REVEAL: REmote Views and Exploration of Antarctic Lithosphere Workshop: The future of Antarctic airborne geophysical capabilities—Workshop Report

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WORKSHOP REPORT

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Denver, CO

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EXECUTIVE SUMMARY

Antarctica is a key element in Earth's geodynamic and climatic systems, yet on the eve of the 50th anniversary of the International Geophysical Year, we lack fundamental geologic and geophysical data from the deep interior of this vast continent. Meager exposures record the 3500 million-year history of a continent that participated in the formation and breakup of both the Rodinia and Gondwana supercontinents. It continues to be tectonically active today, although its kinematic relation to the global plate circuit and its role as substrate to the world's major ice sheets remain in question. The Mesozoic break-up of Gondwana resulted in a major re-arrangement of the continental masses, which isolated Antarctica from mid-latitude oceanic influences by establishing the powerful circum-Antarctic current. This event was largely responsible for development of the massive West and East Antarctic ice sheets that blanket 98% of the continent and fundamentally influence world climate today. The West Antarctic Ice Sheet (WAIS) contains enough grounded ice to raise global sea level 5 meters, were it to melt completely, and hosts ice streams that potentially could evacuate the ice over short geologic timescales. Recent measurements show the ice sheet is undergoing rapid and dramatic change in some regions and reveal an ice-sheet-wide history of large fluctuations in extent and volume. Although the East Antarctic ice sheet is apparently more stable, it exerts a profound influence on global climate and covers numerous sub-glacial lakes that may have existed for millions of years. Major interest lies in the age of these lakes, their tectonic history, their resident biota, and the record of Antarctic climatic history that may be contained in the sediments beneath them.

Global geodynamics was and continues to be a major influence on the formation, nature, and dynamics of the ice sheets. In turn, understanding geodynamics requires deciphering Antarctic geologic and tectonic history. For example, the mass balance and response of the WAIS to climate forcing appear to be strongly influenced by geologic and geophysical parameters such as the distribution of sedimentary basins and the geothermal heat flux into the base of the ice. Precambrian structures may have influenced the style and location of younger tectonic and magmatic events that are manifested by the major features of the continent today, such as the Paleozoic and Mesozoic orogens of the Transantarctic Mountains, Mesozoic rift zones, and Cenozoic volcanic provinces. In turn, these events have influenced ice sheet dynamics and, therefore, global climate.

Despite the central role that Antarctica has played in shaping the present global environment, fundamental, first-order parameters such as bedrock elevation, lithology, structure, age, tectonic history and ice volume remain poorly known over large portions of the continent. Given the extensive ice cover, airborne geophysical data, constrained by field-based geologic mapping, ground-based geophysics, and petrologic, geochemical and geochronological analysis of outcrop and drill-hole samples, is the best way to characterize broad areas of the Antarctic lithosphere. However, the U.S. Antarctic program currently lacks an effective means to collect and integrate airborne geophysical data with other datasets under broad science objectives defined by the earth science community. Regional high-resolution aerogeophysical coverage is also required by other national Antarctic research programs. In order to address scientific and logistical issues, the National Science Foundation sponsored an international workshop attended by 45 geologists, geophysicists and glaciologists in Denver, CO in August, 2002.

The REVEAL workshop framed a set of key issues in Antarctic research that require airborne gravity, magnetic, laser altimetry and ice-penetrating radar measurements from long- and mid-range fixed-wing and helicopter platforms. Science goals and potential target areas were developed in the context of three major themes: (1). geology and ice sheet dynamics; (2). crustal architecture of the East Antarctic shield, and (3). geodynamics of rifting in an ice-covered environment. Investigations directed at these themes will form the basis for an integrated, multidisciplinary initiative to study the relationship between Antarctic geodynamic processes, ice sheet dynamics and global environmental change. Specific goals of these research themes are outlined here.

1. Geology and ice sheet dynamics. *Antarctic geological processes are the driving forces for ice sheet dynamics and global environmental change that affect current and long-term large-magnitude sea level changes. Key scientific issues are:*

- <u>What are the geologic controls on ice sheet dynamics</u>?
    - Extensional tectonics form rift basins and generate high heat flow that influence basal ice conditions. Measuring the 3-d geometry of rift basins and location of sub-ice volcanoes will help clarify the relation between tectonics and ice sheet dynamics.
    - Paleoclimate and ice sheet modeling studies are hampered by incomplete knowledge and/or poor resolution of boundary conditions which include reconstructions of global and regional paleogeography, paleotopography, heat flow, distribution of subglacial sediments, and Cenozoic volcanic rocks.

- <u>What are the masses of the ice sheets and fluxuations of sea levels on different time scales</u>?
    - In order to understand the relation between ice mass balance and sea level, the current volume of the ice sheet needs to be determined.

- <u>What are the distribution, nature and origin of the sub-glacial lakes and their relation to crustal structure and heat flow</u>?
    - The presence of subglacial lakes may have important implications for ice sheet dynamics as well as for terrestrial and marine glacial environments. Study of the lakes provides a means to understand the interaction between geologic and biologic processes. In addition, the extreme environments of these lakes may be analogous to those of early Earth and planets, revealing the conditions under which life began.

2. Crustal architecture of the East Antarctic shield. *Unraveling the role of Antarctica in global geodynamic processes requires a basic understanding of the poorly-known East Antarctic shield and West Antarctic basement. Key questions to be addressed about the origin and evolution of Antarctic lithosphere are:*

- <u>What was the role of East Antarctica in Precambrian continental growth processes</u>?
    - Because East Antarctica occupied the center of early supercontinents such as Rodinia and Gondwana, and may represent ~15% of Earth's Precambrian crust, it holds a key to understanding the processes governing continental growth spurts in the late Archean to Latest Neoproterozoic and issues such as the role of magmatism, accretionary and collisional tectonics, continental break-up, and subduction in early continental Earth history.

- What are the origins, extents and ages of interior basins?
    - Tectonic, erosion, subsidence and glacial history can be determined by knowing the age, lithology and 3-d geometry of sedimentary basins in East Antarctica.

- What are the distribution, magnitudes, and focal mechanisms for earthquakes?
    - A lack of seismic data limits definition of lithospheric structure and neotectonics.

- What is the timing and magnitude of Mesozoic to Cenozoic extension in Antarctica and its effect on the global plate motion circuit?
    - Extension in the latest Mesozoic rifted Australia and New Zealand from Antarctica. Study of the timing of extension, uplift and magmatism provides a means to determine mechanisms of continental breakup and relative motion between East and West Antarctica.

    - Rates of extension and lithospheric thinning have a direct influence on magma production rates and volcanism; however, the higher production rates in the late Cenozoic do not appear to be the result of higher rates of extension.

3. Geodynamics of rifting in an ice-covered environment*. Understanding lithosphere geodynamics in Antarctica's ice-covered environment will clarify its feedback on other global systems.*

- What are the feedbacks between mountain uplift and ice sheet and climate models?
    - Preliminary ice sheet modeling studies suggest the Gamburtsev Subglacial Mountains are the likely location for initiation of the East Antarctic ice sheet and therefore, could be a key factor in understanding the onset of glaciation in the Paleogene. Episodic uplift of the Transantarctic Mountains throughout the Cenozoic may have influenced ice sheet dynamics and therefore, climate. In addition, climate change may have led to increased erosion rates, accelerating uplift and sedimentation into the Ross Sea.

    - Rapid unloading of ice sheets may enhance magma production rates. The largest Cenozoic volcanoes in Antarctica are located at the edges of the East and West Antarctic ice sheets, where waxing and waning is largest.

In order to address these science questions, three strategies involving various airborne platforms and geophysical instruments were considered:

- Regional (lines spaced 5-10 km apart) gravity, magnetic, laser altimetry and ice-penetrating radar surveys from a long-range aircraft such as a P-3 Orion or LC-130.

- Detailed (line spacing < 5 km) fixed-wing gravity, magnetic, laser altimetry and ice-penetrating radar surveys for detailed areas of interest with moderately thin (<~2000 m) ice.

- High-resolution helicopter magnetic surveys (line spacing < 1.5 km) accompanied by ground gravity and radar measurements would help constrain the magnetic and gravity signatures of areas underlain by outcrop and thin ice (<500 m thick).

The integration of these airborne geophysical capabilities with the science targets outlined above will be coordinated through a community-based science plan. The recommendations of the REVEAL workshop (available at http://crustal.cr.usgs.gov/antarctica and http://www-bprc.mps.ohio-state.edu/) will be linked to glaciology (http://igloo.gsfc.nasa.gov/wais), drilling (http://www.es.ucsc.edu/~tulaczyk/fastdrill.htm), marine, climate modeling (http://www.geo.umass.edu/ace), and seismic infrastructure (http://anquetil.colorado.edu/seap2003/) targets in order to develop priorities for integrated scientific studies. Details of the formal science plan and management structure will be developed in mid-2003.

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INTRODUCTION

Charge for the workshop

Improved knowledge of sub-ice geology and structure and ice volumes throughout Antarctica are required to address key scientific questions. A clear understanding of the geological evolution of Antarctica provides an essential foundation for studying early crustal evolution as well as subsequent resource distribution, biosphere evolution, and glacial and climate history. The aim of the workshop was to help develop an organized, long-term program of research to characterize the composition and 3-dimensional structure of Antarctic lithosphere and ice sheets. The primary focus of the workshop was to identify integrated, multidisciplinary approaches, with a focus on airborne geophysical capabilities, that should be used in this exploration and how they might be coordinated. Given the extensive ice cover, collection of airborne geophysical data, constrained by field-based geologic mapping, ground-based geophysics, and petrologic, geochemical and geochronological analysis of drill-hole samples, is the best and most cost-effective method to characterize broad areas of sub-ice basement and expand our knowledge of Antarctica, the last continental frontier on Earth. Indeed, past workshops for the geology, glaciology and biology communities identified various regions of the continent that require airborne geophysical data coverage to help address key scientific questions.

History

Previous science justifications for airborne geophysical surveys

Previous broad-scale workshops from the geology/geophysics community (e.g. SEAL (1988), TAM (1994), LIRA (1994), Southern/Central TAM (1996), East Antarctic Margin (1997), ANTEC (2001)) (some summaries in workshop report section of www-bprc.mps.ohio-state.edu) identified a variety of locations for multidisciplinary studies that included airborne geophysical surveys. Of these areas, funded proposals included incomplete data collection for 4 areas. No broad science plans emerged from the workshops. The clear question arose: "How can we make this workshop different in that something concrete and fundable emerges?"

Previous airborne geophysical facility

The Support Office for Aerogeophysical Research (SOAR), based at the University of Texas under a cooperative agreement with the National Science Foundation and subcontracts to Lamont-Doherty Earth Observatory and U. S. Geological Survey, collected and reduced 275,000 line-km of high-quality ice-penetrating radar, laser altimetry, gravity and magnetic data from a Twin Otter for 9 out of 10 field seasons between 1991 and 2001 (Blankenship et al., this report). Funding for the facility was provided by the Antarctic Geology and Geophysics, Glaciology (total from both programs of ~$600-700k/yr exclusive of science funding) and Polar Research Support (~$350-400k/yr exclusive of camp and LC-130 support costs) budgets. Data were collected for geologic and geophysical studies over large areas in Marie Byrd Land, central West Antarctica, Victoria Land to Dome C, the South Pole area and Lake Vostok, in addition to smaller surveys in a variety of places near the Transantarctic Mountains (Fig. 1).

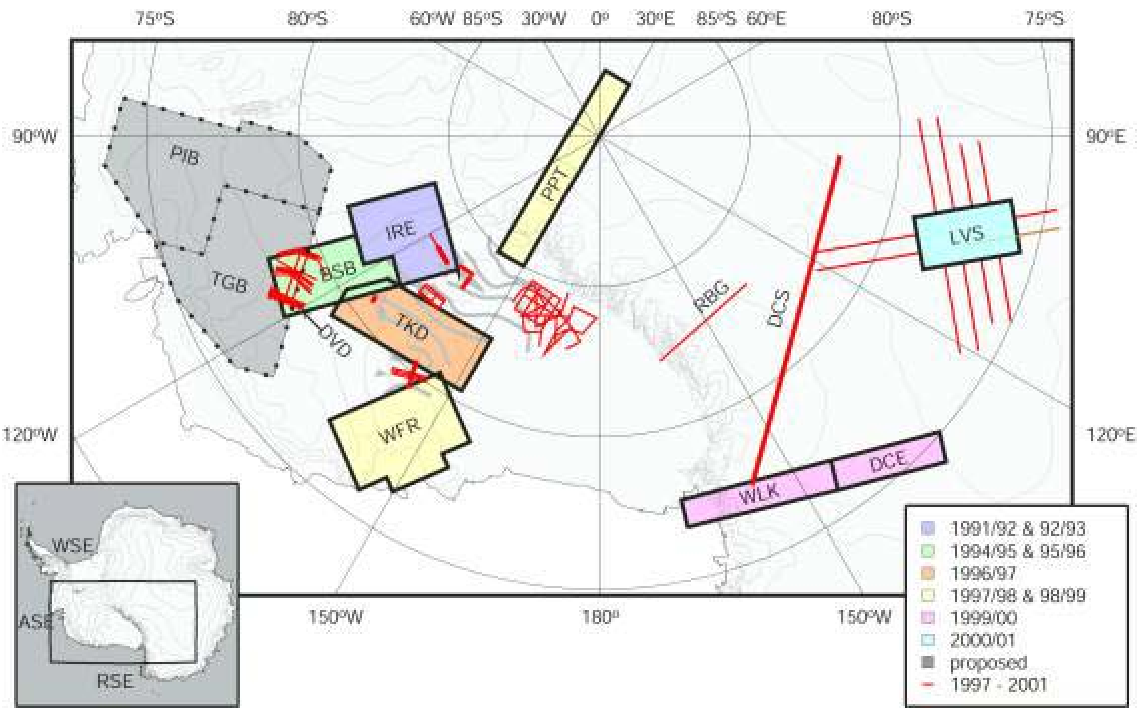

Figure 1 Coverage map of SOAR aerogeophysical surveys beginning with the CASERTZ projects (IRE, BSB and TKD) and continuing through the most recent subglacial Lake Vostok survey (LVS). Colored regions were flown with regular grids, individual flight tracks are shown (in red) for line-oriented surveys. The gray, dash-bordered regions (PIB and TGB) are proposed for a proposed future project (Morse et al, this report, from Blankenship, this report).

Interpretation of these and airborne magnetic data collected by the German, British, Russian, and Italian Antarctic programs over Victoria Land, the Antarctic Peninsula and Dronning Maud Land, for example, have shown the utility of airborne geophysics for mapping Precambrian granitic and metamorphic rocks, Paleozoic intrusive and volcanic rocks, Jurassic dolerites and

Mesozoic basins formed in association with Gondwana break-up and Cenozoic sedimentary and magmatic rocks as well as major basement structures. Comparing the airborne geophysical data from continents once attached to Antarctica such as Australia and Africa have led to increased understanding of the Precambrian basement framework for parts of Wilkes Land and Dronning Maud Land (e.g. Finn, this report; Jacobs, this report). These studies illustrate the utility of high-resolution (spacing between flight lines 5.5 km and less) and low altitude (less than 1000 m above the surface) airborne geophysical data for mapping sub-ice geology and revealing regional tectonic processses. Glaciological studies have also benefited from airborne geophysical data, which have helped constrain the thickness, layering, and morphology of parts of the ice sheets. However, recent compilations of primarily airborne geophysical data including BEDMAP (Fig. 2) (ice thickness data), ADMAP (Fig. 3) (magnetic data) and ADGRAV (Fig. 4) (gravity data), show large holes in data coverage as well as extensive areas with data whose resolution is too low to be useful for mapping sub-ice geology or details of the volume and stratigraphy of the ice sheets.

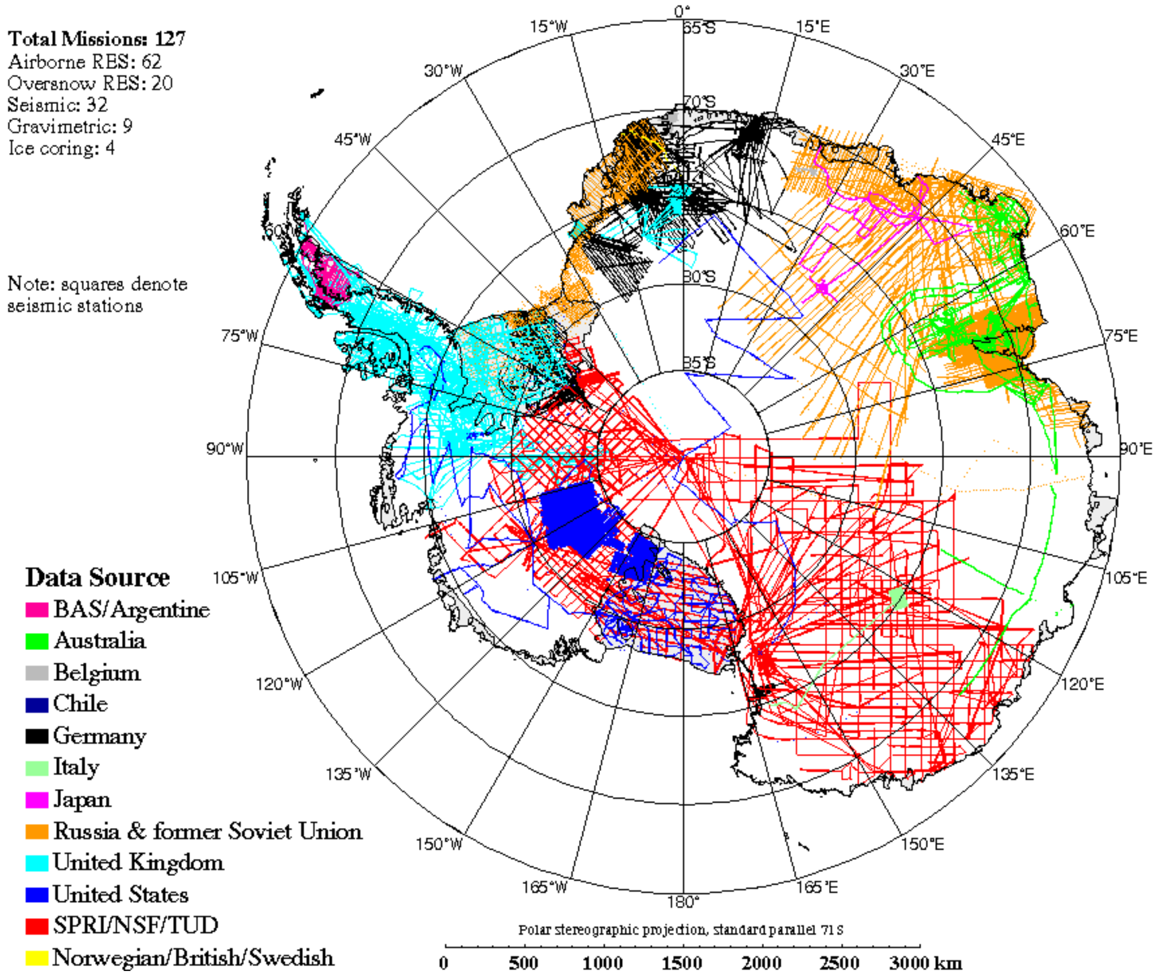

Figure 2 Coverage of ice thickness measurements in Antarctica (Lythe et al., 2000).

