investigation in reference lakes such that high resolution records can be established for the longer lake cores. Recent work has shown the a regional synthesis of lake records is required, such that a direct comparison can be made with paleoclimatic records from ice cores.

Lake coring is principally conducted from a floating platform, either a raft or small boat, and cores are retrieved using simple gravity, piston or impact corers. The most advanced corer used in the Antarctic is the Austrian UWITEC piston corer.

Terrestrial shallow drilling (W Dickinson and A Pyne)

The acquisition of outcrop data data has reached a practical limit of scientific value in many parts of Antarctica, and it is now necessary to look for new information below the ground surface. With the exception of ice coring, the largest on land effort at coring was the Dry Valleys Drilling Project (McGinnis, 1981) in the 1970's. Present environmental protocols and high costs effectively reduce the future of this type of land-based, deep drilling project to one-off, multinational programs. However, shallow drilling projects with relatively low budgets and small environmental impacts, offer a cost effective way to obtain a wealth of new scientific data throughout the continent.

Numerous scientific objectives are now focused on the Quaternary and Late Cenozoic history of Antarctica, which is beyond the range of conventional ice cores. To obtain this history, the need for shallow (<50 m) cores from a wide variety of areas has become increasingly important. Scientific coring objectives of shallow land-based drilling include; beach depsoits, permafrost, and rock glaciers. It is worth noting that high quality core can be successfully recovered in unlithified, coarse-grained sediments if they are ice-cemented, a common situation in Antarctica.

A number of past projects have used a variety of shallow land-based drilling techniques to acquire core from depths of less than 100 m. Unfortunately, only some of these projects used equipment and expertise gained in previous projects. As a result, we believe a consortium of organizations and institutes should establish a land based drilling unit. We see this consortium modelled afer the ODP, but on a greatly reduced level of funding and equipment. Not only would this unit act to store and maintain drilling equipment, but it would also act as a centre of expertise in drilling techniques. Because the drilling equipment is light weight and protable, it could be transported around the continent at a minimum of cost to meet the needs of consortium members.

A case study of coring the Sirius Group at Table Mountain (Nov-Dec. 1996). Coring permafrosted sediments with protable equipment in a cold environment is largely an on-site experiment because of inaccessibility to workshop facilities and supplies of drilling equipment. Shallow core drilling of permafrosted sediments is common and well understood in most Arctic environments (Kudryashov and Yakolev, 1991) and in som alpine environments (Haeberli *et al.*, 1988), yet only a few such drilling projects (Robinson and Milton, 1985; Wilson and Barron, 1988) have been completed in Antarctica.

In November and December 1996, ice cemented sediments of the Sirius Group were cored at Table Mountain. All equipment was helicoptered to the area, but from there, it was hand carried between the drill sites about 400 meters apart. During the 23 days in the field, a total of 49 m was drilled and 42 m of core recovered. Nineteen holes averaging 3.5 m deep were drilled, but to holes were 8 m and 9.5 m deep.

Future equipment and plans

Over the next three austral summers, proposed plans for a land-based shallow drilling project include coring ice-cemented glacial beach deposits. These deposits contian clasts ranging from several centimenters to meters in diameter lodged in a matrix which may range from mud to coarse sand. Both the recovery and quality of core for these sediments would be extremely poor if they were not cemented by ice. In some sediments and escecially rock glaciers, ice is the main matrix material. To recover this range of material, which despite being frozen may be friable, large diameter triple and double tube core barrels of HQ (63.5 mm core) and NQ (46 mm core) sizes are necessary. In addition, both surface set diamond bits and tungsten chip bits must be used. A universal bit, which can drill through ice and hard clasts within a deposit, is not available. Most of this drilling equipment is regularly used in the mining industry and is readily available throughout the world.

Cooled compressed air is the only realistic alternative to liquid drilling fluids. It is safe to the environment and will not dissolve the ice in the core and bore hole. Depending on the depth of the coring objective, accessibility and site conditions, three types of systems, all using compressed air will be available. The first system is a very light weight (< 1000 kg) and portable Winkie drill system that has a maximum depth limit of about 20 m. Only a small compressor and light weight drill rods can be used and the equipment can be disassembled and handcarried by a party of four for distances up to several kilometers over glacial moraines. The two other systems allow for drilling deeper than 20 m, but require considerably more weight and equipment to be transported into the field. The Webster models HP-50 and HP-150 are rated to reach depths of 50 m and 150 m, respectively. Their total weights are 3000 kg and 4000 kg, of which half consists of drill pipe. Helicopter support would be essential for moving rig modules (5) in polar environments. The operation of these units would require two persons, and all accessory equipment is readily available within New Zealand. Because of the shallow drilling programme at Victoria University is limited by available funding, we are seeking collaboration with other workers both in terms of funding and drilling targets.

Cosmogenic surface exposure dating in Antarctica: progress and potential (M Bentley)

Cosmogenic surface exposure dating relies on the build-up of in situ cosmogenic surface isotopes in the top few metres of exposed bedrock. Several isotopes are available: the choice being driven by the timescale of the problem and the sample lithology (Table 2). Whilst it is possible to interpret exposure histories from analysis of a single isotope, the final results can be ambiguous and so most workers now use multiple isotopes. Potential questions that can be approached with cosmogenic isotopes include exposure ages of surfaces or erratic boulders; average erosion rates; and constraints on maximum uplift rates.

Applications in Antarctica:

Cosmogenic isotopes have been applied over two main timescales in Antarctica:

1. Last Glacial Maximum (LGM) c. 20,000 years. Isotopes have been used in a number of studies in the Ross Sea, Antarctic Peninsula and Australian East Antarctica to determine the timing of the LGM and subsequent deglaciation. Most exposure dates have been derived from erratic boulders.
2. Mid-Miocene onwards (last c. 10 Ma). Cosmogenic isotopes have been used (so far almost exclusively in the Transantarctic Mountains) to determine the age of the Sirius Group Formation, the timing of EAIS over-riding of the mountains, and also to determine long-term erosion rates. Examples of recent results include

Isotope	*Target minerals*	*Dating limits*
^{3}He	Olivine, clinopyroxene, quartz	Few ka- 10 Ma
^{21}Ne	Olivine, quartz, plagioclase	7 ka - <10 Ma
^{10}Be	Quartz	3 ka – c. 5 Ma
^{26}Al	Quartz	5 ka – c. 3 Ma
^{36}Cl	Calcite, whole rock (basalt)	5 ka – c. 1 Ma

Table 2: Cosmogenic isotopes in common use. The lower dating limits can usually only be achieved using very high energy mass accelerators. For most isotopes, Holocene-age samples are problematic.

- Sirius Group tillites yield noble gas ages of 5.3 to 10 Ma. Assuming conservatively low erosion (2.5 cm Ma-1) and uplift (50m Ma-1) rates this implies an age of c. 20 Ma for the Sirius group. Any increase in erosion or uplift rates implies even older age. The implication of this is that the ice sheet over-riding event was prior to the early Miocene.
- Maximum erosion rate on high plateau is <20cm Ma-1 (<1m Ma-1 on rectilinear slopes). The implication of these long-term erosion rates is that there was little Antarctic response to Pliocene warmth.

Future potential to contribute towards ANTOSTRAT objectives:

- Timing of last great ice sheet expansion or other erosional events;
- Matching shelf record to onshore source regions (timing ± erosion rate);
- Establishing erosion rates for palaeo-modelling;
- Constrainting maximum uplift rates;
- Comparing EAIS and WAIS behaviour - is the contrasting behaviour seen at the LGM also seen in earlier record ?
- Improving ages, now constrained to ~10 Ma timescale and ~ 2–10% precision.

Regional Working Groups

Discussions in the Regional Working Groups focussed on the best approach to obtain paleoclimate information for three priority time intervals; i) Plio-Pleistocene, ii) middle-Miocene and iii) Eocene-Oligocene (Fig. 3).

Antarctic Peninsula:

The Antarctic Peninsula has relatively easy access and geoscientific surveys are carried out by a number of countries. Paleoclimate information would best be obtained by ship-based offshore (shelf) drilling.

Objective i) can be reached by drilling off Seymour Island, the outer shelf, inter-lobe areas, and onshore James Ross Island. Targets for objectives ii) and iii) are off Seymour Island, and inner shelf basins on the Pacific margin.