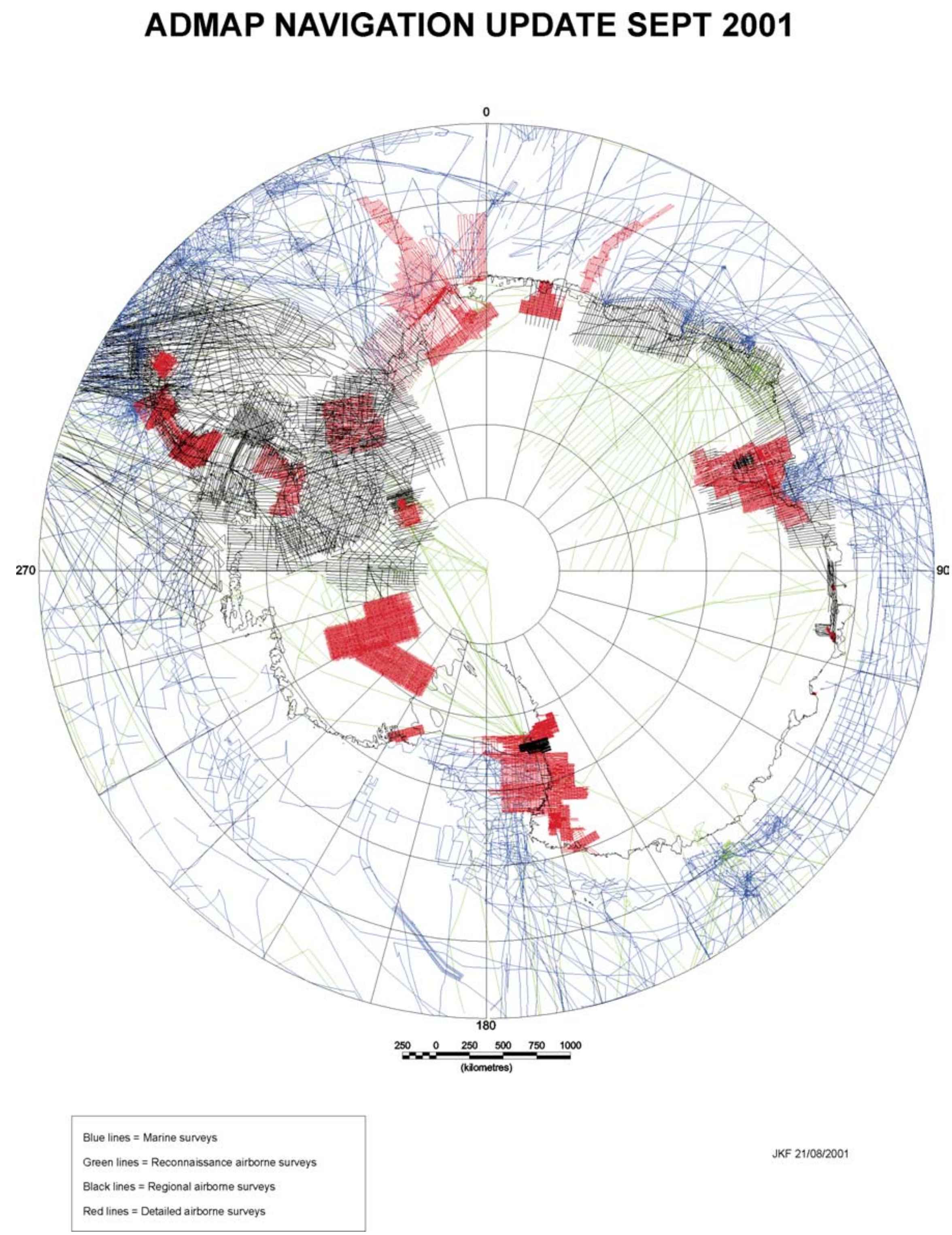

Figure 3 Coverage of airborne magnetic surveys in Antarctica (ADMAP, 2001)

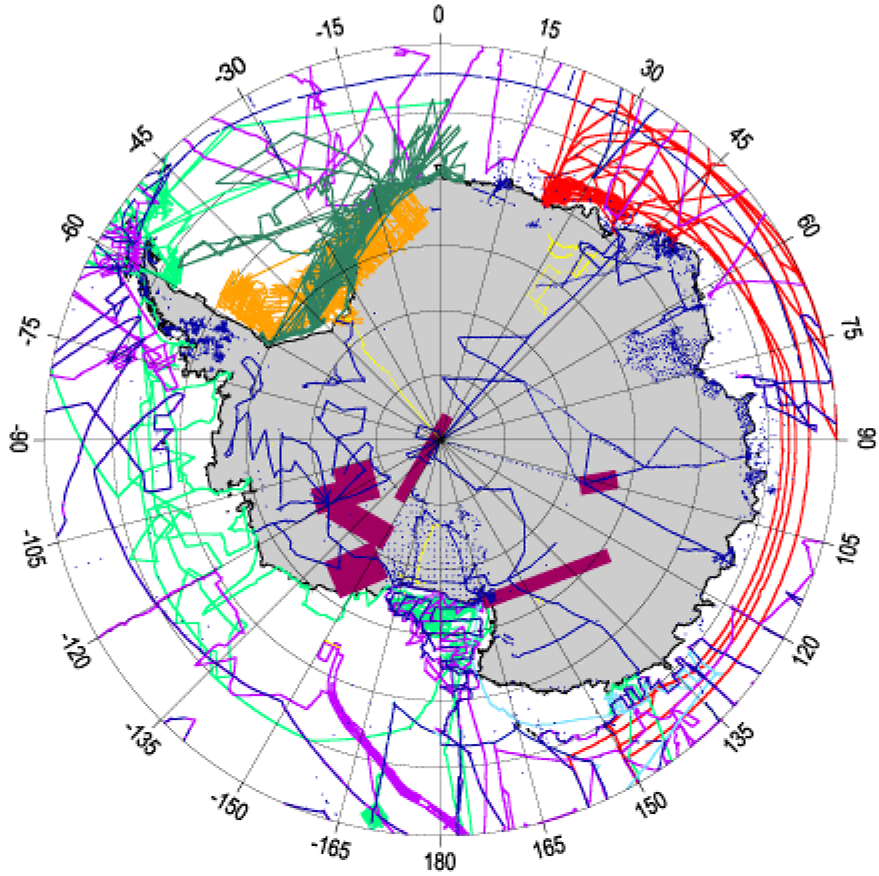

Figure 4 Coverage of gravity data in Antarctica (ADGRAV compilation, http://data.ldeo.columbia.edu/adgrav/)

The loss of the SOAR facility leaves the U.S. Antarctic program without a cost-effective means to remotely map sub-ice geology as well as ice sheet character, limiting the ability to address fundamental questions in Antarctic geoscience and glaciological research. Interest from the scientific community to study remote areas in East Antarctica as well as look in detail at areas around exposed rocks require airborne platforms such as long-range aircraft (C-130's, P-3) or helicopters in addition to the Twin Otter. Therefore, new airborne geophysical capabilities are necessary.

Previous science plans

In the Antarctic geology and geophysics community, several single-project workshops led to formal science plans, including the Lake Vostok workshop (http://www.ldeo.columbia.edu/vostok/index.html) which led to airborne geophysical work, Andrill (http://andrill-server.unl.edu/) and Cape Roberts (http://www.geo.vuw.ac.nz/croberts/) international drilling programs. The Antarctic glaciology community has operated a broad science plan for study of the West Antarctic Ice Sheet for ~10 years that completed 80-85% of its objectives (http://igloo.gsfc.nasa.gov/wais/). A new initiative, the Amundsen Sea Embayment Study, guides work for the next 5 years (http://igloo.gsfc.nasa.gov/wais/).

Workshop Program

The REVEAL workshop was designed to draw upon the expertise of geologists, geophysicists and glaciologists investigating Antarctica, together with experts on remote geologic mapping in a variety of environments. The specific tasks for the workshop participants are outlined below.

1). Identify scientific targets suitable for investigation with airborne geophysical tools such as gravity, magnetic, laser altimetry and ice-penetrating radar instruments. Areas of study with airborne geophysical data identified by previous workshops were outlined in overview talks. Talks and posters on current geology knowledge of selected areas in Antarctica and applications of various kinds of geophysical data laid the foundation for discussions on important science questions. A plenary discussion led to identification of key scientific issues by the larger group. These were written on sticky notes and organized. This organization led to the structuring of 3 break-out groups (Geology and Ice dynamics, Rift processes, and Crustal architecture) that met several times during the meeting (recommendations in next section).

2) Determine airborne geophysical capabilities. Talks and posters provided a background on airborne geophysical instruments and platforms and utility of the data for geologic and glaciologic studies. A panel discussion on types of instruments and platforms as well as ways to access airborne geophysical capabilities provided the background for further discussions. Types of

airborne instruments and platforms required to address science targets were identified in the 3 break-out groups. During several plenary discussions, the desired means to generate airborne geophysical data were fleshed out.

3). Determine how to mesh the science goals with the airborne geophysical capabilities in a 5-10 yr multidisciplinary science plan. Talks and posters on interdisciplinary studies linked through science plans were presented. Examples of science plans included Canada's Lithoprobe (http://www.geop.ubc.ca/Lithoprobe/), NSF-sponsored initiatives such as RIDGE (http://ridge.oce.orst.edu), UNAVCO (http://www.unavco.ucar.edu/), IRIS (http://www.iris.edu/). A panel discussed management models for connecting airborne geophysical data collection with science targets. Examples of university-based facilities such as SOAR were compared with data collection done with consortia as well as private contractors.

SCIENTIFIC JUSTIFICATION FOR AIRBORNE GEOPHYSICAL DATA COLLECTION

Geology and Ice Dynamics Working Group

1. Group Theme: Antarctic geological processes are the driving forces for ice sheet dynamics and global environmental change that effect current (West Antarctic Ice Sheet (WAIS)) and long-term, large-magnitude sea level changes (East Antarctic Ice Sheet).

2. Key scientific issues:

- Understanding geologic controls of the two ice sheets in general
- Ice sheet mass and sea levels on different time scales
- Geodynamic evolution of the Gamburtsev Mountains and their relation to ice sheet nucleation
- Tectono-thermal and volcanic development of the WAIS
- The geological response to continental glaciation and deglaciation, erosion, uplift, sedimentation, seismicity, and volcanism

3. Key locations to address scientific issues (Figure 5):

- The Amundsen Sea Embayment area, West Antarctica
- Gamburtsev Mountains, East Antarctica

4. Key observations and models required:

- ice thickness
- surface and bed rock elevation topography
- sediment thickness
- distribution of volcanic rocks
- tectonic structures
- lithospheric thickness
- distribution of glacial and subglacial water
- identification of internal layering of ice sheet
- fabric of ice sheet
- age-depth structure of the ice

5. Tools:

- 3-D: airborne gravity, magnetic, ice-penetrating radar and laser altimetry measurements
    - regional surveys with a long-range aircraft, local with Twin Otter
- 2-D: seismic refraction, reflection and tomographic data
- 1-D: drilling

6. Outcomes:

- improve estimates of the volume of the ice sheets
- map bedrock elevation and lithology
- improve ice sheet and climate models
- large-scale ice sheet models
- map bed roughness
- map subglacial layer properties (porosity, water pressure and acoustic impedance)
- detect crevasses
- help constrain location of ice cores
- constrain physical controls on the ice motion
- constrain histories of the climate forcing and of the ice-sheet response

Crustal Architecture Working Group

1. Group Theme: To obtain a basic understanding of the origin and evolution of East Antarctic shield and the role of East Antarctica, the last frontier, in global geodynamics.

2. Key scientific issues:

- How and when was East Antarctica assembled?
- How does the assembly of East Antarctica tie in with paleogeography – i.e., Rodinia assembly and Gondwana assembly?
- What are the Gamburtsev Mtns?
- What was the role played by the Gamburtsev Mtns in ice sheet nucleation?
- Are the Gamburtsev Mountains still anomalously high, which might suggest a longstanding thermal anomaly?

- What is the current volume of the ice sheet? (Mass balance considerations)
- What are the variations in crustal thickness and how might they influence ice sheet dynamics?
- What are the extent and age of interior basins?
- What are the distribution, magnitudes, and focal mechanisms for earthquakes?
- What are the distribution, nature and origin of the sub-glacial lakes and their relation to lithospheric structure?

3. Key locations to address scientific issues (Figure 5):

   - Transantarctic Mountains—Gamburtsev Subglacial Mountains—Lambert Rift-Prince Charles Mountains (A, Fig. 5)
   - Wilkes Land—Dome C—Vostok—Denman Glacier (B, Fig. 5)

4. Key observations and models required:

   - ice thickness
   - surface and bed rock elevation topography
   - location and thickness of sedimentary basins
   - sub-ice lithology
   - distribution and type of faults
   - crustal thickness
   - locations of Archean and Proterozoic blocks and sutures within the East Antarctic shield
   - locations of subglacial lakes

5. Tools:

   - 3-D: airborne gravity, magnetic, ice-penetrating radar and laser altimetry measurements
     - regional surveys with a long-range aircraft (P3), local with Twin Otter; survey outcrops with helicopter magnetic, ground gravity and radar measurements
   - 2-D: seismic refraction, reflection and tomographic data, MT data
   - 1-D: drilling (both chips and core samples)
   - Heatflow
   - Geochronology
   - Thermochronology
   - Petrology
   - Paleomagnetic measurements

6. Outcomes:

   - Construct regional 3-D sub-ice geologic maps of East Antarctica
   - Construct heat flow maps of East Antarctica
   - Constrain detailed 3-D structure of East Antarctic crust
   - Constrain tectonic history of East Antarctica
   - Constrain position of East Antarctica within Rodinia and earlier supercontinents

- Help constrain locations of ground-based geophysics
- Help constrain locations of drill holes (and type of drilling)

Rift Processes Working Group

1. Group theme: To understand lithosphere geodynamics in an ice covered environment and its feedback on other global systems with special emphasis on the rifted continent of Antarctica as a unique ice-covered geodynamic setting.

2. Key scientific questions:

   - What drives the uniquely high-amplitude, episodic uplift of the Transantarctic Mountains?
   - What is climate/ice sheet role in causing unique uplift of the Transantarctic Mountains?
   - How have the mountains influenced the climate?
   - How do extensional tectonics affect ice sheets?
   - What is the timing and magnitude of Mesozoic to Cenozoic extension in Antarctica?
   - What is the effect of extension in Antarctica on the global plate motion circuit?

3. Key locations to address scientific issues (Figure 5):

   - Prince Charles Mountains
   - Gamburtsev Mountains
   - Pensacola Mountains
   - Ross Ice Shelf
   - Parts of Marie Byrd Land

4. Key observations and models required:

   - ice thickness
   - surface and bed rock elevation topography
   - location and thickness of sedimentary basins
   - sub-ice lithology
   - distribution and type of faults
   - crustal thickness
   - age of sub-ice basins and volcanic rocks
   - plate motion models

4. Tools:

   - 3-D: airborne gravity, magnetic, ice-penetrating radar and laser altimetry measurements
     - regional surveys with a long-range aircraft (P3), local with Twin Otter; survey outcrops with helicopter magnetic and ground gravity and radar measurements
   - 2-D: seismic refraction, reflection and tomographic data
   - 1-D: drilling

- seismicity measurements
- plate motion models
- geochronology

5. Outcomes:

- Better delineation of rift basins and their connectivity
- 3-D maps of rift basins
- Map the distribution, volume, chronology of volcanic rocks
- Map sub-ice faults
- Constrain location and required depths of drill holes

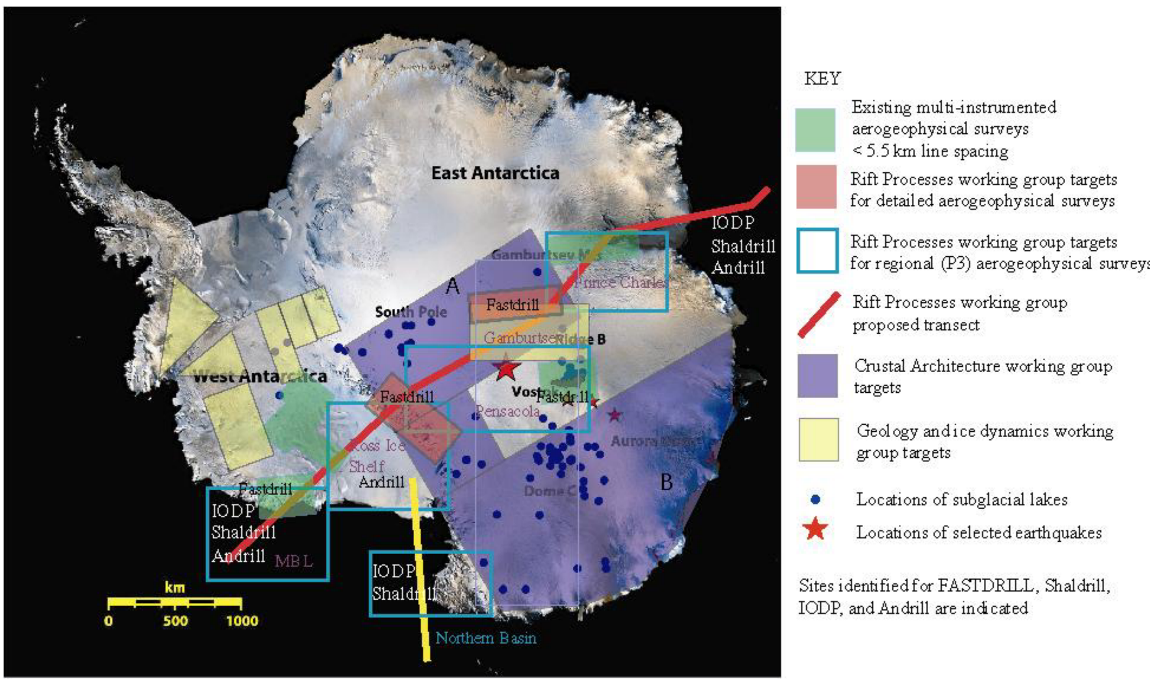

Figure 5. Locations map of proposed areas of study recommended by the break-out groups.

Plenary Discussions

1. Aerogeophysical survey specifications:

The optimum survey specifications for gravity and magnetic data are with a 1:1 ratio of flight height (height above the target) to flight line spacing (Reid et al., 1990). Therefore, close line spacing (<2000 m) is not warranted over the thick ice (> 3000 m) of the continental interior. Additional cross lines are required to level these data and improve the bed elevation and laser altimetry coverage which are optimally flown with equally-spaced orthogonal lines.

- Regional multi-instrumented surveys from a long-range aircraft —debate centered on whether these should be spaced at 5 or 10 km. The proponents of the ~5-km line spacing argued that only closely-spaced lines are useful for geologic interpretation and that larger areal coverage is a secondary consideration. The proponents of wider spaced survey lines contended that areal coverage is important due to the paucity of data in Antarctica. Scouting lines could be flown from McMurdo, to determine the best location for a survey within a given block.

- Twin-engine fixed wing multi-instrumented surveys were recommended for detailed areas of interest (line spacing < 5 km) determined from analysis of the regional survey data. This would include areas were the ice is relatively thin (<~2000 m thick). Flying these detailed surveys could involve cooperation with the British Antarctic Survey (BAS), Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR) and Alfred Wegener Institut (AWI).