Ross Sea:

Plio-Pleistocene targets can be reached by shallow shipboard drilling within troughs in front of the Trans-Antarctic Mountains (TAM), and by further drilling on land in the Dry Valleys, on Prospect Mesa and on the backside of TAM. Mid-Miocene sections have been obtained by ODP Leg 28 sites and the Cape Roberts Project, and is accessible in the Eastern Ross Sea. Paleosols on land in the Dry Valleys are also considered to include this stratigraphic interval. Information on the early glacial environment during Eocene-Oligocene was first derived from sediments recovered at ODP Site 739 (Prydz Bay) and has been the focus of the Cape Roberts Project (Ross Sea) with drilling from landfast sea ice. Other targets are sediments below the Beardmore Glacier.

Wilkes Land

Sediments representing the Plio-Pleistocene are accessible by piston coring, dredging and shallow drilling in the inner shelf troughs, the shelf banks or by ODP drilling on the shelf and continental rise. Stratigraphic representation of the early glacial environment and the middle-Miocene glacial expansion could be obtained by drilling a shelf transect.

Prydz Bay

Eocene to Plio-Pleistocene sediments can be obtained by ODP drilling of the prograding sequences in Prydz Bay to reach objectives i-iii. Eocene sediments are also accessible on the Mac Robertson Shelf by dredging, but preferable to be sampled by a portable remotely operated drilling system (PROD). Pliocene sediments would be the target for sub-ice coring beneath the Amery Ice Shelf, and also drilling on land on the Vestfold Hills. Paleotopography of the Antarctic continent is important input to climate models and the Gamburtsev Mountains represent a major unknown. High priority should be given to obtain information of the geologic history of the mountain range.

Weddell Sea

Documentation of middle Miocene glacial expansion and Plio-Pleistocene glacial oscillations of the East Antarctic Ice Sheet in the Weddell Sea can be obtained by drilling the prograding shelf sequences in the eastern Weddel Sea and the Crary Trough Mouth Fan in the southern Weddell Sea. The best techniques would be ODP drilling on the continental slope and rise supplemented with shallow drilling of eroded foreset beds on the shelf.

SYNTHESIS AND DIRECTIONS

The ANTOSTRAT strategy to determine ice sheet history is to sample sediments transported to the circum-antarctic continental margin by the ice sheets (Fig. 3). The principal approach will be to assemble the necessary site documentation and forcefully argue for continued ODP drilling on the Antarctic continental margin. This activity will be supplemented by shallow drilling from other platforms on the shelf to provide geologic input climate modeling of ice sheet history.

A shallow drilling strawman (Y Kristoffersen and A Cooper)

Shallow drilling is penetration to less than 100 meters below the sea floor. A possible strategy to achieve a systematic program is outlined in the following shallow drilling strawman (Fig. 4).

An ANTOSTRAT shallow drilling activity will have two main components; science and logistics. The objectives of the science program are set out in *SCAR Report* no. 16: Report of a Workshop on Antarctic Late

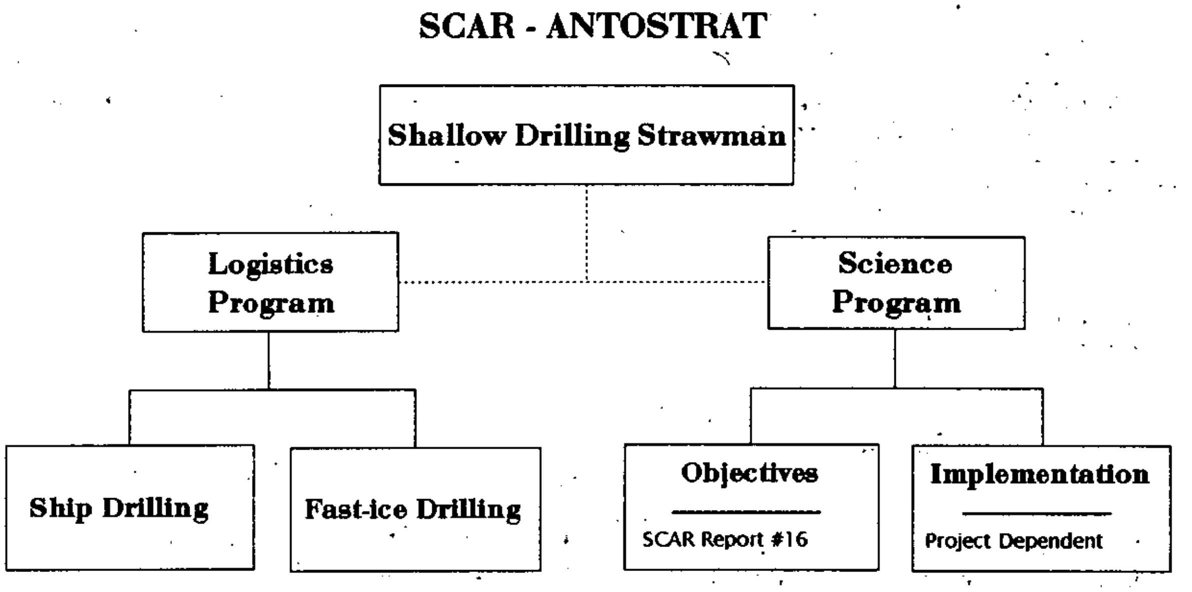


Figure 4. Conceptual framework for acquiring marine geological samples.

Phanerozoic Earth System Science held in Hobart 6-11 July 1997. The focus for the next decade (1998-2008) is onset and development of Antarctic glaciation. Discussions at the current workshop identified three time periods as high priority – early Cenozoic glaciation, middle Miocene ice build-up, and Plio-Pleistocene glacial/ interglacials. Implementation of the logistic requirements of components of a science program are dependent on the individual projects.

The logistics of shallow drilling would encompass two principally different platforms – ship drilling and fast ice drilling around Antarctica (Fig. 5). Drilling from a ship can be either as a "piggy back" operation with a mobile drill rig mounted on an Antarctic research vessel, or a contracted dedicated drilling vessel, or use of the ODP diamond coring system. The following guidelines would apply for drilling from a ship:

- A multi-vessel approach (mobile or fixed diamond coring system) will promote wide participation and enhance capabilities;
- Drilling depths would be less than 100 mbsf:
- Priority of targets would progress from shallower-water to deeper-water as technology amd operational experience improves and funding allows; and
- The first shallow drilling leg would take place before the Spring of 2003.

Drilling from land fast sea ice could be either as a light operation with shallow penetration, or extended penetration with the proven Cape Roberts type system. The following guidelines would apply for drilling from fast ice:

1. Focus on proven equipment and trained personnel (or on existing equipment that could be used in the field in 1-2 years), to ehance chances of success and to encourage immediate planning of new cooperative projects;
2. Shallow penetration systems should be encouraged to promote wide participation, enhance capabilities, and augment geologic sample databases; and
3. Extended penetration capability and good recovery documented by the available Cape Roberts system should be applied to other suitable environment.

SCAR - ANTOSTRAT

Shallow Drilling Strawman

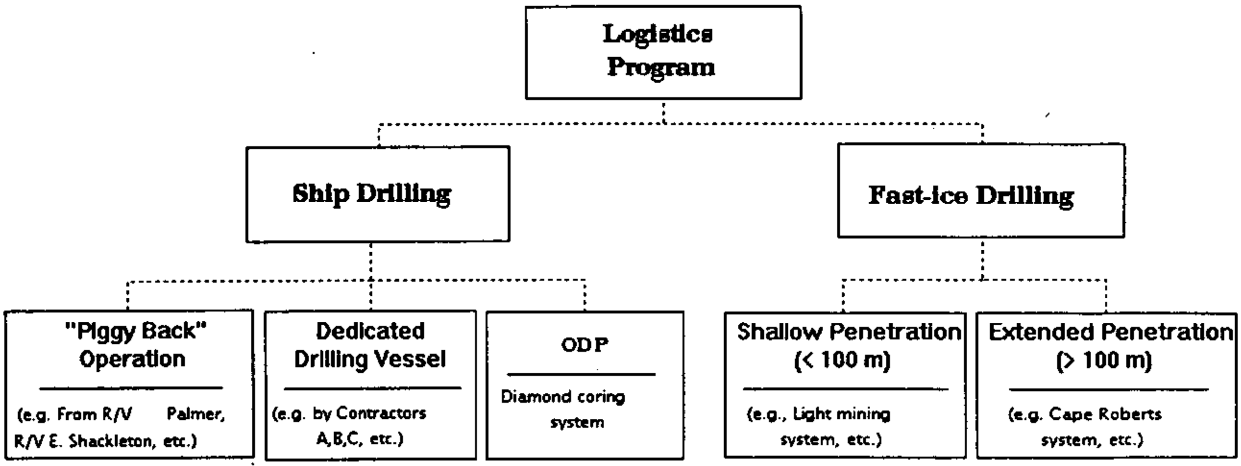


Figure 5. Overview of approaches and recommendations for shallow drilling operations in the antarctic continental margin