- High resolution helicopter magnetic surveys accompanied by ground gravity and radar measurements (line spacing < 1-2 km) would help constrain the magnetic and gravity signatures of areas of outcrop and very shallow ice (<750 m thick). These data could be compared to areas on adjacent continents with high-resolution aeromagnetic data such as Australia and parts of southern Africa. Flying these detailed surveys could involve cooperation with the BGR and Italian programs, which have extensive experience in flying helicopter magnetic surveys.

2. Links to other groups:

For a long-term science plan to succeed, links with other programs are necessary. The following constitute a partial list of groups with common interests with the U. S. Antarctic Geology and Geophysics and Glaciology programs.

- Antarctic Climate Evolution (ACE; http://www.geo.umass.edu/ace/)
- International Trans-Antarctic Scientific Expedition (ITASE; http://www.ume.maine.edu/itase/)
- West Antarctic Ice Sheet Initiative (WAIS; http://igloo.gsfc.nasa.gov/wais/)
- Sub-glacial Antarctic Lake Exploration (SALE; http://salegos-scar.montana.edu/)
- Ice Sheet Mass Balance and Sea-level contributions (ISMASS; http://www.antcrc.utas.edu.au/scar/ismass.html)
- Seismic Evolution of Antarctic Plate (SEAP; http://anquetil.colorado.edu/seap2003/)
- Age of Antarctica (AGEANT/IGCP)
- Antarctic Neotectonics group (ANTEC; http://www.antec.scar.org/)
- FASTDRILL (http://www.es.ucsc.edu/~tulaczyk/fastdrill.htm)
- SHALDRIL (http://www.arf.fsu.edu/arfhtml/arfpages/shaldril.html)
- ANDRILL (http://andrill-server.unl.edu/)

- International Ocean Drilling Program (IODP; http://www.iodp.org/)
- INTERNATIONAL COMMUNITIES (Australia, Britain, France, Germany, Italy, Japan, Russia)
- Scientific Committee on Antarctic Research (SCAR; http://www.scar.org/)

3. Obstacles to doing the work
   - Competition from "Big Science" (not ours)
   - Earmarking
   - Inadequate levels of available funding to support all Antarctic Geology and Geophysics initiatives
   - Lack of a clear means to coordinate between various Antarctic communities
   - Inadequate coordination between national programs for international collaboration
   - Management issues – how to manage the airborne geophysical data collection, reduction, dissemination and archiving
   - Difficulty of integrating data sets and investigators
   - Technologies – are they all there yet to meet goals?
   - Access to P3 or other long-range aircraft for community-based facility
   - Access to ice-penetrating radar instruments for community-based facility

DESIRED ELEMENTS AND MANAGEMENT MODEL FOR AIRBORNE GEOPHYSICAL DATA COLLECTION, REDUCTION, DISSEMINATION AND ARCHIVING

Platforms and Instruments

1. Long-range aircraft: (Next section taken from Brozena, this report). Due to the extended distances of areas of interest from McMurdo and heavy constraints on logistical support for deep-field camps in Antarctica, long-range aircraft are the most cost-effective means to conduct airborne geophysical surveys. Of the current likely options, the LC-130 or the P3, the P3 was identified as the optimum platform mainly due to heavy competition for use of LC-130 time in Antarctica. A P-3 can fly more than six times farther in a single flight than a research configured Twin-Otter (4500-6000 km depending on altitude and fuel reserve requirements). This range makes science targets deep into the Antarctic continent feasible from a McMurdo base (Fig. 6). Operation from McMurdo eliminates any requirement for LC-130 support and base-camp logistic personnel.

Given weather and ice-runway conditions, the optimum period for P-3 operations is mid-October to early December. The most effective use of the P-3 would be to schedule a 240 hour block of flight-time for a field season. Roughly 35-40 hours of transit (each way) are required to move the aircraft from the United States base to McMurdo and back. This would leave approximately 165 flight-hours of science operation from McMurdo. Flying 4-5 eight to nine hour flights per week would allow completion of 18 to 20 project flights from McMurdo in four weeks. Two additional weeks are reserved for weather or maintenance problems.

Two organizations with ties to the NSF Polar program operate P3 Orion aircraft, Navy Research Laboratory and NASA. In both cases, the most cost- and logistically- effective means to access the P3 is to develop science collaborations with personnel at these organizations. An additional partner could be the Russian Polar Research Marine Geophysical Expedition, which has successfully operated an Illyushin-38 aircraft similar to the P3 in the Arctic with a magnetometer, gravity meter and ice-penetrating radar system.

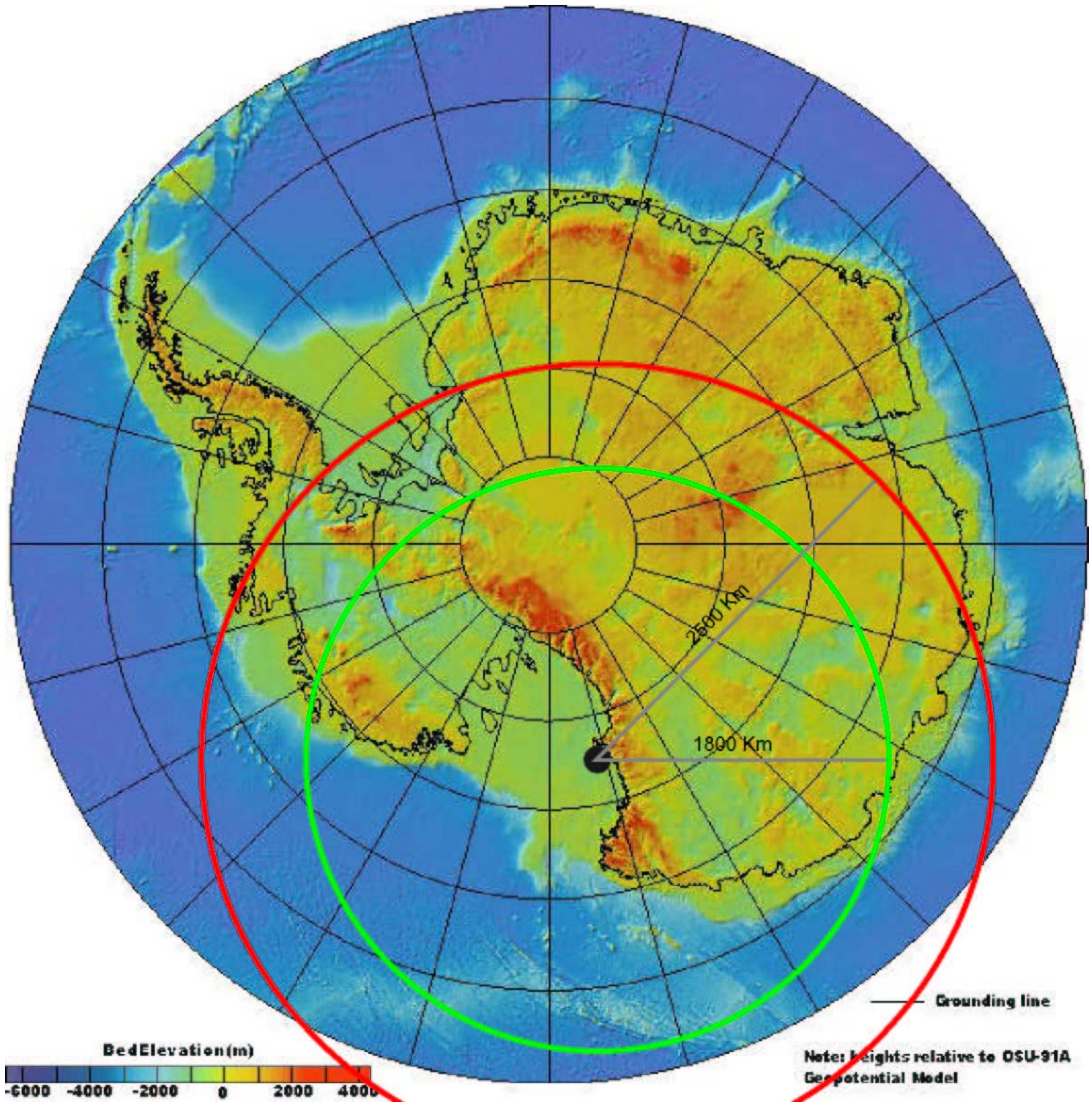

Figure 6 (from Brozena, this report) Red circle represents the maximum distance the P3 can operate from McMurdo; green circle represents a more conservative alternative.

2. Twin engine fixed wing aircraft. The U.S. Antarctic program successfully collected airborne gravity, magnetic, laser altimetry and ice-penetrating radar data over 9 seasons with a Twin Otter (Blankenship et al., this report). This same Twin Otter has been contracted by the Australian Antarctic program (C. Wilson, this report) to conduct gravity, magnetic and ice-penetrating radar measurements over the Prince Charles Mountains with a private company, FUGRO, responsible for the gravity and magnetic measurements and the BGR providing the radar

instruments, thus showing the continued utility of the platform. The BAS operates a similarly instrumented twin-engine platform, the Dash-7. Both the BGR and AWI operate twin-engine Dorniers for magnetic and radar surveys. These platforms would be useful for flying detailed surveys (< 5 km line spacing) within the regional surveys collected by the long-range aircraft.

3. Helicopter magnetic surveys. (This section taken from Damaske, this report). Helicopter-borne magnetic surveys are, in most cases, carried out during geological-geophysical expeditions where helicopters are widely used to transport scientists to their study area. The magnetic equipment is towed beneath the helicopter, can easily be installed in any type of helicopter and does not require significant modifications of the aircraft. Helicopter operations can be performed from virtually any base, whether the terrain is flat or rugged, in mountains or on the inland ice and even from a ship with just enough space to land a helicopter on. An advantage over fixed wing aircraft is the helicopter's superior performance to climb and descend over steep mountainsides when surveys require a constant ground clearance. One disadvantage is their limited range. Because of limited space and weight restrictions, surveys measuring simultaneous magnetic, gravity, and ice thickness data are, to date, impractical for helicopters.

Helicopter magnetic surveys over outcrop and adjacent areas with only a cover of thin ice, provide a good opportunity for international cooperation. The US Antarctic program and the BGR have cooperated on such surveys with ground gravity data collection (e.g. Damaske et al., 2002). The BGR paid for the time of the NSF contracted-helicopter, provided personnel and the magnetic equipment while NSF supported air and field logistical operations, personnel and the gravity survey.

4. Instruments/Operators: For the fixed-wing platform, airborne gravity, magnetic, laser and ice-penetrating radar instruments are desired. For helicopter-based operations, easily installed, plug-in, towed magnetometer systems are feasible. All operations require high-precision

positioning instruments, mainly GPS with pressure altimeters and standard inertial-navigation systems as well as data acquisition and reduction computers and personnel.

Airborne geophysical capabilities

Access to airborne geophysical capabilities can be provided in a variety of ways ranging from an in-house facility such as SOAR which housed or leased instruments that were mounted on a Twin Otter contracted by NSF, and supplied personnel to collect, process and archive the data to privately contracting out data collection and reduction. Comparison of assorted types of existing facilities led to a first-cut to determine the desired means to obtain airborne geophysical capabilities for Antarctic work (Table 1). Management and science collaboration of the facility were the most debated issues. In particular, an argument was made that the most cost-effective means to collect aerogeophysical data is by academic institutions and that the people running it need to be PhD scientists who require professional credit for their work via involvement in the interpretation of the data. Others argued that technicians and engineers who do not require scientific credit collect geoscience data (see UNOLS example) at many academic institutions and could therefore collect aerogeophysical data. In addition, industry involvement (as in the Lithoprobe seismic data collection described below) in data acquisition, reduction, dissemination and archiving can be cost-effective in some cases. To better resolve these issues, future detailed discussions by a small (undetermined) group to compare costs of various options and make recommendations on how to gain airborne geophysical capabilities in the most cost-effective manner with the least conflict of interest was recommended. The spread sheet below, based on group discussions, provides a starting point for future recommendations.

Table 1 Comparison of attributes of various facilities

Means	Platforms	Instruments	Survey Design	Data Acquisition	Data Reduction	Data Release	Data Archive	Ops Mgt	Science Oversight	Science Collab.	Funding Agency	Amount (actual $)
SOAR	no	grv., mag., radar, laser, GPS	help	yes	yes	yes	yes	site-based mngr.	no	no/yes	NSF	1 M
CASERTZ (NSF project)	no	grv, mag., radar, laser, GPS	yes	yes	yes	yes	yes	Pi-based	no	yes	NSF	
ICDS	no	drilling rig	no	yes	no	no	no	site-based mngr.	no	no	NSF	
WAISCORES	no	core looking	yes	yes	yes	yes	send to	science office	yes	yes	NSF	
ITASE	no	drilling rig	yes	yes	yes	yes	send to	site-based mngr.	no	yes	NSF	some
UNOLS	SHIPS	grv., mag., imaging	no	yes	yes	yes	send to	consortium of univ. reps. & NSF	no	no	NSF, ONR	100's M
IRIS/PASCAL	NA	seismometers	no	help	no	infrastructure, req.	yes	consortium	yes	no	NSF	5M
UNAVCO	NA	GPS	yes	help	yes	yes	yes	consortium	yes	no	NSF/NASA	2M
NRL/Weather radar	P3		no	no	no	no	no	NSF	no	no	NSF	1M
private industry	yes	grv., mag., laser, EM, etc. (no RADAR)	yes	yes	yes	no	no	pvt.	no	no	NA	
GVT-NICL (Nat. Ice Core Lab) (USGS)	no	fabric analyzer,	no	no	yes	yes	yes	site-based mngr.	yes	no	NSF	
Deep Submergence	yes	lots	no	yes	yes	no	yes	site-based mngr.	yes	no	NSF, NOAA, ONR	lots
Andrill		drill rig	yes	yes	no	yes	yes	consortium	yes	yes	5 Ant. Pgms.	1 M
Lithoprobe Seismic	no	no	no	contract	yes	yes	yes	Lithoprobe committee	yes	no	NSERC	1M
***Provider** (attributes of desired "facility")	not own, access	contract & partnership where possible, acquire what is needed	technical input	yes	yes	yes	yes	science team leader & operations mgnr.	yes	routine--no; developmental--yes	NSF + international coop optimal	

Detailed explanations of the desired attributes of the airborne geophysical capabilities provider as described in Table 1 follows:

Means: (Provider): supplier of airborne geophysical capabilities
Platform: The provider does not necessarily need to own airborne platforms; access can be through contracts, Memoranda of Understanding, etc.
Instrumentation: Inexpensive instruments such as magnetometers, and GPS receivers, for example, could be bought and managed by the science support contractor (now Raytheon). Science groups should have some occasional money to buy and acquire instrumentation needed. Other instruments, such as the gravity meter and ice-penetrating radar can be leased or obtained through a partnership perhaps driven by proposals or needs outlined in an overarching science plan.
Survey design: An oversight committee advises on survey design and other technical issues and coordinates with other science projects on appropriate survey design.
Data Acquisition: The provider sends personnel to collect and assure quality of the data to the field.
Data Reduction: The provider will reduce the data.
Data Release: The provider will release data according to a pre-arranged schedule
Data Archive: The provider will archive data in standard formats.
Operations Management: Science team leaders and operations managers oversee projects. A suggested management structure is outlined below.
Science Collaboration: Do data collectors work on the data? No, for routine data collection such as GPS, gravity, magnetic, laser, and proven ice-penetrating radar technologies; yes, for developmental instrumentation such as the coherent radar. However, all parts of the process need to be made explicit from the beginning.
Funding Agency: NSF and international cooperation. This could involve sharing logistical and operations costs, supplying platforms, instruments and personnel, etc.

Discussion on two end-member models (Fig. 7) that link the airborne geophysical facility with science projects was lively. In model A (Fig. 7a), a facility provides platforms, instruments, and acquisition personnel for competed science proposals. An example of this model is the University-National Oceanographic Laboratory System (UNOLS) (http://www.unols.org/), an organization of 64 academic institutions and National Laboratories involved in oceanographic research that either operate or use the U.S. academic research Fleet. They are joined for the purpose of coordinating oceanographic ships' schedules and research facilities. UNOLS is governed by an elective body, the UNOLS Council. The Council, which is composed of sea-going scientists, vessel operators and marine technicians, ensures that ship and equipment schedules are coordinated to make efficient use of finite resources. This coordination is governed by one simple reality - every dollar used to support ships is one less dollar for science. As most of the Council members are seagoing scientists, there is a strong incentive to maintain a cost efficient and highly effective operation. The benchmark for success of the Fleet is the success of the research projects conducted on board each ship.

In the favored model, B, the facility is directed by a community-based science plan (Fig. 7b). A facility operations management committee could work directly with the steering committee for the science plan, as in the Canadian Lithoprobe program (see below and www.geop.ubc.ca/Lithoprobe/). The providers are also linked to proposers and vice versa.

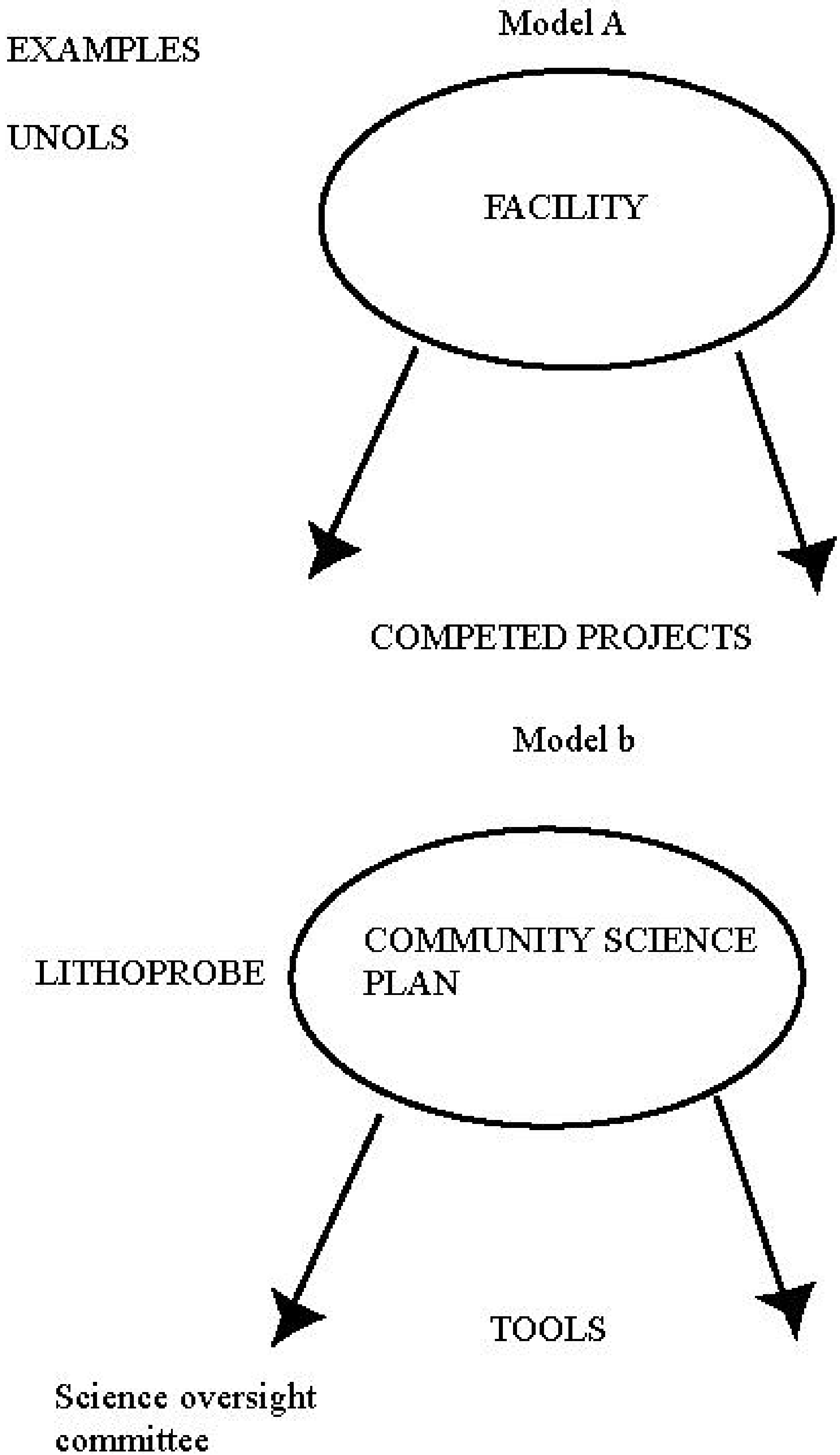

Figure 7 End-member models for integration of tools such as airborne geophysics with the community.