SUMMARY

The Antarctic Offshore Stratigraphy Project (ANTOSTRAT) convened a workshop in conjunction with the 8th International Symposium on Antarctic Earth Science in July 1999 in Wellington, New Zealand, to follow up recommendations for future research made by a previous SCAR ANTOSTRAT Workshop on Antarctic Late Phanerozoic Earth System Science held in Hobart, Australia in 1997. The objectives of the workshop were to identify specific actions needed by the earth science community for geological studies to model Antarctic paleoenvironments over the past 100 million years. Over 40 researchers from 12 countries attended and participated in the discussions.

The workshop recommended that the future research effort should focus on three particular time periods of the climate history - early Cenozoic glaciation, middle Miocene ice build-up, and Plio-Pleistocene glacial/interglacials. Geological data are urgently needed as input and constraints to paleoclimatic modeling, and require focus on collection and analysis of ground-truth geologic information from around Antarctica and its continental margin.

A principal contribution of new geologic information will come from continued ANTOSTRAT coordinated effort in promoting and justifying further ODP drilling. However, to complement ODP results and to get better access to the ice-proximal record, the workshop considers shallow drilling (up to 100 m pentration) on the continental shelf and upper slope as the principal ANTOSTRAT strategy for the coming decade.

Shallow drilling can be implemented by two principal approaches – ship-based drilling and drilling from land-fast ice. Drilling from a ship can be with a mobile rig mounted on an Antarctic research- or supply-vessel, or by a contracted dedicated drilling vessel. A multi-vessel approach will promote wider participation and enhance capabilities. Drilling from land-fast sea ice could be shallow penetration with a small system or extended penetration with the proven Cape Roberts type system. Shallow- penetration systems should be encouraged to promote wide participation and enhance capabilities. The workshop set a goal of having the first shallow-drilling campaign in the field and cutting core before the Spring of 2003.

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ACKNOWLEDGEMENTS

We thank the organizers of the 8th International Symposium on Antarctic Earth Sciences for arranging facilities for the meeting. We appreciate the support of SCAR and the Joint Working Groups in providing funds to help pay travel expenses for several participants to attend the workshop. We futher appreciate the support of National Antarctic Program managers in facilitating where they can the efforts of ANTOSTRAT to promote multinational field programs for acquisition of fundamental geoscience data. Many colleagues worldwide have provided advice and time in creating the strategies laid out here and in the predecessor workshop report (*SCAR Report* 16), and we appreciate their input.

APPENDICES

Appendix 1: Agenda of ANTOSTRAT Workshop on Geologic Studies to Model Antarctic Paleoenvironments over the past 100 Ma

Saturday 10 July:	0830–0840	Welcome	
	0840–0900	Antostrat strategy and Hobart Report	A Cooper
	0900–0915	Status of ANTOSTRAT databases	A Cooper / G Brancolini
	0915–0925	The PANGEA data base	D Fuetterer
	0925–0945	Input needs for Antarctic paleoclimate modeling	B Oglesby
	0945–1030	Review of sources of available information	
		ODP drilling	P Barker
		Cape Roberts drilling	P Barrett
	1030–1045	Coffee break	
	1045–1230	Marine shallow drilling	Y Kristoffersen
		Dredging and coring	A Maldonado
		Under-ice coring	R Scheerer
		Lake coring	I Goodwin
		Terrestrial outcrop sampling	W Dickinson
		Surface exposure dating	M Bentley
	1230–1330	Lunch	
	1330–1345	Formation of working groups	
		ODP drilling	
		Drilling from fast ice platforms	
		Marine shallow drilling	
		Dredging and coring	
		Under-ice coring	
		Lake coring	
		Terrestrial outcrop sampling	
	1600–1730	Report of working groups	
	1730–1815	Discussion of paleoclimate modeling	Oglesby/Barrett
Sunday 11 July:	0830–0930	Session of ANTOSTRAT Regional Working Groups	
		Antarctic Peninsula	
		Ross Sea	
		Wilkes Land	
		Prydz Bay	
		Weddell Sea	
	0930–1000	Report of Regional Working Groups	
	1000–1015	A shallow drilling initiative	Y Kristoffersen
	1015–1030	Coffee break	
	1030–1200	Discussion of strategies and implementation	Cooper/O'Brien
	1200–1215	Wrap-up of the geological sampling part of the workshop	Y Kristoffersen
	1215–1315	Lunch	
	1315–1815	Special session on Antarctic Seismic Data Library	
	1815	End of workshop	

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Effort Explores 130 Million Years of Antarctic Paleoenvironment

Antarctic climate history has been dominated by events and turning points with causes that are poorly understood. To fill the gaps in ourknowledge, a new effort is under way in the inter-national geologiccommunity to acquire and coordinate the circum-Antarctic geologic data needed to derive and model paleoenvironments of the past 130 m.y. The effort, which focuses principally on using shallow (<100 m) stratigraphic drilling and coring to acquire the geologic data, is being led by the Antarctic Offshore Stratigraphy Project (ANTOSTRAT), a group that works under the aegis of the Scientific Committee on Antarctic Research (SCAR).

About 40 scientists from 12 countries met this past summer in Wellington, New Zealand, at an ANTOSTRAT meeting to discuss strategies for implementing the desired paleoenvironmental field and modeling studies. The meeting was held in conjunction with the 8th International Symposium on Antarctic Earth Sciences.

The southern continent has occupied a polar position over the last 130 m.y., and has strongly affected global climatic events. Such events include the mid-Campanian cooling of the Antarctic environment, climatic warming in late Paleocene- Eocene times, the onset of Antarctic glaciation at about 40 Ma with global cooling at the Eocene-Oligocene boundary, mid-Miocene transition to full scale glaciation and "thermal isolation of Antarctica" followed by early to mid-Pliocene warming events, and the intensification of Northern Hemisphere glaciation at 2.5 Ma with multiple glacial and interglacial periods to the present. To model such global and regional climate events, a diverse suite of paleoenvironmental data, such as topography and bathymetry, global and regional paleogeography, and forcing factors (atmospheric CO2 [2 is subscript], solar luminosity, etc.) is needed. Yet, at present, most of these data either do not exist or are toolimited for the desired resolution of the models.

Workshop discussion centered on which paleoclimate events could realistically be modeled and how the data needed for these and other model attempts could be acquired. Three periods and events were chosen for the initial focus of the project due to data availability: the early Cenozoic glaciation, middle-Miocene ice build up, and Plio-Pleistocene glacial/interglacials. However, participants emphasized that the other periods are important, and data should continue to be acquired for later model studies of these periods.

To initiate the model studies, a Climate Modeling working group was established within ANTOSTRAT. The group, which is coordinated by Robert Oglesby (e-mail: roglesby@purdue.edu), was tasked with initiating greater interaction of Antarctic geoscientists with global climate modelers. The modeling group will work with the ANTOSTRAT regional working groups and interested scientists from other geographic areas and disciplines to compile the paleoenvironmental information needed for implementing the desired paleoclimate models.

Acquisition of new paleoclimate data is a key issue. Three principal sources are published literature, personal contacts, and new geologic samples. The first two sources require thorough searches, and are relatively straightforward. Acquisition of new geologic samples is a far more difficult and costly task, due to the remoteness of Antarctica and the severe operating conditions in the ice-covered and deep-water sampling areas.

The next era of geologic sampling on and around Antarctica will require all available sampling tools, which include shallow-drilling (<100 m below sea floor (mbsf)) systems now in development, drill ships of the Ocean Drilling Program (ODP) and its next generation, drilling from land-fast sea-ice, conventional sea-floor sediment coring and dredging, sub-ice drilling, terrestrial drilling, and lake-sediment coring. The ultimate goal is to achieve 100% core recovery, so that an unbroken geologic record of paleoenvironments can be derived at the sampling site for use in the paleoclimate models.

Selecting safe drill sites requires knowledge of the subsurface structures. Many offshore areas around Antarctica could be drilled immediately. Over the past decade ANTOSTRAT's five regional working groups (Antarctic Peninsula, Ross Sea, Wilkes Land, Prydz Bay, and Weddell Sea) have carefully coordinated and compiled the seismic-reflection data bases and the extensive published geologic framework and stratigraphic studies needed for drill-site selection. The ANTOSTRAT Antarctic Seismic Data Library System, for example, holds the multichannel seismic-reflection data bases, and these are accessible to all researchers.