LINK BETWEEN FACILITY AND SCIENTIFIC JUSTIFICATIONS

Examples of science plans

Various types of science initiatives (WAIS, Lithoprobe, RIDGE, etc.) were discussed as examples of viable approaches for long-term (5-10 years) community based plans to address key scientific issues.

The West Antarctic Ice Sheet Initiative (WAIS), a multidisciplinary study of rapid climate change and future sea level, was a ~10-year science plan. The Antarctic glaciology group worked together to reach an agreement on regions to receive highest priority; for example, Ice streams C and D, Siple Dome, and currently, the Amundsen Sea Embayment. There is cooperation on use of materials such as ice cores that are stored in central facilities for use by many groups. At the same time, individual field programs receive support for more decentralized activities. The joint use of costly-to-obtain material such as ice cores potentially offers a direct analogy for aerogeophysical data. Science results and interdisciplinary discussions are held at annual workshops.

The Canadian LITHOPROBE project, funded by the National Science_Engineering Research Council of Canada (NSERC) and Geological Survey of Canada (GSC) with additional support from private industry, has been underway for 14 years and is entering its final funding cycle of 5 years (Clowes, this report). The annual budget is approximately $4M Canadian plus $2-2.5M from the GSC and further cash or in-kind contributions from industry. Objectives are: a) to obtain deep understanding of the geological elements of the continent, from which resources are derived and that control natural hazards; and b) to obtain regional background information useful to mining and petroleum industries. Interpretation of regional, multidisciplinary geological investigations supported by seismic imaging of crustal structure in ten transects over the ~20 years of LITHOPROBE, has involved almost all of the top geoscientists in Canada at one stage or another.

Geology, geochemistry and geochronology studies accompany the geophysical surveys. A training aspect is a crucial element of the program, with the intent to prepare graduate students and new researchers in multidisciplinary efforts that attain more comprehensive understanding of earth processes, crustal growth and geological resources.

The organizational structure involves an advisory component (scientific and disciplinary) with a steering committee and an operational component overseen by a secretariat. The advisory committee and a Board of Directors include representatives from universities, industry, and the geological survey. A central office exists at the University of British Columbia, and the ten transects have been supported by regional offices that operated during the time of scientific activity on each transect. The only physical manifestation of the program is the LITHOPROBE seismic processing facility (LPSF), situated at the University of Calgary; the seismic processing software provided by Lithoprobe resides in the regional offices. A general call for proposals has been used to identify new transects, with an annual grants competition for all NSERC-eligible university scientists. Data sharing and communication are achieved through annual transect workshops during the active phase of data collection, with funds provided to the transect coordinator. Research efforts are collaborative, with involvement of 32 universities, federal and provincial surveys, industry, and international collaborators.

The program overcame initial skepticism from the non-geophysics community by creating non-exclusive transect teams and ensuring that geologists and industry have a stake. It flourished by a proactive approach to demonstrate the value of the program to society and to the entire earth science community. LITHOPROBE overcame initial negativism from base-metal mining community through communication and data sharing; with focused efforts to identify components of research of direct applicability to mining exploration and development. The program worked to continually obtain new funds and did not allow the funds available to earth science research to diminish. Science ownership and authorship issues are usually resolved because the LITHOPROBE participants recognize the vast mutual benefit from interdisciplinary efforts that provide information about crustal structure, geochronological control, and geochemical evolution. The goal to obtain deep understanding of the geological infrastructure of the continent cannot be achieved without collaboration. In addition, data are released to the general community after a 2-year proprietary period during which they are interpreted by the primary investigators.

The RIDGE science program began in 1987 with a series of workshops that identified integrated study sites that could allow comprehensive studies of representative sea-floor spreading environments and ridge processes (Karson, this report). Exploration to survey poorly known and potentially important areas was acknowledged as a valid goal. First funding came in 1990, with an annual budget of ~$7M, with ~30% allotted to ship costs. University-National Oceanographic Laboratory System (UNOLS) coordinates the costly equipment (ships and multichannel seismic instruments, gravity meters, magnetometers, etc.), with expenses paid by NSF through agreements from the universities. Proposals are reviewed via normal NSF panels. In the RIDGE 2000 phase, a resounding theme has become planetary renewal and life in the deep oceans. The budget request to NSF for RIDGE 2000 is $30M/year. As for LITHOPROBE, interdisciplinary collaboration is through strong communication, outreach, and information exchange, achieved through workshops, institutes, and publications (glossy newsletters and workshop reports). As a result, a strong RIDGE culture and community has developed.

A common theme from RIDGE, LITHOPROBE, WAIS and ANDRILL is that the participating research groups convened to identify overriding scientific objectives then prioritized specific targets or sites for collaborative investigation. Each phase of investigation produced data to be available to all participants and at the same time allowed opportunities for individual funding and investigation. Proprietary periods where principal investigators have sole access to data are generally limited to about 2 years before data are publicly available.

Recommendation for a science plan involving NSF Antarctic Geology and Geophysics, Glaciology, Ocean and Climate, and Biology programs

The science targets (Fig. 5), general recommendations for tools required to address the key scientific issues, and more specific recommendations on desired access to one data type, airborne geophysical (Table 1), and a management structure (Fig. 8) form the starting points for a community based science plan. The overarching concepts for the science plan center on crustal evolution and lithospheric architecture of Antarctica as fundamental controls on tectonic evolution, paleoenvironments and landscape development and solid-earth processes as feedbacks and drivers for ice sheet dynamics and global environmental change. The next steps for generating a community based science plan include:

- Summarizing recommendations from the REVEAL workshop for presentation at future science meetings in 02-03 such as WAIS (September, 2002); FASDRILL workshop (October, 2002); Geological Society of America meeting (October, 2002), American Geophysical Union meeting (December, 2002), and the Seismic Exploration of the Antarctic Plate workshop (March, 2003).
- Refining and prioritizing science recommendations from REVEAL in this process.
- Convening a small group to evaluate the cost-effectiveness of various models for airborne geophysical capabilities.
- Designing drilling and seismic capacities for the science plan by future NSF OPP-funded workshops (WAIS, FASTDRILL and SEAP).
- Convening a steering committee of workshop organizers (e.g. ACE, ANDRILL, ANTEC, FASTDRILL, REVEAL, Marine Infrastructure, SEAP) and other selected members to write the strategic science plan with later community input. The science plan will include recommendations on scope, cost, time lines and management structure for a 10 year program.
- Determine logistical impediments to wheeled long-range operations.

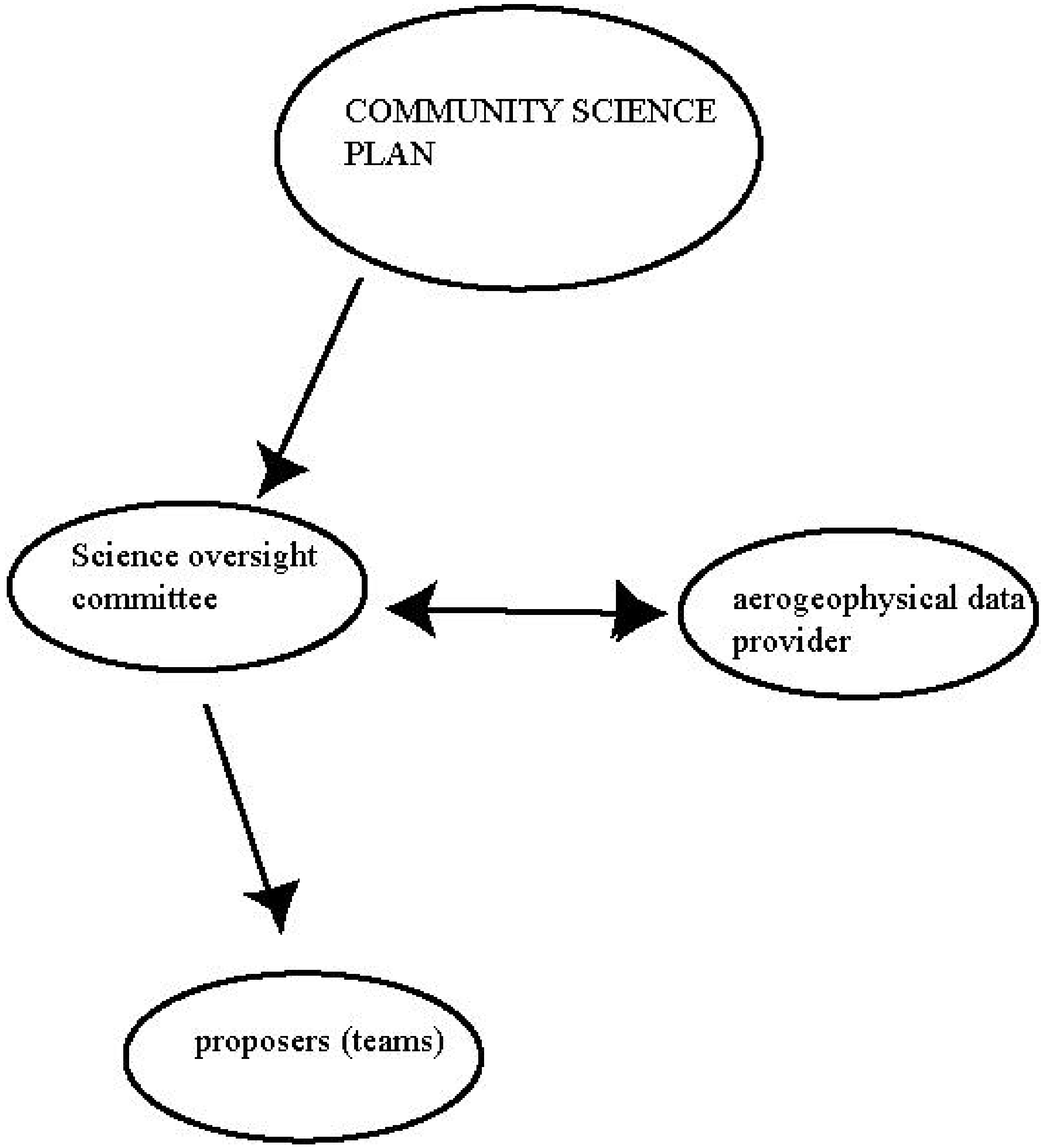

Figure 8. Proposed management structure for integration of airborne geophysical data providers and a community-based science plan

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APPENDIX I

Conference Convener

Carol Finn, U. S. Geological Survey

Conference Organizing Committee

Sridhar Anandakrishnan, Penn State University

John Goodge, University of Minnesota, Duluth

Kurt Panter, Bowling Green State University

Christine Siddoway, Colorado College

Terry Wilson, The Ohio State University

Conference Logistical Support

Victoria Rystrom, U. S. Geological Survey

Eric Anderson, U. S. Geological Survey

Appendix II

Workshop Agenda

Monday, August 5, 2002

Time	Activity or Session Name
5:00 pm	Arrival, registration, put up posters
6:00 pm	Welcome and Workshop Introduction: • REVEAL WORKSHOP Overview and Workshop Objectives — C. Finn 30 min • Current Initiatives/Previous science targets — T. Wilson 30 min
7:00 pm	Meal/Icebreaker
9:00 pm	Close

Tuesday, August 6, 2002

Time	Activity or Session Name
7:30 a.m. - 8:30 a.m.	Breakfast
8:30 am- 8:45 am	***1. The Known: Antarctic Geology and Geophysics*** a) Introduction, Summary of workshop themes, objectives and priorities (C. Finn)
8:45 am - 10:30 am	b) TALKS: Regional Geology (Known and Unknowns) (A. Grunow) • Exposed basement geology of the Transantarctic Mountains: What we think we know — J. Goodge 25 min • Major crustal provinces between the Grunehogna and Napier cratons (East Antarctica) and their aeromagnetic signature: where are the key areas for future research? — J. Jacobs 25 min • An update on the progress of Australian Geologic research in the southern Prince Charles Mountains, East Antarctica — Steve Boger 25 min. • Mesozoic-Cenozoic Geology of Antarctica: Progress and Unknowns — T. J. Wilson 25 min

	LIST POSTERS
10:30 am -11:00 am	Break and Poster Viewing Session • Goodge: Exposed basement geology of the Transantarctic Mountains: What we think we know • Panter: Potential contaminates of Late Cenozoic volcanism in South Victoria Land, Antarctica: a geochemical view of the deep crust • Stump: Byrd Glacier Discontinuity: First-order geological and physiographic feature • Wilson, T.: Exploration of Antarctic Lithosphere: Neotectonic Objectives • Studinger: Subice geology inland of the Transantarctic Mountains in light of new aerogeophysical data • Studinger: Geophysical Evidence for a Geologic Boundary within East Antarctica • Boger: An update on the progress of Australian Geologic research in the southern Prince Charles Mountains, East Antarctica • Wilson, C: The Prince Charles Mountains Expedition of Germany-Australia (PCMEGA) 2002-2003 • Kanao: "Structure and Evolution of the East Antarctic Lithosphere " Geoscience Program, - Outline and Scientific Significance • Jacobs: Major crustal provinces between the Grunehogna and Napier cratons (East Antarctica) and their aeromagnetic signature: where are the key areas for future research? • Steinhage: Aerogeophysics in Dronning Maud Land and the adjacent sea • Karner: The paradoxical gravity anomaly of the Ross Sea, Antarctica • Keller: Structure of the seafloor north of the Ross Sea, Antarctica • Cande: Cenozoic Reconstructions of the Australia-Antarctic-Pacific Plate Circuit: Implications for Motion Between East and West Antarctica • Bell : Defining Multiple Stages of Extension in Central

	West Antarctica • Behrendt: The use of aeromagnetic and radar ice sounding surveys over the West Antarctic Ice Sheet to study late Cenozoic volcanic centers at the base to the ice - a historical perspective • Mukasa: Marie Byrd Land, West Antarctica: evolution of Gondwanaland's Pacific margin constrained by zircon U-Pb geochronology • Siddoway: Structural analysis and geophysical investigations reveal extended crust on the eastern Ross Sea margin • Morse: An airborne geophysical survey of the Amundsen Sea Embayment, Antarctica
11:00 am-12:00 pm	DISCUSSION— large group (Moderator: T. Wilson; Recorder: B. Csatho) • Do we need to modify the current science targets? • Summarize ideas for dividing science targets into 3 groups. Decide grouping for afternoon break-out groups. • Solicit issues that need to be addressed in break-out groups (e.g. science objectives, why Antarctica is unique, major obstacles (technological and logistical) to collecting data/completing project, tools required, time table, etc.)
12:00 am-1:00 pm	LUNCH & CONTINUED POSTER VIEWING FROM AM
1:00 pm	c. TALKS: Remote Geologic Mapping: Resolving sub-ice geology (K.Panter) • Lake Vostok: An Opportunity to Study East Antarctica Interdisciplinary — Bell 25 min • The links between glaciology and lithospheric imaging in Antarctica — Anandakrishnan 25 min • Thermal Regimes and Architecture of the Crust and Upper Mantle Inferred from Electrical Conductivity Investigations— Wannamaker 25min
2:15 am -2:30 pm	BREAK

2:30 pm-3:20 PM	c) Talks continued • Antarctic drilling, coring, and logging: how and why? — Jarrard 25 min • Geophysical mapping of subsurface geology: From the local to the supercontinental — Finn 25 min
3:30 am -5:15 pm	BREAK-OUT GROUPS (composition based on morning discussion. Look at posters relevant to science targets) (Moderators: S. Anandakrishnan, C. Siddoway, K. Panter; Recorders: S. Mukasa, D. Wiens, S. Cande) • Discuss existing science targets • Discuss tools needed and time table for each area • Prioritize targets • Address issues raised in morning group discussion session
5:15am-5:30 pm	BREAK
5:30 pm-6:30 pm	e) DISCUSSION (large group) (Moderator: S. Anandakrishnan; Recorder: J. Brozena) • each break-out group summarizes discussions • all study areas are prioritized • time tables are linked
6:30 pm	CLOSE
7:30 pm	DINNER

Wednesday, August 7, 2002

Time	Activity or Session Name
7:30 a.m. - 8:30 a.m.	Breakfast
8:30 am - 10:00 am	***2. The Unknown: Modern tools and approaches for remotely exploring Antarctic Geology*** A) TALKS (M. Studinger) • Integrated geological and geophysical investigations of the oceanic crust–Analogs for Antarctic Investigations— Jeff Karson 30 min • Canada's LITHOPROBE project: Multidisciplinary transect studies of Precambrian regions — Ron Clowes 30 min