Now that seismic-reflection data bases are mostly organized, the ANTOSTRAT community has shifted emphasis to collecting and analyzing geologic samples. High-resolution seismic and sea-floor imaging studies will continue. However, it is hoped that greater efforts and resources will be directed toward ground-truth sampling studies. Such studies will build upon drilling efforts of the past 3 decades focused on understanding Antarctic glacial history, such as those of the Deep Sea Drilling Program and the Ocean Drilling Program (ODP). Prior drilling has not achieved, with few exceptions (for example, CIROS and Cape Roberts drilling projects in the southwest Ross Sea), the high core-recovery rates needed for detailed paleoclimate models. But the drilling has provided the stratigraphic calibrations and paleoenvironmental data that are the foundation for current Antarctic glacial history models. The next generation of paleoclimate models will require cores from never before sampled geologic-time periods at sites around Antarctica.

To promote this goal, in the mid 1990s ANTOSTRAT submitted a coordinated suite of proposals to ODP for circum-Antarctic drilling to better resolve Antarctic Ice Sheet history. Two were accepted; Leg 178 was drilled in the Antarctic peninsula, and Leg 188 will be drilled in early 2000 in Prydz Bay. Three other proposals are under consideration for future drilling in the Ross Sea, Wilkes Land, and the Weddell Sea. At the workshop, the regional working groups reviewed the recent ODP and Cape Roberts drilling results and updated pending ODP proposals based on the new drilling information.

To expedite recovery of the paleoenvironment data, highest priority was given to shallow drilling with high core-recovery using high-speed, diamond-bit coring. For offshore areas, where most future drilling will be done to access known stratigraphic sections, shallow drilling feasibility studies are underway in the U.S. Antarctic Program, Norwegian Program, and others. Equipment being considered includes "piggy back" drill rigs mounted on large national research vessels, tethered sea-floor drill rigs, commercial drilling vessels, and others. Several drilling firms are interested in adapting existing drilling systems for the difficult Antarctic drilling conditions, with cost estimates of $.7-$1.2 million for a 45- day leg on a drill rig only or up to $4 million for a dedicated drill ship.

Some recent efforts at offshore shallow drilling have been made and include a campaign by the British Geological Survey to use a portable rock drill capable of collecting 5 m cores along the Antarctic Peninsula and a Norwegian/Finnish field program on the Weddell shelf using a light-duty "piggy back" mining drill rig that drilled down to 16 mbsf in diamicton. The ANTOSTRAT working groups identified other circum-Antarctic areas where shallow drilling could effectively be used to recover samples covering the key time periods for the paleoclimate models. Sites of particular interest are those in former ice-stream troughs, where deep erosion by formerly grounded glaciers has exposed Cenozoic and possibly Mesozoic rocks close to the seafloor.

Geologic samples are also needed from onshore and ice-covered areas, for example, ice-free land areas, subglacial regions, lakes, and near-shore zones. These areas would have different operating parameters, but shallow-drilling techniques could be used. For example, safe and successful drilling recovered several hundred meters of core in the Dry Valley region in the 1970s during the Dry Valley Drilling Project (DVDP). Another project recently used portable drilling systems with compressed air as a coolant (~30 m penetration). Also, drilling at land-fast sea ice has achieved excellent recovery to depths of more than 900 mbsf and in water depths close to 400 m in the southwest Ross Sea area. As an example of the good core-recovery achievable, in 1997 the Cape Roberts project obtained a 148 m glacigenic sequence 16-20 Ma in age and in 1998, a 650 m sequence of similar rocks 19- ~31 Ma in age, with core-recovery of about 95%. Similar fast-ice drilling can be done elsewhere around Antarctica if a logistically simpler drilling approach for shallow penetration (<100 mbsf) is used. Projects with this capability have already been proposed to better define paleoenvironments. These include, for example, a project that would drill a late Pleistocene-Holocene record in the 800-m-deep fjord in front of Mackay Glacier at 77°S in the McMurdo Sound area, and a project that would drill into Cenozoic strata beneath fast ice of the Weddell Sea shelf and under thick ice of the Ross Ice Shelf.