	• The scientific and technical evolution of Antarctic over-ice aerogeophysics using an instrumented Twin Otter—Don Blankenship 30 min LIST POSTERS
10:00 am-10:30 am	BREAK and POSTER VIEWING SESSION • Anandakrishnan: The links between glaciology and lithospheric imaging in Antarctica • Csatho: Investigation of Geologic Control on Ice Sheets Using Airborne Geophysics and Remote Sensing • Tikku: Lake Concordia: a second significant subglacial lake in East Antarctica? • Studinger: Ice flow, landscape setting, and geological framework of Lake Vostok, East Antarctica • Gohl: Geodynamics – ice-sheet dynamics interactions: Research plans for investigations of the Lambert Rift – Prydz Bay (East Antarctica) • Blankenship: The scientific and technical evolution of Antarctic over-ice aerogeophysics using an instrumented Twin Otter • Blankenship: Investigating the Crustal Elements of the Central Antarctic Plate (ICECAP): The Case for Long-range Aerogeophysics • Brozena: P-3 Orion aircraft for long-range aerogeophysical research in Antarctica. • Damaske: Helicopter-borne magnetic surveys in Antarctica • Grunow: Magnetic property information and the new Antarctic Rock Magnetic database: an overview • Krabill: Airborne Lidar Topographic Mapping of the Dry Valleys • Roest: Revealing Tectonic Domains: The Use of Large Scale Magnetic Anomaly Compilations • von Frese: Integrating airborne and new satellite magnetic and gravity observations for lithospheric investigations of the Antarctic. • von Frese: Aerogeophysical polar explorer (APEX) for

	bi-polar lithospheric investigations • Wannamaker: Thermal Regimes and Architecture of the Crust and Upper Mantle Inferred from Electrical Conductivity Investigations • Ritzwoller: Crustal and upper mantle structure beneath Antarctica and surrounding oceans • Wiens: The Transantarctic Mountains Seismic Experiment (TAMSEIS): Investigating the Lithospheric Structure of the East-West Antarctica Boundary • Xie: Lateral Variations in the Guided Wave Attenuation in the Eurasian Crust with Tectonic Implications • Elliot: Sub-ice drilling: regional geologic mapping and specific targets • Clow: The CTDI Rapid-Access Drilling System: An Exploration Tool for the Polar Sciences • Harwood: The ANDRILL Initiative: Stratigraphic Drilling for Climatic and Tectonic History in Antarctica
10:30 am-12:30 pm	c) Panel-led discussion on links between Airborne Geophysical Capabilities and Science Targets • Moderator D. Elliot; Recorder: C. Siddoway • Panelists--S. Anandakrishnan, D. Blankenship, J. Brozena, R. Clowes, J. Karson, C. Wilson • discuss models from other communities that link science plans with facilities • discuss current state of airborne geophysical platforms and instruments in Antarctica • discuss structure of break-out groups • determine requirements that need to be discussed in break-out groups on science oversight and airborne geophysical capabilities **Managed Scientific program examples:** • MARGINS http://doherty.ldgo.columbia.edu/margins/Home.html • RIDGE http://ridge.oce.orst.edu • LITHOPROBE http://www.geop.ubc.ca/Lithoprobe/ • WAIS (other glaciological links on this page as well)

	http://igloo.gsfc.nasa.gov/wais/ **Examples of NSF-funded facilities** • SOAR http://www.ig.utexas.edu/research/projects/soar/soar.htm • IRIS http://www.iris.edu/ • UNAVCO http://www.unavco.ucar.edu/ **Airborne geophysics-related links** • Fugro http://www.fugro.com • Geosoft http://www.geosoft.com • PRJ http://www.prj.com • PGW http://www.pgw.on.ca/ • FALCON http://falcon.bhpbilliton.com/ • Bell geospace http://www.bellgeo.com/ • Carson http://www.aerogravity.com/ • USGS geophysical products http://crustal.usgs.gov/crustal/geophysics/index.html
12:30 pm - 1:30pm	LUNCH + poster viewing
1:30 pm- 3:30 pm	d) BREAK-OUT GROUPS (Look at posters relevant to discussions) • Airborne geophysical facility type (platforms, instruments, data processing, release and archive capabilities, means to integrate new with existing data, etc.) and model (in-house data collection/reduction/archive; contract various aspects, etc.) Moderator: W. Roest, Recorder: D. Damaske • Science plan (how to link airborne geophysical facility with science targets; potential management models, etc.) (Moderator: J. Goodge; Recorder: M. Ritzwoller)
3:30 am -4:00 pm	BREAK
4:00 pm- 5:00 pm	d) BREAK-OUT GROUPS Continued--DRAFT STATEMENTS ON DESIRED AIRBORNE GEOPHYSICAL FACILITY AND MEANS TO CONNECT TO SCIENCE TARGETS
5:15 pm -6:15 pm	e) DISCUSSION Summary- Large group: (Moderator: R. Bell; Recorder: K. Gohl) • Each break-out group summarizes discussions.

	recommendations and outstanding issues • Decide whether to reconvene break-out groups or large group in morning
6:15 pm	CLOSE
7:30 pm	BANQUET — Tamayo Mexican Restaurant

Thursday, August 8, 2002

Time	Activity or Session Name
7:30a.m. - 9:00 am	Breakfast
9:00 a.m.-10:30 am	***3. INTEGRATION*** a) DISCUSSION AND DRAFT STATEMENT ON POSSIBLE PROJECTS AND RECOMMENDATIONS FOR AIRBORNE GEOPHYSICAL FACILITY AND SCIENCE MANAGEMENT STRUCTURE (large group or break-out groups as needed) (moderator: J. Goodge; recorder: A. Tikku) • Summary and discussion of desired science targets, priorities, time table (from working groups), whether to integrate into larger science plan • Summary and discussion of features of airborne geophysical facility (from working group) • Summary and discussion of desired elements (if any) of science oversight for the facility (from working group)
10:30 am -11:00 am	BREAK
11:00 am	b) DISCUSSION ON PROPOSAL STRATEGY (large group) (Moderator C. Finn; recorder M. Studinger) • How to integrate with drilling, marine, seismic infrastructure, WAIS and other workshops? • Final science targets + strategy for writing proposals • Final airborne geophysical facility recommendations • Final science oversight format recommendations • Next steps (who coordinates document/proposal writing for science + facility + management + interface with other communities??)

12:30 pm	END

Appendix III

Abstracts- Alphabetical by author

The links between glaciology and lithospheric imaging in Antarctica

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New geophysical methods are continually being refined to better understand the links between the ice sheet and the lithosphere. In addition to the powerful potential field methods, electrical and seismic techniques, and radar sounding, newer technologies like GPS, interferometric SAR, satellite altimetry and gravity are improving our understanding of the Antarctic cryosphere.

The ice sheets of Antarctica represent both an opportunity and a problem for the continued study of the lithosphere. The problem is easy to identify: the blanketing of the continent in ice interposes a kilometers-thick layer that is difficult to pierce for sample retrieval and analysis. In addition, the ice sheet imposes different challenges for geophysical imaging of the lithosphere than are faced in other parts of the planet. Potential field methods lose resolution with greater distance between source and sensor. Heat flux measurements are difficult to make and are affected by the flow of the ice and the history of accumulation and air temperature. Electrical methods must account for the dielectric and resistivity properties of the ice and the thickness of the ice sheet. Seismic methods require new tools to collect and analyze data in the presence of the large acoustic impedance contrast between ice and rock.

That said, the opportunities are also great. The ice sheets contain a detailed record of ice/air/rock interactions and climate history. The high-resolution layering chronology allied to possibly long time-scales that the ice sheet has existed provide some of the best paleoclimate data anywhere. The isotopic composition of the ice and of the air trapped in bubbles provides some of the best such data. In addition, analysis of ash layers, entrained debris, and basal accreted ice all provide insights into the physical interactions of ice and lithosphere. Englacial layer warping can provide information about regions of enhanced heat flow. Combining the ice-sheet research with the lithospheric goals is the best way to advance both fields.

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The use of aeromagnetic and radar ice sounding surveys over the West Antarctic Ice Sheet to study late Cenozoic volcanic centers at the base to the ice - a historical perspective

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The West Antarctic Ice Sheet (WAIS) flows through the volcanically active, late Cenozoic West Antarctic rift system. Active subglacial volcanism and a vast (>1 million cubic kilometers) extent of subglacial volcanic structures have been interpreted from aerogeophysical surveys over central West Antarctica in the past decade using Twin Otter aircraft in the CASERTZ and SOAR programs. These results were combined with results over the WAIS from 1958-1964 aeromagnetic profiles acquired using U.S. Navy R4D8s and P2Vs and 1978-79 combined aeromagnetic and radar ice thickness profiles collected using a U.S. Navy geophysical LC130 (which later crashed in Antarctica with a loss of six people).

Edward Thiel of Univ. of Wisconsin Madison collected the first aeromagnetic profiles over the WAIS in 1958; he was killed along with four others in a P2V magnetic survey aircraft at Wilkes Station in 1961. Behrendt, J.C., and Wold, R.J.,(1963) reported the approximate extent of an interpreted subglacial volcanic province beneath the WAIS based on 14,000 km of aeromagnetic profiles they acquired in 1960-61. Behrendt, (1964), extended this interpretation based on an additional 40,000 km of aeromagnetic profiles collected by Per Gjelsvik and Richard Wanous (University of Wisconsin undergraduate electrical engineering students) in 1963-64 over the WAIS and Transantarctic Mountains. In 1978-79 a cooperative study by Scott Polar Research Inst. (David Drewry) and USGS (Behrendt et al., 1980; Jankowski et al., 1983) reported on the first combined aeromagnetic and radar ice sounding surveys in Antarctica working with technical support from Applied Physics Laboratory, Johns Hopkins Univ. and Technical Univ. of Denmark. These results allowed still better definition of the volcanic province based on 50- and 100-km spaced surveys over West Antarctica.

From December 1991 to January 1997 we acquired an orthogonal gridded aeromagnetic survey at a 5-km line spacing (Blankenship et al. 1993, 2000, Behrendt et al. 1994) over central West Antarctica combined with radar ice sounding, aerogravity and laser surface altimeter measurements. This survey allows a significantly improved quantitative interpretation of the volcanic province beneath the WAIS.

Modeling of magnetic anomalies constrained by radar ice sounding shows volcanic sources at the base of the ice throughout large areas, whose subglacially erupted hyaloclastite edifices have been eroded by moving ice, as in Iceland. The 1800 m-high divide of the WAIS is underlain by the 400 km-long volcanic Sinuous Ridge, which rises above sea level; most hyaloclastite edifices there have also been glacially removed, indicating migration of the ice divide through time. Northeast of the divide of the WAIS there is a 400-nT positive magnetic anomaly over the shallowest, most rugged bedrock topography (elevation +380 m, above sea level), probably comprising subaerially erupted flows erupted when the Sinuous Ridge area was deglaciated. Uplift of the Sinuous Ridge may have forced the advance of the WAIS.

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Defining Multiple Stages of Extension in Central West Antarctica

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Detailed gravity and magnetic data over central West Antarctica provide an insight to its tectonic history [Bell et al, 2002]. Werner deconvolution solutions of the aeromagnetic data were used to estimate the depth to magnetic basement and the sediment thickness in the basins while the Bouguer anomalies were used to define the infilling history and thus age of the basins. We are able to use the Bouguer anomalies to distinguish large Mesozoic basins with positive gravity anomalies similar to the major Ross Sea basins from more recent basins with negative anomalies. The Interior Ross Embayment contains three distinct groups of sedimentary basins. One group of basins, ~100 km long and parallel to the southern Transantarctic Mountains and the Whitmore Mountains, is characterized by 30 km wide gravity lows and sediment thicknesses of ~5 km. These basins have no simple equivalent in the Ross Sea. The second set of basins comprises the Bentley Subglacial Trench and a basin north of Siple Dome, are 100 km wide and up to 200 km long, and oriented NW/SE. These wide basins are associated with Bouguer gravity highs, contain a minimum of 5 km sediment as indicated by the depth to the magnetic basement and are similar to the major basins in the Ross Sea. Adjacent to these basins are features with Bouguer lows and magnetically shallow basement. The third group of sedimentary basins are oriented NNW/SSE, are associated with Bouguer lows and deep magnetic basement. These basins include the elongate Trunk D Basin, the seismically mapped Onset Basin and several small basins west of Byrd Station. No evidence of these structures exists east of Byrd Station.

We have linked these three groups of basins to the three periods of West Antarctic extension. We suggest that those basins parallel to the mountains formed during the Jurassic. The larger basins, including the Bentley Subglacial Basin and the Siple Dome Basin, show positive Bouguer gravity anomalies and probably resulted from the Late Cretaceous extension event that also produced the Victoria Land Basin, the Central Trough and the Eastern Basin as well as the basins on the Campbell Plateau. Cenozoic reactivation produced the elongate Siple Dome Basin, the Onset Basin and the minor faulting in the western Ross Sea.

Lake Vostok: An Opportunity to Study East Antarctica Interdisciplinary

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Lake Vostok, located beneath the 4-kilometer-thick East Antarctic ice sheet, is approximately the size of Lake Ontario with depths up to 1000m. Lake Vostok is a major unexplored system that may contain unique reservoirs of genetic material and organisms with novel adaptations. Clearly defined by a combination of seismic data and satellite altimetry in the late 1990's the first large-scale systematic aerogeophysical study of the lake was conducted in 2000-2001, supported by the U.S. National Science Foundation. The aerogeophysical study included both a focused high-density survey grid and long lines extending 100's of kilometers away from the Lake to constrain the large-scale setting. This survey design combined with key ground based observations including GPS ice velocities and broadband seismic stations has produce tremendous insights into Lake Vostok and East Antarctica.

The lake and the overlying ice sheet are closely linked as the ice sheet thickness drives the lake circulation while melting and freezing at the ice sheet base will control the flux of water, biota and sediment through the lake. Early studies of the lake suggested that large amounts of melting occurs along the eastern shoreline. We use ice-penetrating radar data and GPS positioning techniques to reconstruct the ice flow trajectory for the Vostok core site which differs significantly from the InSAR derived velocity field. We find the ice sheet has a significant along-lake flow component, persistent since the Last Glacial Maximum. Accretion rates are greatest at the shorelines and the accreted ice layer is transported out of the lake. The accreted ice is clearly imaged in the ice penetrating radar data and can been seen at the base of the ice sheet to the east, downflow, from the lake. Export of accreted lake water along the southern shoreline indicates a lake water residence time of 13,300 years.

A number of scenarios have been advanced for the tectonic origin of Lake Vostok ranging from a continental rift to a glacially carved valley. The vast discrepancy in the origins for Lake Vostok reflects our poor understanding of East Antarctic geology. The regional gravity data is dominated by a major step that cannot be attributed to a crustal boundary. The gravity field is best modeled by an overthrust former continental margin and a recent reactivation. The crustal structure recovered from receiver function analysis close to the lake and the presence of minor seismic activity near the lake supports this scenario.

The scientific and technical evolution of Antarctic over-ice aerogeophysics using an instrumented Twin Otter.

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The University of Texas Institute for Geophysics (UTIG) and the U.S. Geological Survey (USGS) first proposed to develop a multi-instrumented Twin Otter aerogeophysical platform in 1989 as part of a project entitled "Corridor Aerogeophysics of the Southeastern Ross Transect Zone" (CASERTZ). This project ultimately succeeded in integrating, for the first time, ice-penetrating radar, laser altimetry, gravity and magnetics for simultaneous operation aboard a survey aircraft.

The CASERTZ project came about in response to a call for a new effort in Antarctic aerogeophysics that was part of a plan generated by both the international and the US Antarctic Research communities for a program to study the structure and evolution of the Antarctic lithosphere (see Dalziel and Zimmerman, EOS, 20(17), 1989). The CASERTZ scientific objective was to understand the lithospheric framework across the West Antarctic rift system in order to determine the geological controls on the dynamics of the West Antarctic ice sheet, the last marine ice sheet. These experiments included a suite of aerogeophysical measurements made within carefully chosen corridors. These corridors covered the eastern portion of the Interior Ross Embayment and encompassed: 1) the initiation zone and catchment regions of ice streams B and C and all of ice stream D from the ice divide to the grounding line (Figure 1, IRE, BSB, and TKD, respectively); and 2) the boundary between the broadly extended portion of the West Antarctic rift system within the Interior Ross Embayment and the crustal provinces dominated by the Whitmore Mountains and the Byrd Subglacial Basin (Figure 1 marked IRE and BSB, respectively). The experimental objective was to characterize and correlate the distribution of sedimentary basins, volcanic rocks and important ice dynamical boundaries within these corridors.

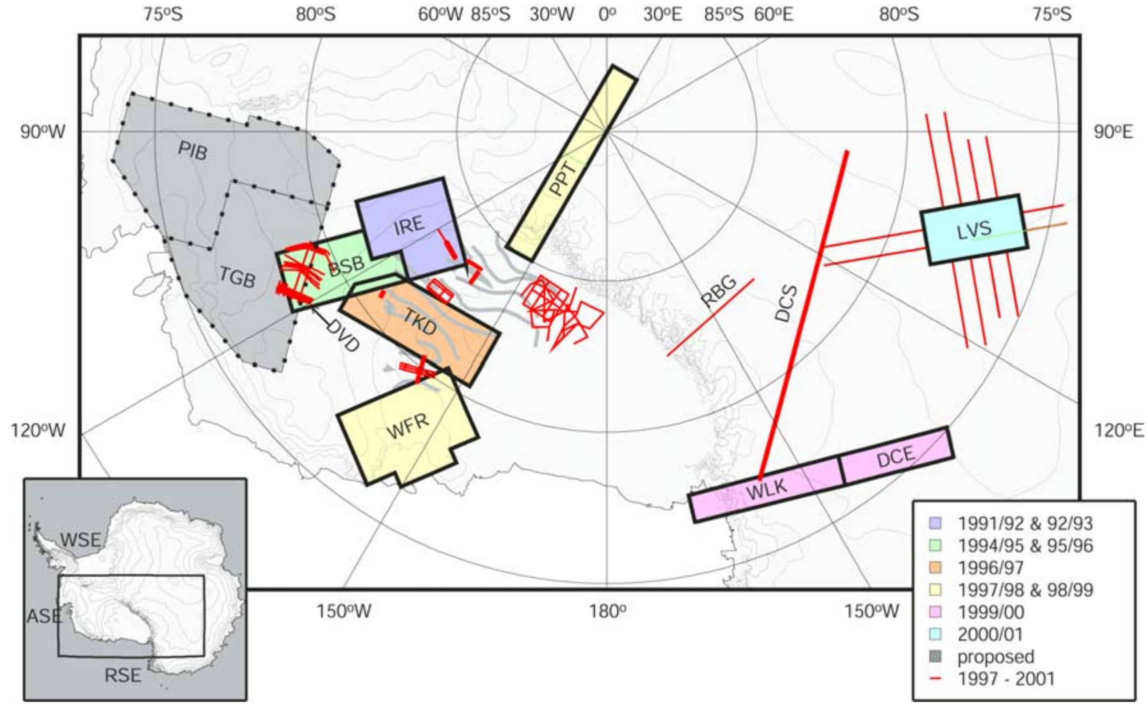

Figure 1: Coverage map of UTIG aerogeophysical surveys beginning with the CASERTZ projects (IRE, BSB and TKD) and continuing through the most recent subglacial Lake Vostok survey (LVS). Colored regions were flown with regular grids, individual flight tracks are shown (in red) for line-oriented surveys. The gray, dash-bordered regions (PIB and TGB) are proposed for the AGASEA project described by Morse et al, this conference.

To achieve its objective, CASERTZ required a system capable of simultaneously measuring the precise surface elevation and ice thickness needed for ice sheet studies, as well as the potential field observations necessary for inferring subglacial geology. UTIG, as lead institution for CASERTZ, benefited substantially from the expertise of its collaborating institutions, which included the USGS as well as the Naval Research Laboratory and Lamont Doherty Earth Observatory (NRL/LDEO). Initially, the CASERTZ instrumentation focus was only ice-penetrating radar, laser altimetry and magnetics in collaboration with the USGS but ultimately, with the assistance of NRL/LDEO, UTIG successfully developed an integrated aerogeophysical platform that included airborne gravity with carrier-phase GPS to support kinematic differential positioning. UTIG also developed flight structures for these instruments including an antenna system for radar sounding, access ports for laser altimetry, a towed magnetometer system and flight-certified equipment racking systems that placed the gravimeter near the aircraft's center of gravity. In parallel with the instrument integration, we also designed and implemented a comprehensive data management system to tightly couple time/position with the integrated aerogeophysical observations. During its initial two field seasons in West Antarctica, UTIG, with the assistance of the USGS and NRL/LDEO, used this system to collect 50,000 line km of geophysical observations within the region shown as IRE in Figure 1 (Blankenship et al., Nature, 361(6412), 1993; Brozena et al., Ant. J., 20(5), 1993; Behrendt et al., Geology, 22(p.527-530), 1994).

In 1994, in response to the science proposal to complete the CASERTZ corridors, the National Science Foundation's Office of Polar Programs requested that the aircraft and its integrated instrumentation package be operated as a facility with a mission of providing aerogeophysical observations to the broader Antarctic science community. This request led to a Cooperative Agreement between UTIG and NSF that created the Support Office for Aerogeophysical Research (SOAR). This six-year agreement defined UTIG's responsibilities as:

assisting in the development of aerogeophysical research projects with NSF/OPP investigators; upgrading the CASERTZ instrumentation package to accommodate new science projects and advances in technology; fielding this instrument package to accomplish SOAR developed projects; and the distribution of the acquired aerogeophysical data as spatially organized transects within six months of its return from the field. An option was included for SOAR to reduce and analyze the aerogeophysical data that it collected for members of the scientific community without that capacity.

Beginning in 1994, UTIG conducted aerogeophysical surveys in seven consecutive Antarctic field seasons. These SOAR developed surveys were performed for the 20 investigators and 14 institutions listed in Table 1. The first six of these seasons were managed under the NSF/UTIG Cooperative Agreement with D. Blankenship as PI; the last, 2000/2001, was managed as a multi-investigator grant to UTIG with D. Blankenship, J. Holt, D. Morse and I. Dalziel as co PI's. To accomplish these surveys, UTIG configured the integrated instrumentation package and installed it in the aircraft on site in Antarctica each season; additionally, base camp operations were established at up to five remote sites each field season. In total, UTIG conducted an additional 225,000 line kilometers of aerogeophysical surveys in 422 flights covering the areas shown in Figure 1. The spatially organized database of geophysical transects was delivered to the various investigators within the targeted six-month time frame.

For the last four field seasons, UTIG was also responsible for the reduction of the aerogeophysical data that it collected in Antarctica for SOAR developed projects. The final results delivered to investigators included profiles and maps of the ice-sheet surface and subglacial bedrock elevation (from ice-sheet thickness); in addition, maps of the distribution of free-air gravity and magnetic anomalies were produced (through the 1999/2000 field season) under subcontract to the LDEO and USGS, respectively. Each field season, UTIG collected about 250 Gbytes of geophysical and positioning data from the aircraft and base-station systems. Approximately 95% of this data volume was generated by the radar sounder with GPS positioning, avionics (primarily inertial navigation parameters and aircraft attitude), magnetometer, laser altimeter and gravimeter data streams contributing successively less data to the total. The large volume of data generated by these surveys necessitated the development of a uniform (and economical) reduction path with special accommodations for the labor-intensive interpretation of the radar sounding data. Based on our most recent experience, when data analysis was centralized at UTIG, a season's worth of such data could be reduced for the essential surface and bed elevation (or ice thickness) as well as the distribution of gravity and magnetic anomalies within about seven months of its return from the field.

Based on the scientific and technical evolution of the CASERTZ/SOAR projects at UTIG, we will present a summary and synthesis of "lessons learned" that are relevant to the scientific development and management of future aerogeophysical studies operating from remote sites in both East and West Antarctica.

Project Title (TLA)	Institutions (Investigators)	Seasons (flights)
CASERTZ and CASERTZ/ALICE (IRE)	U. Texas (Blankenship), USGS(Hodge), USGS (Behrendt), NRL (Brozena), and Columbia U. (Bell)	91/92 & 92/93 (93)
CASERTZ/WAIS (BSB and TKD)	U. Texas (Blankenship), Columbia U. (Bell) and USGS (Finn and Behrendt)	94/95 (32), 95/96 (88), 96/97 (58)
Ice Stream D Radar ** coincident with CASERTZ/WAIS-TKD*	U. Wisconsin (Bentley)	95/96 (38), 96/97 (58)
West Antarctic Glaciology V (WAG)	NASA (Bindschadler)	97/98 (15), 98/99 (1), 99/00 (1)
Laser Altimetry for Ice-Sheet Volume-Balance	Ohio State U. (Whillans and Csatho)	97/98 (12),

		99/00 (13)
Stress Transmission at Ice-Stream Shear Margins	Ohio State U. (Whillans and van der Veen)	97/98 (2), 99/00 (1)
Contrasting Architecture and Dynamics of the Transantarctic Mountains (TAM - PPT, RBG, WLK)	Columbia U.(Bell and Buck) and U. Texas (Blankenship)	97/98 (4), 98/99 (31), 99/00 (40)
Air-Ground Study of Tectonics at the Boundary Between the Eastern Ross Embayment and Western Marie Byrd Land, Antarctica (WFR)	UC Santa Barbara (Luyendyk) and Colorado College (Siddoway)	97/98 (4), 98/99 (64)
WAIS Ice Divide Migration (DVD)	U. Washington (Waddington) and U. Texas (Morse and Blankenship)	99/00 (11)
Understanding the Boundary Conditions of the Lake Vostok Environment: A Site Survey for Future Studies (LVS)	Columbia U. (Bell and Studinger)	2000/01 (36)
A Broadband Seismic Investigation of Deep Continental Structure Across the East-West Antarctic Boundary (DCS)	Washington U. (Weins), Penn State (Nyblade) and U. Alabama (Andakrishnan)	2000/01 (10)

Table 1. Summary of UTIG aerogeophysical investigations in Antarctica. Three-letter acronyms given after project titles correspond to labels in Figure 1.

Investigating the Crustal Elements of the Central Antarctic Plate (ICECAP): The Case for Long-range Aerogeophysics

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The East Antarctic ice sheet (EAIS), which dominates the Antarctic Plate, is the largest and least ephemeral of Earth's ice sheets. It contains ice equivalent to a global sea level rise of ~70 meters. It has been established in recent years that the bedrock of an ice sheet plays a major role in controlling its behavior. However, the inaccessibility of the central Antarctic Plate has permitted only reconnaissance geophysical studies, generally comprised of widely spaced airborne radar sounding profiles, except in a few limited areas. Hence very little is known about the bedrock geology as the region is less than 1% ice-free and the exposed rocks are almost entirely coastal. A convergence of research activity, however, has focused attention on this least known of the Precambrian shield areas of the globe.

The highlands of the central Antarctic Plate have been the nursery for East Antarctic ice sheets at least since the early Oligocene separation of Antarctica and Australia. Over the last decade, great strides have been made in compiling a marine geological, geophysical and geochemical record of the deposits left by these ice sheets. In addition, enormous resources have been invested in extracting a Pleistocene paleoclimate record from the central reaches of the contemporary East Antarctic ice sheet. Most recently the scientific community has realized the importance of the isolated biome represented by the subglacial lakes that characterize the domes of the central East Antarctic ice sheet and evolve in concert with them. The impact of these research efforts and discoveries have been to spur major international research initiatives to study the evolution of the East Antarctic ice sheet and its subglacial environment.

Critical to understanding these offshore and ice core records as well as the distribution/isolation of any subglacial lake systems is developing a comprehensive understanding of the crustal elements of the central Antarctic Plate which supported the nucleation of the contemporary East Antarctic ice sheet as well as its predecessors throughout the Cenozoic. A complete understanding of the evolution of these East Antarctic ice sheets of course requires knowledge of the boundaries, elevation and paleolatitude of these crustal elements through time as well as evidence of their morphological, sedimentological and tectono-thermal history. The basic impediments to gaining this understanding are the subcontinental scale of the central Antarctic Plate and the one to four kilometers of ice cover that inhibits direct access. It is possible however to provide a substantial framework for understanding these crustal elements through a comprehensive program of long-range airborne geophysical observations. Measurements required to characterize this crust in the context of both contemporary and paleo-ice-sheet evolution include:

1.) Distribution of gravity and magnetic anomalies to characterize subglacial lithology (e.g., sediments, crystalline basement and volcanics), identify crustal boundaries and estimate lithospheric flexure through potential field modeling.

2.) Absolute bedrock elevation (from ice sheet surface elevation and thickness) to provide a necessary boundary condition at a scale suitable for models of both contemporary and paleo-ice-sheet (or lake) evolution as well as for potential fields modeling.

3.) Detailed subglacial morphology and physical character of the ice-rock interface to identify any "preserved" glacial geomorphology and map fault scarps indicative of Cenozoic (or older) tectonic processes as well as to determine the location, properties and connectivity of subglacial sedimentary units (and lakes).

4.) Contemporary basal melt distribution (from ice sheet layering) to estimate the current distribution of geothermal flux for indications of tectono-thermal history and as a necessary boundary condition for models of ice sheet (and lake) evolution.

We will review the techniques required to obtain these measurements and present a compatible plan for a program of long-range aerogeophysics, including gravity, magnetics, ice-penetrating radar data and laser/radar altimetry, over the crustal elements of the central Antarctic Plate that comprise the subglacial highlands beneath Domes A and C of the contemporary East Antarctic ice sheet.

An update on the progress of Australian Geologic research in the southern Prince Charles Mountains, East Antarctica

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The southern Prince Charles Mountains is one of the last unstudied regions of exposed bedrock in east Antarctica. Prior to 1998-99, the region had been the visited by infrequent Australian and Russian expeditions during the 1960’s, 1970's and 1980’s. These studies were of a reconnaissance nature and provided valuable data regarding the distribution of the various rock types, their metamorphic grade and geochemistry. However, these studies did not provide useful constraints on the orogenic history of this region or how this might relate to the cycle of supercontinent formation in the Late Proterozoic, which East Antarctica has been shown to be an important component. Australian Geoscientists revisited this region over the summer of 1998-99 and began a program of more detailed investigation that included structural mapping, thermodynamic modeling and U-Pb SHRIMP geochronology. These data point to the existence of two distinct geologic terranes. Each preserve a convergent deformational history coupled with significant decompression. However, 2.2 Ga separates the formation of each, the northern terrane (lambert Province) was deformed during the Cambrian and the southern (Ruker Province) during Archaean. The Cambrian terrane preserves identical ages and a similar metamorphic evolution to rocks recognized along the coast at Prydz Bay. Together these regions define a laterally continuous belt of late Cambrian (~550-500 Ma) metamorphics that stretch from the Antarctic coast at least 700 km inland to the southern Prince Charles Mountains. This orogenic belt separates the Proterozoic metamorphics recognized in the Rayner Complex, from Archaean rocks in the southern Prince Charles Mountains and the Vestfold Hills. Given the abrupt change in the age of the rocks across this boundary, it is interpreted to represent a suture. If this scenario is correct, it suggests that a large section of east Antarctica and India that did not form part of east Gondwana, or Rodinia, as they are currently reconstructed. This has implications for the construction of both supercontinents.

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P-3 Orion aircraft for long-range aerogeophysical research in Antarctica

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There is a long-standing need for a long-range Antarctic research aircraft. We have been investigating the feasibility of operating wheeled P-3 Orion aircraft from the sea-ice runway at McMurdo station. Recently the NRL flight support group determined that such operations are safe and practical, based on information and meetings with NSF and Air National Guard personnel. Although presently limited to operations within approximately 2000 km of McMurdo, a P-3 could support major science objectives over a significant portion of the continent.

Although the recent small aircraft aerogeophysical programs in Antarctica have been extremely productive, the logistic costs and difficulty associated with establishing base camps and fuel dumps, and the relatively slow speeds and short range of Twin-Otter class aircraft preclude their use for many research problems in Antarctica. A long-range airborne alternative is imperative for many studies. The NSF sponsored C-130 flights of magnetometers and TUD RES system in previous decades demonstrated the utility of this approach. A long-range aircraft with a modern measurement suite including airborne gravity, magnetics, ice topography and RES instrumentation, could provide the most cost-effective method of answering questions of crustal structure and evolution of key parts of the Antarctic continent. Examples of recent long-range aerogeophysical measurement programs include: airborne gravity and magnetic surveys aboard NRL P-3 Orion aircraft, including very large surveys over Greenland and the Arctic Ocean basins; ice topography and RES measurements over Greenland by NASA; and Arctic and Antarctic aerogeophysical measurements from the Russian IL-18.

Ideally, a long-range aircraft would be ski capable like the LC-130. This allows routine operation from snow runways or even from unprepared sites at a cost in increased drag and reduced payload. Unfortunately, LC-130 aircraft are in extremely short supply and must be used to support Antarctic logistics. It is also quite expensive to modify a C-130 airframe for RES antennas, a magnetometer or any down-looking instrumentation. Another possibility is the Basler modified DC-3. However, this aircraft is intermediate in range and payload between the Otter and LC-130, and does not have a track record for installation and operation of science equipment for geophysical surveys, making it difficult to determine the costs and availability of the aircraft for the necessary extensive modifications. Cruise speed is also quite low, limiting the size of surveys.

The use of long-range wheeled aircraft has also been extensively discussed. Russia has considerable Antarctic experience with the IL-18, a large four-engine turboprop similar to the P-3. This includes several flights from the sea-ice runway at McMurdo during the 1990-1991 field season. NRL has been investigating the possibility of basing a research modified P-3 Orion aircraft from this runway for several years. A P-3 can fly more than six times farther in a single flight than a research configured Twin-Otter (4500-6000 km depending on altitude and fuel reserve requirements). This range makes science targets deep into the Antarctic continent feasible from a McMurdo base. Operation from McMurdo provides significant logistic and cost advantages since there is no need to establish a base camp and fuel cache. This eliminates any requirement for C-130 support and base-camp logistic personnel. Survey fuel would come from the ship-delivered supply at McMurdo, rather than airlifted at great cost by a C-130.

In addition to long-range capabilities, the P-3 is an excellent science platform. They were specifically designed as an aeromagnetics platform for anti-submarine warfare with non-magnetic extended tail cones for the magnetometer. The NRL aircraft have been modified for cargo interiors for easy installation of science equipment and a specially modified bomb-bay compartment for installation of down-looking sensors and antennas. In this configuration the P-3 has a scientific payload of more than 3000 kg and can carry up to 8 scientists in addition to the flight crew. We have done a preliminary design analysis for the addition of RES antennas mounted fore-and-aft below the bomb-bay. This method permits installation of a coherent array of four to six antenna sections for beam-forming. Structural requirements for antennas on an aircraft that cruises at indicated airspeed of 450 km/hr in icing conditions are stringent. However, the fore-aft bomb-bay mounting would be considerably easier and less expensive than the wing-mounted antennas used on the C-130 or the NASA P-3.

Last year NRL management agreed to determine the feasibility of deploying a P-3 to McMurdo. Meetings were held with NSF, personnel from the former Navy VXE-6 squadron, the Air Guard 109th Airlift Wing and SPAWARS Antarctic weather specialists. Most recently, the OIC of the NRL Flight Support detachment traveled to Christchurch to meet on-site with the 109th deployed group. Based on this information our Chief Staff Officer has determined that we can operate the P-3 safely from McMurdo, and is willing to provide aircraft services for this purpose.

Analysis of historical weather data and previous discussions with VXE-6, 109th and science personnel involved with airborne operations at McMurdo indicate that the P-3 should arrive at the sea-ice runway by October 15 and depart by the first week of December. The most effective use of the P-3 would be to schedule a 240 hour block of flight-time for a field season. Roughly 35-40 hours of transit (each way) are required to move the aircraft from the United States base to McMurdo and back. This would leave approximately 165 flight-hours of science operation from McMurdo. Flying 4-5 eight to nine hour flights per week would allow completion of 18 to 20 project flights from McMurdo in four weeks. Two additional weeks are reserved for weather or maintenance problems. Emergency runways in case of poor landing conditions at the sea-ice runway would be Pegasus and the new sea-ice runway being established near McMurdo.

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Cenozoic Reconstructions of the Australia-Antarctic-Pacific Plate Circuit: Implications for Motion Between East and West Antarctica

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Reconstructions of the Australia-Antarctic-Pacific plate circuit constrain at least one and perhaps two episodes of Cenozoic separation between East and West Antarctica. The younger episode of separation occurred between chrons 20 and 8 (43 to 25 Ma) and is constrained both by the systematic misfit of magnetic anomalies east of the Balleny Fracture Zone relative to the rest of the Southeast India Ridge, and by the presence of a set of linear magnetic anomalies straddling the Adare trough, northeast of Cape Adare (Cande et al., 2000). This episode of separation resulted in roughly 175 km of extension in the western Ross Sea Embayment. An earlier stage of Cenozoic East-West Antarctic motion may have occurred between chrons C27 and C24 (61 to 53 Ma) and involved as much as 100 kms of additional extension across the Ross sea. The evidence for this earlier stage of extension comes from the misfit of magnetic anomalies and fracture zones in three now widely separated regions of the far South Pacific (north of the Ross sea, east of the Emerald basin, and in the South Tasman sea) when reconstructed back to chron C27 using the most recent rotation parameters for Australia-East Antarctica, Pacific-West Antarctica and Australia-Lord Howe Rise. This model would explain the development of the Iselin trough, a prominent graben structure northeast of the Iselin bank, as the consequence of local deformation related to the counterclockwise rotation of a small microplate centered on the Iselin bank between chrons C27 and C24. We propose that the westernmost sedimentary basins in the Ross sea (the Victoria Land and Northern basins) developed principally during the mid-Cenozoic stage of separation, while the Central trough (and a string of smaller basins north of it) may have initiated as a consequence of the earlier stage of motion. The early Cenozoic stage of separation closes the remaining gap between the Iselin bank and Northern Victoria Land and is also coincident with the age usually cited for the initial uplift of the Transantarctic Mountains (55 Ma).

The CTDI Rapid-Access Drilling System: An Exploration Tool for the Polar Sciences

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There are currently two types of deep drilling systems for support of research in Antarctica, ice-coring drills (ICDs) and hot-water drills (HWDs). Since ICDs are optimized for recovering high-quality ice cores, they are inherently slow and expensive to operate, limiting our ability to recover subglacial samples to 1-2 sites per decade. In addition, the acquisition of geologic information generally is not included in the site selection process for deep ice cores. In contrast, hot-water drills can rapidly drill through polar ice with effective drilling rates of 30 m hr-1. These drills are quite capable of drilling an array of 1-km deep boreholes in a single season. However, the heating requirements for HWDs are such that they become enormous if depths beyond 1 km are to be accessed (the weight of a HWD + fuel capable of reaching 3.5 km would exceed 272,000 kg). These drills require a vast logistical effort to deploy them to even a single site in Antarctica. Thus, it does not appear feasible to drill arrays of holes to bedrock in East Antarctica using HWDs.

Given the limitations inherent in current deep drilling systems, Clow and Koci (2002) proposed the development of a new type of drilling system for polar research based on commercial coiled tubing (CT) technology. CT technology has undergone very rapid development since its first operational use in 1991. This stems from a number of advances that CT drills have over traditional rotary rig drills for a wide range of commercial applications. While coiled tubing drills (CTDs) can penetrate rock at the same rate as rotary drills, CT drilling systems are much more compact, require smaller drilling crews, can be mobilized and demobilized much faster, and offer a higher degree of safety and control. The advantages are so great that by 2001, ~ 70% of all oil-drilling in northern Alaska was being performed with CTDs. Unlike ICDs and HWDs, CTDs are specifically designed for drilling rock. Thus, all the components (injector, tubing, etc.) have adequate strength to break rock cores free under tension.