The Antarctic interior includes many sedimentary basins that undoubtedly contain stratigraphic evidence of continental-cryosphere evolution; these are basins that need to be sampled. Yet to date, no in situ rocks have been recovered from beneath the Antarctic Ice Sheet except surficial glacigenic sediment from several regions in the interior of the Ross Embayment from beneath the Ross Ice Shelf and the West Antarctic Ice Sheet. Hot water drilling provides relatively easy access through grounded ice less than 1500 m thick, and the deployment of rock drills through hot-water holes is feasible, though off-the-shelf technologies require modification including freeze-up prevention. Priority was also given to drilling of the Gamburtsev Mountains in central East Antarctica, because their origin is recognized as critical to modeling the development of the ice sheet; drilling hypothesized volcanoes in the interior of West Antarctica that could affect ice-sheet stability; drilling within mountain valleys through which major ice rivers flow and record major Neogene fluctuations of the ice sheet; and drilling in lakes to achieve a high-resolution record of the Pleistocene-to-Holocene climatic variations. Drilling is expensive and requires highly-skilled drilling crews familiar with Antarctic conditions. With high costs, international cooperative efforts will likely be needed. For offshore and fast-ice areas, a multiplatform capability involving "piggy back" operation, a dedicated drilling vessel, portable fast-ice drill camp, etc., is ANTOSTRAT's vision for promoting high participation single-nation and cooperative Antarctic projects dedicated to acquiring geologic ground-truth information.

ANTOSTRAT's goal is to see a new national or multinational shallow-drilling program in the field before the spring of 2003. Geologic sampling using conventional sea-floor coring and dredging equipment, especially in canyons and highly eroded areas, remains important to stratigraphic mapping and paleoenvironment projects, and is encouraged for national expeditions if the preferred option of shallow drilling is not possible.

In conclusion, the workshop participants recognized that major advances in Antarctic geo-science, especially in costly operations, have come principally from coordinated efforts by researchers in all national programs. ANTOSTRAT, which is open to all, invites input from the broader science community to help better understand Antarctic and global paleoclimates.

The ANTOSTRAT Workshop on Antarctic Late Phanerozoic Earth System Science was held 10–11 July, 1999, in Wellington, New Zealand. Additional background information on ANTOSTRAT and related paleoclimate projects can be found at:
http://www.antcrc.utas.edu.au/scar/antostrat/antostrat.html

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Appendix 4: List of Acronyms and Abbreviations

ANTIME	Antarctic Ice Margin Evolution
ANTOSTRAT	Antarctic Offshore Stratigraphy Subcommittee
CIROS	Cenzoic Investigations of the Western Ross Sea
CRP	Cape Roberts Programme
EAIS	East Antarctic Ice Sheet
GCM	General Circulation Model
ITASE	International Trans-Antarctic Scientific Expeditions
LGM	Last Glacial Maximum
MSSTS	McMurdo Sound Sediment and Tectonic Studies
ODP	Ocean Drilling Programme
PANGAEA	Network for Geological and Environmental Data
PICE	Paleoenvironments from Ice Cores
PROD	Portable Remotely Operated Drilling System
RWG	Regional Working Group
SCAR	Scientific Committee on Antarctic Research
SDLS	Seismic Data Library System
TAM	Transantarctic Mountains
WAIS	West Antarctic Ice Sheet

SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement *SCAR Bulletin*. Its purpose is to provide SCAR National Committees and other directly involved in the work of SCAR with the full texts of reports of SCAR Working Group and Group of Specialists meetings, that had become too extensive to be published in the *Bulletin*, and with more comprehensive material from Antarctic Treaty meetings.

SCAR Bulletin

SCAR Bulletin, a quarterly publication of the Scientific Committee on Antarctic Research, is published on behalf of SCAR by Polar Publications, at the Scott Polar Research Institute, Cambridge. It carries reports of SCAR meetings, short summaries of SCAR Working Group and Group of Specialists meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership. Selections are reprinted as part of *Polar Record*, the journal of SPRI, and a Spanish translation is published by Instituto Antártico Argentino, Buenos Aires, Argentina.

Polar Record

Polar Record appears in January, April, July, and October each year. The Editor welcomes articles, notes and reviews of contemporary or historic interest covering the natural sciences, social sciences and humanities in polar and sub-polar regions. Recent topics have included archaeology, biogeography, botany, ecology, geography, geology, glaciology, international law, medicine, human physiology, politics, pollution chemistry, psychology, and zoology.

Articles usually appear within a year of receipt, short notes within six months. For details contact the Editor of *Polar Record*, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, United Kingdom. Tel: 01223 336567 (International: +44 1223 336567) Fax: 01223 336549 (International: +44 1223 336549)

The journal may also be used to advertise new books, forthcoming events of polar interest, etc.

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