The new drilling system (CTDI) proposed by Clow and Koci (2002) takes full advantage of the research and development already done by the oil & gas industry. The CTDI is both modular and LC-130 transportable. With an effective drilling rate of 40 m hr-1 in ice, it is estimated the CTDI could drill through 3-4 km of ice in 6-8 days, including drill setup, sealing the firn layer, and downtime. Drilling and coring rates in rock are expected to be quite variable, depending on rock type. Based on commercial CT experience, we estimate the CTDI should be able to achieve effective drilling rates of 10-40 m hr-1 (rock types ranging from sandstones through moderately hard dolomites) and coring rates of ~ 3 m hr-1. The drilling system would be fully steerable, allowing multiple sidetracks to be drilled from which multiple cores could be obtained. Horizontal drilling out to 900 m from the main wellbore would be possible. The geologic and geophysical information acquired with the CTDI drilling system would greatly complement that acquired by airborne geophysics and other means.

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Canada's LITHOPROBE project: Multidisciplinary transect studies of Precambrian regions

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Lithoprobe is Canada's national, collaborative, multidisciplinary, earth science research project established to develop a comprehensive understanding of the evolution of the northern half of North America1. The project's principal scientific and operational components are built around a series of ten transects or study areas (Fig. 1). Each of these is focused on carefully selected geological features within Canada that represent globally significant geotectonic processes. The transects span the country from Vancouver Island to Newfoundland and from the U. S. border to the Yukon and Northwest Territories; and geological time from 4 Ga to the present. For each transect, an integrated scientific program addresses fundamental problems of the structure and evolution of the lithosphere and is carried out by a multidisciplinary transect team headed by a Transect Leader(s). Eight of the transects involve studies of Precambrian regions. In this summary, I highlight results from three of these.

Trans-Hudson Orogen Transect (THOT): Of the network of Paleoproterozoic orogenic belts that stitched together older elements of the North American continent, only the 500-km-wide Trans-Hudson orogen of Saskatchewan and Manitoba, developed from 1.90-1.78 Ga, exposes a complete orogenic section. The orogen was sandwiched between Archean continental blocks, the Rae-Hearne craton to the northwest and Superior craton to the southeast. Research within THOT and the associated NATMAP (National Mapping Project) Shield Margin Project2,3, a special focus of study in the southeastern part of the orogen, has fundamentally changed our understanding of the architecture and tectonic history of the orogen. Results include discovery of a previously unknown Archean continental block, the Sask craton, that underlies the central zone of the orogen and extends southward below the overlying sediments. The Precambrian geology of a large area overlain by thin Phanerozoic sediments is established through an innovative program of drilling and studies of basement core samples coupled with potential field studies tied to exposed rocks.

Alberta Basement Transect: The crust that underlies most of Alberta consists of two parts, Precambrian crystalline rocks and an overlying veneer of sedimentary strata. The crystalline rocks are an extension of the exposed Canadian Shield and contain an important record of growth and evolution spanning nearly one billion years. The veneer constitutes the Western Canada Sedimentary Basin (WCSB) that hosts much of Canada's petroleum resources. The AB Transect examines the evolution of the Precambrian crust, the overlying sedimentary basin and possible interactions between them4,5,6. Unprecedented new information has been generated. Precambrian tectonic domains are established using aeromagnetic and gravity maps and analyses of (limited) basement drill samples derived from petroleum exploration. Multichannel seismic reflection (MCS) and refraction/wide-angle reflection (R/WAR) studies of the lithosphere reveal previously unknown Precambrian orogenic development that is co-eval with that in the THO and provide evidence for north-dipping subduction during collision of the Wyoming and Hearne-Rae cratons.

Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT): The transect is focused on studies, in Labrador and northern Quebec, of the processes by which the northeastern Canadian (Laurentian) Shield evolved. Its study area, originally almost terra incognita, includes two Archean cratons, the Nain and Superior; a smaller block of reworked Archean crust trapped between the two larger cratons as they obliquely moved toward each other; and five Proterozoic orogens, two of which suture the three Archean blocks, while the others record the progressive southerly accretion of juvenile (new) crustal material to the growing Laurentian continent. Coordinated field geological studies coupled with existing potential field data and new MCS and R/WAR experiments have led to new understanding of tectonic development in the area7. The Torngat orogen, the suture between two of the Archean blocks, is shown to be a narrow, doubly-vergent belt that is associated with a prominent crustal root with Moho relief of 12 km that has been preserved since its formation. Geochemical and geochronological studies help establish the tectonic development of the region.

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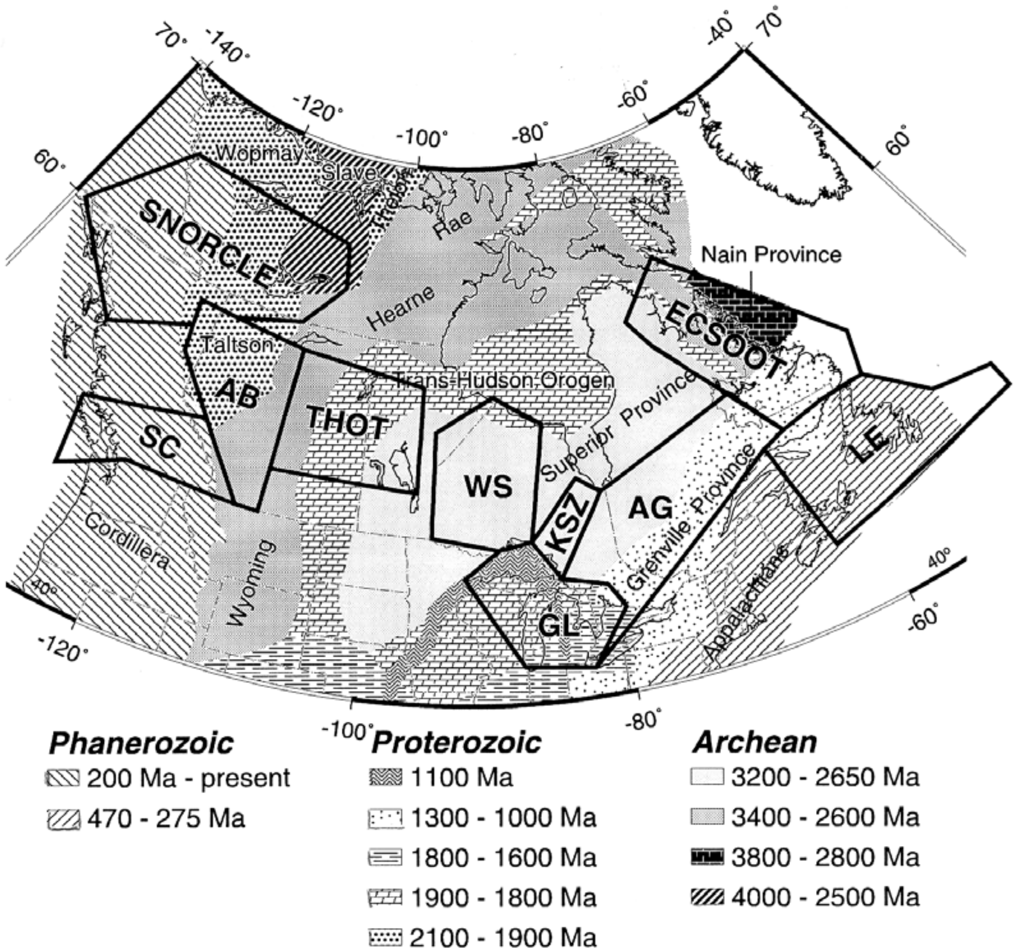

Fig. 1. *Location of LITHOPROBE transects (study areas) on a simplified tectonic element map of northern North America. The transects are: SC - Southern Cordillera; AB - Alberta Basement; SNORCLE - Slave-Northern Cordillera Lithospheric Evolution; THOT - Trans-Hudson Orogen; WS - Western Superior; KSZ - Kapuskasing Structural Zone; GL - Great Lakes International Multidisciplinary Program on Crustal Evolution (GLIMPCE); AG - Abitibi-Grenville; LE - Lithoprobe East; and ECSOOT - Eastern Canadian Shield Onshore-Offshore.*

Investigation of Geologic Control on Ice Sheets Using Airborne Geophysics and Remote Sensing

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For investigating the role of geologic control on glacial drainage and to map major geological boundaries on ice covered areas we combine and jointly analyse geophysical, remote sensing and glaciological data. Changes in structurally- or lithologically-controlled bedrock relief, in the type of the materials constituting the glacial bed and in heat flux associated with volcanism, are aspects of subglacial geology that can fundamentally affect ice sheet flow behaviour. Understanding the relationship between sub-glacial geology, regional ice-flow and ice sheet surface features help to assess the controls on glacial drainage system, mass balance and stability of the Greenland and Antarctic ice sheets. We use a combination of geophysical (airborne magnetics and gravity, ice-penetrating radar) and remote sensing (laser altimetry, visible, NIR and SAR imagery) methods to map ice-covered areas and to establish the relationship between geologic boundaries and surface features apparent on satellite imagery. Results from both Greenland and Antarctica are presented.

The regional airborne magnetics and gravity maps of Greenland reveal the boundaries of the major geologic provinces covered by the inland ice. We combine the potential field maps, ice penetrating radar profiles, satellite imagery and glaciological data in a GIS environment to study the geologic control on the ice flow. In NW Greenland, over the Humboldt, Petermann and Ryder glacier drainage basins, important glaciological features, such as shear zones, zones of subglacial melting and relict flow features, follow major structural boundaries. We suggest that the Precambrian Franklinian Basin extends southward beneath the ice sheet. In this region the ice flow is primarily controlled by bed conditions and not by bed topography. Subglacial melting appears to show a pattern related to the magnetic anomalies of the central Greenland magmatic province.

The regional structural and magmatic architecture of the Transantarctic Mountains (TAM) in southern Victoria Land has been investigated within the TAMARA collaborative research program. As a part of the program we used regional structural maps from satellite imagery and aeromagnetic data to test models for the structural origin of the prominent lineaments of TAM and to map the Jurassic Ferrar magmatic intrusive architecture. A major transverse structure, the Radian lineament, extends westward beneath the ice sheet. The analysis of glaciological data reveals increased ice velocity, suggesting that the subglacial bed is soft, perhaps lubricated by meltwater or water–

saturated till. Our modeling tests whether this structure marks a fault, whether it displaces the Beacon Supergroup strata and Ferrar dolerite and whether there is any signature of basement offset associated with the lineament.

Helicopter-borne magnetic surveys in Antarctica

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Helicopter-borne magnetic surveys form a substantial part of magnetic mapping of the Antarctic. They are, in most cases, carried out during geological-geophysical expeditions where helicopters are widely used to transport scientists to their study area. The aeromagnetic equipment can easily be installed in any type of helicopter and does not require modifications of the aircraft with only a few requirements to be met. Using a towed bird configuration has the additional advantage of being away from "magnetic noise" of the aircraft. Helicopter operations can be performed from virtually any base, whether the terrain is flat or rugged, in mountains or on the inland ice and even from a ship with just enough space to land a helicopter on. Another advantage over fixed wing aircraft is the helicopter's superior performance to climb and descend over steep mountainsides when surveys require a constant ground clearance. One disadvantage is their limited range. Also a helicopter survey is more affected by local weather and requirements for flying over water (which, however, can be overcome by using twin engine helicopters). Because of limited space and weight restrictions, surveys attempting simultaneous measurements of the magnetic and gravity fields as well as ice thicknesses are (until today) impractical for helicopters.

Sub-ice drilling: regional geologic mapping and specific targets

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The basic outline of the geology of Antarctica is well known. East Antarctica is a Precambrian craton bordered by successively younger orogenic belts, terminating with the Mesozoic-Cenozoic belt along the Pacific margin. Understanding of the tectonic history and the role of Antarctica in global processes is limited by the 98% ice cover of the continent. Antarctica is one of the keys to understanding the course of Cenozoic climate changes. Antarctica is also an integral part of the global plate circuit and its tectonic evolution is essential for understanding earth history, particularly from the time of Gondwana break-up. Both these facets of Antarctic geologic history will be advanced by information that can be obtained by sub-ice sampling. Such sampling will also provide information on many regional problems, from the basic distribution of age provinces across the craton to identifying sub-glacial crustal terrains in West Antarctica.

The East Antarctic craton from 15°W to 90°E consists of Archean and Proterozoic igneous and metamorphic rocks which have correlatives in the Africa-India part of Gondwana. The sub-glacial morphology suggests a broadly elevated terrain. Towards its eastern margin, this sector includes the sub-glacial Gamburtsev Mountains (80°S 75°E), which represent isolated intraplate mountains of uncertain but possible volcanic origin. The Lambert Graben, along 70°E, is a major intraplate rift with a history going back to the Paleozoic. Rocks in this sector, and from 90°E to 160°E, are overprinted by the so-called ~500 Ma Pan-African thermal event. From 90°E to 160°E outcrops are far fewer, Archean and early Proterozoic rocks are less common but clearly have correlatives in Australia, and undeformed sedimentary strata are present. This sector has broad regions of low sub-glacial elevation and significant elongate regions well below sea-level. Further, satellite data suggest thinner crust than in the 15°W to 90°E sector. The rifting and basin fills are most likely Cenozoic in age and the sedimentary sections will contain a high latitude, marine and/or lacustrine, transition from the Late Paleocene Thermal Maximum through to at least the Miocene onset of full-scale glaciation. The low region at about 150°E in the Wilkes Land sector extends southward on the polar plateau side of the Transantarctic Mountains; it will contain a Cretaceous and younger marine and non-marine section, with the Cenozoic part related to uplift of the mountains and the glacial history. Specific targets in East Antarctica include: the Gamburtsev Mountains; the rift basins of Lake Vostok and the sub-glacial deeps near Dome C; and the sedimentary basin on the plateau flank of the Transantarctic Mountains.

West Antarctica comprises a set of blocks and basins developed on a series of disrupted orogenic belts. Disruption of the late Paleozoic-early Mesozoic Gondwana plate margin and foreland region began in the Jurassic and continues to this day. The Ellsworth-Whitmore Mountains crustal block is a fragment of the Gondwanide orogen preserving the fold and thrust belt and its adjacent hinterland into which mid-Jurassic plutons were emplaced. Based on the Haag Nunataks, the isolated blocks in the Weddell ice shelf region appear to be parts of the Gondwana craton. All these blocks are targets for drilling in order to constrain the pre-break-up configuration of the South Africa-Antarctica sector of Gondwana, and may also include massive basaltic rocks related to break-up.

The West Antarctic sedimentary basins contain a geologic history, complementary to that recorded on the continental shelves, of break-up and subsequent episodes of rifting, magmatic activity, and sediment deposition. The record of Cenozoic climate change will differ from that of East Antarctica, in particular in recording the waxing and waning of the marine ice sheet of West Antarctica. The relationship between sub-glacial geology and ice sheet flow is potentially significant considering the high heat flow of West Antarctica. Targets in West Antarctica include the basement ridges between ice-stream filled rifts; inferred volcanic edifices, both point sources (volcanoes) and regional features such as the Sinuous Ridge; sedimentary basins; and sub-glacial outcrops that might record previous episodes of deglaciation.

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Geophysical mapping of subsurface geology: From the local to the supercontinental

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Airborne magnetic and gravity data are widely used to map buried subsurface lithology and structure and are, in many cases, the most expeditious and cost-effective means to accurately map geologic features in the third dimension (depth) at a range of scales. Aeromagnetic and gravity anomaly data provide a means to extrapolate known geology exposed in generally widely separated uplifts into broad covered areas, and identify and delineate large-scale structural features that are not readily discernable solely from outcrop mapping. These data sets can be displayed at various scales, depending on their resolution. For example, continental-scale magnetic and gravity anomaly maps help provide a comprehensive magnetic view of continental-scale trends not available in individual data sets, helps link widely separated areas of outcrop, and unifies disparate geologic studies. Regional compilations for various continents that have recently become available can help constrain global plate reconstructions for a variety of supercontinents including the Neo-Proterozoic continent of Rodinia as well as earlier ones. Geophysical signatures of known units from one continent can often be traced to others, helping constrain the age and lithology of buried units. Combining regional potential-field data sets, which provide information on the lateral extent of geologic units, with 2-d methods such as seismic refraction and reflection, and MT data can yield 3-dimensional information on subsurface crustal structure. Drill cuttings and core samples provide ground-truth for the geophysical data in completely covered areas. Local, high-resolution maps often reveal buried contacts, geologic units and small-scale structures such as faults, folds and dikes, particularly useful for unraveling the structural history of a region. These data sets can be combined with geochemical studies of drill core and cuttings to produce detailed 3-d geologic and structure maps.

A variety of analysis tools are available for interpretation of potential-field data. For example, linear magnetic and gravity anomalies with steep gradients delineate magnetic and density discontinuities often inferred to be faults. The locations of the steepest gradients can be located and plotted as lines for comparison with mapped faults. Horizontal offsets of anomalies can be used to infer the existence of strike-slip faults, whereas vertical motion can be inferred from comparison of the amplitudes and wavelengths of anomalies on either side of a postulated normal or reverse fault. Rose diagrams of magnetic and gravity trends can also be constructed for structural interpretation. Depth estimates obtained from magnetic and gravity anomalies determine whether sources are surficial or deep, provide constraints on the depth to cystalline basement and the thickness of sedimentary basins. Two- and three- dimensional modeling of selected anomalies characterizes rock properties, providing constraints on lithology, and dips of faults or other structures. Incorporating other geophysical and geological data in the models can yield a well-constrained geologic model. Successful geologic interpretation of geophysical data requires geologists and geophysicists to work closely together during the duration of a project.

Geodynamics – ice-sheet dynamics interactions: Research plans for investigations of (1) the Lambert Rift – Prydz Bay (East Antarctica) and (2) the Amundsen Sea Embayment (West Antarctica) systems

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Although time scales of geodynamic and ice-sheet dynamic behaviour seem to differ in magnitudes, the Antarctic lithospheric structure and dynamic affect the regional ice-sheet motion. Both the Prydz Bay/Lambert Graben and the Pine Island Bay/Amundsen Sea Embayment form two important ice drainage regions along defined and suggested major tectonic boundaries in East and West Antarctica, respectively.

The Lambert Graben constitutes the largest known continental rift system in East Antarctica with rift shoulders well exposed above the ice-sheet. Yet, despite the geotectonic and glacial importance of the rift, its crustal dynamics and tectonic effects on the glacier transport mechanism have not been investigated in detail. The Lambert Graben remains one of the more fundamental boundaries of the Precambrian geology of the East Antarctic shield. Rocks of different ages (500 vs. 1000 Ma) occur either side of the Graben which appears to limit the extent of the Pan-African belts. Modeling of gravity and magnetic anomalies across the Lambert Rift suggests that it is an active continental rift valley with signatures of magmatism. Thermally controlled tectonic uplift and subsidence and the variability of crustal heat flow beneath the rift have substantial influence on ice-stream flow rates. A well constrained model of rift evolution and associated glacial-tectonic processes during its recent history would directly feed into an improved mass-balance budget for the Antarctic ice-sheet. We propose an international cooperative project in which the entire column and cross-section of the Lambert Rift from the upper mantle to the glacier will be imaged. The objectives include (a) the investigation of the structure of the Lambert Rift from the upper mantle through the crust to the overlying glacier using integrated land and marine seismic, geological, geodynamic and glaciological methods, (b) the determination of the influence of current tectonic motion and heat supply on the glacial dynamics of the Lambert Glacier, and (c) the delineation of structural units of the East Antarctic lithosphere towards an improved understanding of the Precambrian and later tectonic evolution of East Antarctica.

On the opposite of Antarctica, the Amundsen Sea Embayment and Pine Island Bay form the third largest ice-sheet drainage basin for West Antarctica, fed by the Pine Island and Thwaites Glaciers. Their importance is demonstrated by recent publications suggesting that the West Antarctic ice-sheet reacts more dynamically to climate change than the East Antarctic ice-sheet. Pine Island Bay follows suggested lineations of major tectonic boundaries. For instance, the boundary between the Thurston Island and the Marie Byrd Land blocks is likely to be located in the Pine Island Bay. Newest plate tectonic reconstructions place the Amundsen Sea Embayment in alignment with the Bounty Trough (E New Zealand). Parts or all of the Embayment probably belonged to the Bellingshausen Plate with an independent motion from 73 to 61 Ma. A major research effort is needed and planned to reveal these tectonic and geological-magmatic boundaries in the Embayment and its adjacent continental margin of Thurston Island and Marie Byrd Land.

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Exposed basement geology of the Transantarctic Mountains: What we think we know

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The East Antarctic shield (EAS) is a key piece in the Proterozoic to early Paleozoic transformation of the Rodinia and Gondwanaland supercontinents. Its Ross orogenic belt marks early Paleozoic plate convergence along the active margin of Gondwanaland, and Jurassic and Cretaceous rift-origin features are documented around the present-day continental margin. Because of nearly complete coverage by the polar ice cap, however, Antarctica remains the single most geologically unexplored continent and little is known about the composition and structure of the shield interior. Exposures of cratonic basement are largely limited to coastal outcrops in George V Land and Terre Adélie (Australian sector), the Prince Charles Mountains and Enderby Land (Indian sector), and Queen Maud Land (African sector), where the geology is reasonably well-known. By contrast, there are few clues to the geology of the EAS for fully one third of its perimeter along the Transantarctic Mountains. Yet, a small window into the Pacific margin of the EAS is provided by exposures of high-grade metamorphic and igneous basement in the Nimrod Glacier area, and the provenance signatures from Neoproterozoic to lower Paleozoic siliciclastic cover successions provide proxy samples of the cratonic interior. Together, these rocks provide important constraints on the nature of the adjacent ice-covered shield.

U-Pb and Sm-Nd data from the Nimrod Group document multiple geologic events spanning 2.5 b.y. of Archean to early Paleozoic history, culminating in thermomechanical reworking and magmatism during the Ross Orogeny. The oldest gneisses represent Archean magmatic crust generated from juvenile mantle melts between ~3.15-3.00 Ga. They are similar in age to rocks in the Denman Glacier area of Wilkes Land, suggesting an incipient period of crust formation in the EAS. Later episodes of high-temperature metamorphism, anatexis and magmatism ensued at ~2.96-2.90 and ~2.5 Ga. Some gneissic, eclogitic, and metaigneous rocks record deep-crustal metamorphism and magmatism between ~1.73-172 Ga (Nimrod Orogeny). Although cryptically preserved, these rocks indicate crustal thickening in the late Paleoproterozoic and are temporally correlated with ~1.7 Ga events in Terre Adélie and the Gawler Craton of Australia. They are also similar in age and character to deep-seated events (Ivanpah Orogeny) in the Mojave province of the southwestern U.S.. The similar pattern of ~1.7 Ga deep-crustal overprinting on Archean protoliths suggests that a collisional belt of this age transected the Antarctic-Laurentian region of Rodinia and may extend from the central TAM beneath the ice sheet to the Gamburtsev Subglacial Mountains or Vostok Subglacial

Highlands. Cryptic age signatures in rocks of the Shackleton Range indicate that modified shield basement may extend to southernmost Queen Maud Land.

Siliciclastic rocks of Neoproterozoic to early Paleozoic age along the TAM margin include narrow rift-margin deposits (≤680 Ma) and a younger (~515-475 Ma) syn- to post-orogenic molasse succession. An EAS source is inferred for both assemblages based on paleocurrent indicators, depositional facies, and ages of detrital minerals. Zircons from mature passive-margin sandstones indicate distal input from the adjacent Archean and Proterozoic shield, with dominant ages of 2.8, 2.5, 1.8-1.6, and 1.5 Ga. The detrital suites also include distinguishable 1.3, 1.1, and 1.0 Ga populations that correlate with individual Grenville-age belts in the EAS and adjacent East Gondwana cratons. The detritus includes significant ~1.4 Ga first-cycle zircon, suggesting erosion of a Mesoproterozoic magmatic province like the trans-Laurentian granite belt. Persistence in the younger succession, and an absence of large cratonic terrains of this age in present-day Antarctica or Australia, suggests that the trans-Laurentian granite province may extend into the ice-covered EAS. Abundant ~1.8-1.6 Ga detritus is consistent with this interpretation, indicating extension of Mojave-Yavapai-Mazatzal crust into the EAS. Together, these data suggest paleogeographic linkage between East Antarctica and western Laurentia prior to ~1.0 Ga.

Although ongoing geological studies will continue to provide new constraints on the composition and evolution of the EAS, they are ultimately hampered by limited exposure. Short of melting the ice cap, indirect methods of study therefore represent the most sensible next-generation approach, including potential-field geophysical surveys over ice-covered regions, seismic reflection and refraction profiles, sampling of glacial tillites, and rock-core recovery from the bottom of deep-ice drill holes. Such methods will allow us to better characterize the composition and structure of the hidden shield areas, and they fit well with the goals of current glaciology programs. The most opportune targets for these types of studies in the Pacific sector of Antarctica are the central Transantarctic Mountains, Wilkes Land basin, Oates Coast, Gamburtsev Subglacial Mountains and Vostok Subglacial Highlands.

Magnetic property information and the new Antarctic Rock Magnetic database: an overview

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Rock magnetic property data from the few but very important bedrock exposures in Antarctica represent the only ground truth for geophysical surveys. Well over 10,000 paleomagnetic cores, representing more than 1000 sites have been collected in Antarctica from Archaen to late Cenozoic rocks. Such a collection represents a unique source of rock physical property data because of the scarcity of outcrops. The magnetic information from these rocks can be very useful for geophysical surveys in interpreting the subice bedrock geology especially when there is significant variability even within similar rock units.

Compiling the rock magnetic data into an Antarctic Rock Magnetic Database (ARMD) is useful for future interpretations of geophysical data and can help address the following issues:

1) demarcation of a crustal boundaries in both East and West Antarctica; are there terrane boundaries in West Antarctica, crustal suture zones in East Antarctica, etc.?
2) the extent of the Cambro-Ordovician magmatic arc in the Transantarctic Mountains
3) geometry and extent of Jurassic Ferrar Group magmatic rocks
4) provenance analyses for paleoclimate research

The magnetics database will soon be accessible on the internet. The database information is set up on the *Site* level. The Antarctic rock magnetic database has been modeled after the Antarctic Geologic Database (AGD): http://bprc.mps.ohio-state.edu/agd/. The AGD is being established at the Byrd Polar Research Center for Antarctic rocks. The computer system for the AGD will act as the server for the ARMD. Basically, the Antarctic rock magnetic database has the same format as the AGD in that many of the AGD primary fields remain the same for the rock magnetic database (Site-coordinates, lithology, age, location, formation/unit name, structural information, etc.). The subfields have been changed to include relevant rock magnetic data such as NRM directions, NRM intensity, bulk susceptibility, anisotropy analyses, magnetic mineralogy, Curie temperature and other information about the samples and locations. It also includes a 'Notes' section where relevant information can be updated, e.g. new isotopic or faunal ages. The magnetics database has a search option for those wishing to obtain the rock magnetic data from a particular region, unit or researcher.

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The ANDRILL Initiative: Stratigraphic Drilling for Climatic and Tectonic History in Antarctica

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REVEAL calls for the integration of geological data collected from a diverse array of tools in order to map the subglacial geology of the East Antarctic lithosphere. Stratigraphic drilling offers a range of geological data to help interpret crustal evolution, basin history, climate and ice history and the influence and feedback of these on biotic, geomorphologic and structural evolution. Drilling, combined with downhole logging and ground-based and airborne geophysics, can provide complementary physical data to constrain and direct interpretations of airborne geophysical data, which will lead to a better understanding of the Antarctic lithosphere. Geophysical data will, in turn, help identify Mesozoic and Cenozoic sedimentary basins as drilling targets. Critical constraints on vertical motions of crustal blocks and feedbacks between surface processes and tectonic processes can be addressed with the recovery of stratigraphic records. Climate and glacial models, fed by geological information of past environmental change will contribute to the resolving the effects of lithospheric loading, ice sheet mass balance, and climate and surface processes. An integrated geophysical and geological program will ensure that drillsites will have the potential to meet scientific questions of broad interest. Sub-ice sampling of basement rocks in East Antarctica is important to REVEAL's objectives. The scientific focus of the proposed ANDRILL and SHALDRIL drilling efforts is initially on Cenozoic climate and glacial history, but lithospheric targets and geophysical and tectonic questions can be incorporated into existing and future plans. REVEAL calls for the integration of diverse tools into an integrated program directed to the resolution of major questions in Antarctic geology.

ANDRILL is a new initiative that uses and expands the technology employed during the Cape Roberts Project to use floating ice (fast ice and ice shelves) as a drilling platform to recover stratigraphic records. This multi-national project proposes to investigate Antarctica's role in Cenozoic-Recent global environmental change through stratigraphic drilling for Antarctic climatic and tectonic history. Four drilling seasons are proposed in the McMurdo Sound area to address diverse scientific questions spanning the last 50 million years, and at varying levels of stratigraphic resolution. Due to the immense ice sheets and major erosional episodes, the Antarctic region is conspicuously lacking in long records of Cenozoic paleoclimate. Stratigraphic records from the Antarctic margin are comparatively more complete, often with expanded sections, and their locations are ideally suited for recording and dating ice sheet oscillations and associated oceanic variations. ANDRILL aims to obtain high-resolution (0.1 to 100k.y.), seismically-linked and chronologically well-constrained stratigraphic records from key locations around the Antarcic continental margin to address key scientific objectives and questions in a series of discrete portfolios. The first of these is the McMurdo Sound Portfolio. Five countries, Germany, Italy, New Zealand, United Kingdom and United States are leading the ANDRILL initiative, and the invitation is open for membership of other nations. McMurdo Sound is located on the margin of the Victoria Land Basin and is influenced by ice and sediment input from both the East and West Antarctic ice sheets. Through persistent sediment supply and subsidence, the McMurdo Sound region has acted like a sedimentary tape recorder for most of the last 45 m.y. It has the best-understood marginal sedimentary record in Antarctica due to the past 30 years of integrated seismic and drill-hole data, which will provide confidence in target location to answer specific scientific questions. Location on the rift margin of the Transantarctic Mountains and within a major Cenozoic volcanic province will allow assessment of the role of tectonics in climate and ice sheet development and provide an excellent chronological framework through input of datable volcanic tephra.

Three phases of data collection and analysis are planned: Phase I – three seasons of geophysical surveys (2001-2004) (aeromagnetic, gravity, and seismic) to document basin extent, architecture and correlate target drilling areas to known drillcores; Phase II – four seasons of drilling (2004-2008) to recover target strata to address key objectives and questions; Phase III – four years of data analysis and integration into glacial, climate and ocean models (2006 to 2010) to determine global links and the role of the Antarctic cryosphere in global environmental change.

Major aims of the McMurdo Sound Portfolio are: (1) To determine the fundamental behavior of the Antarctic cryospheric system (ice sheet, ice shelf, and sea-ice), including the magnitude and frequency of its changes on centennial to million-year time-scales; (2) To obtain geological records from critical intervals in the development of the Antarctic cryosphere to guide and constrain glacial and climate models; (3) To document the evolution and timing of major Antarctic rift and tectonic systems and the stratigraphic development of associated sedimentary basins; and (4) To determine, through correlation of near-ice margin and southern Ocean stratigraphic records, the role of Antarctic ice sheets on long- and short-order Cenozoic climate change, particularly in modulating thermohaline ocean circulation and changes in sea-level elevation.

The ANDRILL initiative is developing a framework for international collaboration that will continue beyond the McMurdo Sound Portfolio. Other portfolios will develop to address these and other scientific questions around the Antarctic margin. Current target areas of the McMurdo Sound Portfolio are in New Harbour (Eocene to Pliocene targets), MacKay Sea Valley (Holocene targets), McMurdo Ice Shelf (Plio-Pleistocene targets) and Southern McMurdo Ice Shelf (Paleogene targets). Workshop reports from the ANDRILL International Workshop in Oxford (April, 2001) and the ANDRILL-US Science Workshop (April, 2002) will be available soon, as well as the ANDRILL Science and Logistical Implementation Plan (SLIP).

A new, powerful drilling system will be developed for ANDRILL to be able to reach deep-water (<1000m) targets and to operate through a thick (>200m) shelf ice. This will expand the capability of the successful Cape Roberts Project technology, which operated from a fast ice platform and achieve consistent core recovery (>95%) and the recovery of a 939m core in the CRP-3 drillhole. This new capability will be able to address diverse geological and geophysical questions and aid REVEAL's goal to better image the crustal structure and composition of the Antarctic lithosphere. ANDRILL technology may provide a future means of sampling key targets beneath the East Antarctic Ice Sheet that are identified by geophysical reconnaissance surveys.

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Major crustal provinces between the Grunehogna and Napier cratons (East Antarctica) and their aeromagnetic signature: where are the key areas for future research?

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A number of key areas for future geophysical exploration of the East Antarctica lithosphere are identified between the Grunehogna and Napier cratons. These include the extend and sub-ice structure of major crustal provinces, such as cratons and mobile belts of different ages. A feature of special interest is the East African/Antarctic Orogen, that resulted from the collision of E- and W-Gondwana during late Neoproterozoic/Early Palaeozoic times. The eastern and western margin of this orogen, the suture zone as well as the general structure of the orogen are only poorly known and require focussed research.

The area under review stretches from the Archean Grunehogna Craton in western Dronning Maud Land to the Napier Complex. Extensive field studies by numerous nations have indicated that both cratons are surrounded by Palaeoproterozoic to Neoproterozoic mobile belts. The most interesting structure of the region seems to be the southern extension of the East African Orogen into East Antarctica, that resulted in major tectono-thermal overprint of Palaeoproterozoic to Mesoproterozoic crust between c. 580 to 500 Ma.

The Grunehogna Craton most likely represents a fragment of the Zimbabwe-Kaapvaal Craton and the contiguity with southern Africa during late Mesoproterozoic times was corroborated by palaeomagnetic data (e.g. Peters et al., 1991). The Zimbabwe-Kaapvaal-Grunehogna Craton is rimmed by the c. 1.1 Ga Namaqua-Natal-Maud Belt, that is characterised by elongate, craton-parallel and high-amplitude positive and negative anomalies. In Antarctica, the craton/mobile belt boundary is not exposed but documented in the available aeromagnetic data (Golynsky & Aleshkova, 2000). The intersections of the craton/mobile belt boundary with the present coast lines in Antarctica and Africa can be used as piercing points for tight continent reconstructions. In Heimefrontfjella, the characteristic anomaly pattern of the Namaqua-Natal Maud Belt terminates abruptly along a major shear zone (Golynsky & Jacobs, 2001). This shear zone coincides with Grenville-age (c. 1000 Ma) Ar-Ar mineral cooling ages to the W and Pan-African (c. 500 Ma) mineral cooling ages to the E (Jacobs et al., 1997). This boundary is interpreted as the western orogenic front of the East African/Antarctic Orogen. Due to intense Pan-African reworking E of the shear zone, the magnetic anomaly pattern is completely different on the eastern side and therefore the orogenic front of the East African/Antarctic Orogen can be mapped under the ice by aeromagnetic means.

The southern boundary of the Maud Belt is not exposed, but aeromagnetic data south of Heimefrontfjella indicate a sudden change of the magnetic anomaly pattern (Golynsky and Aleshkova, 2000). This Coats Land block is marked by a complex random anomaly pattern with short wavelength, thus is significantly different from the Maud Belt. In Coats Land, unmetamorphosed late Mesoproterozoic rocks are exposed in a few nunatak, that overly a basement of unknown age. Since the unmetamorphosed rocks in Coats Land are slightly older (c. 1110 Ma; Gose et al., 1997) than the metamorphism in the Maud Belt (c. 1090-1060 Ma; Jacobs et al., in prep.) the not accessible basement of the Coats Land block should be Archean to early Mesoproterozoic in age.

South of the Coats Land block comes the Shackleton block, the latter of which is again aeromagnetically different from the Coats Land block (Golynsky and Aleshkova, 2000). The Shackleton block is exposed in the northern Shackleton Range, where the Archean to Palaeoproterozoic Stratton and Pioneers Groups are exposed. Both units have undergone a strong tectono-thermal overprint at c. 500 Ma and are thrust E-wards along the Otter Highland Thrust over the Palaeoproterozoic Read basement, the latter of which lacks Lower Palaeozoic overprint and was interpreted to represent the eastern foreland (e.g. Kleinschmidt & Buggisch, 1994; Tessensohn et al., 1999). Neoproterozoic sedimentary rocks together with mafic and ultramafic rocks including pillow lavas indicate that the Shackleton Range might contain a Late Neoproterozoic/Early Palaeozoic suture zone (Talarico et al., 1999). It is obvious that both, the Pan-African structures in the Heimefrontfjella and in the Shackleton Range are more or less co-linear.

The coastal outcrops in central Dronning Maud Land, the Sør Rondane and Lützow Holm Bay, all indicate a Grenville-age basement that underwent different degrees of Pan-African reworking (e.g. Shiraishi et al., 1994; Jacobs et al., 1998; Jacobs & Thomas, 2002), with an Early Palaeozoic, yet undiscovered suture hidden under the ice.

The Napier Craton is rimmed by the c. 1.0 Ga Rayner Province, that seems slightly younger than similarly aged rocks to the W. At least the western part of the Rayner Province was differentially reworked at c. 500 Ma (Shiraishi et al., 1997), but structures here seem to be at almost right angles to the generally N-S trending (African N) East African/Antarctic Orogen (Golynsky et al., 2002). Thus, it might be speculated that there is a suture at a right angle joining Lützow-Holm Bay and Prydz Bay.

Most of the crustal provinces, boundaries and structures identified in this short review are only in part exposed, therefore, especially the outline of these crustal provinces, their sub-ice structure and potential suture zones require further geophysical research.

From this perspective further focussed work and key areas are:

1) Refinement of Grunehogna craton-Maud Belt boundary and the intersection with the present continental margin
2) Southern boundary of the Maud Belt and its eastern continuation.
3) Mapping of the western front of the East African/Antarctic Orogen
4) Identification of non c. 550 Ma overprinted crust within the East African/Antarctic Orogen
5) Outline of voluminous Pan-African post-tectonic granitoids under the ice

6) Identification of (the) Pan-African suture zone(s) and sub-ice mapping of major Pan-African structures

7) Outline of the eastern margin of the East African/Antarctic Orogen and evaluation of a possible triple junction near Lützow-Holm Bay.

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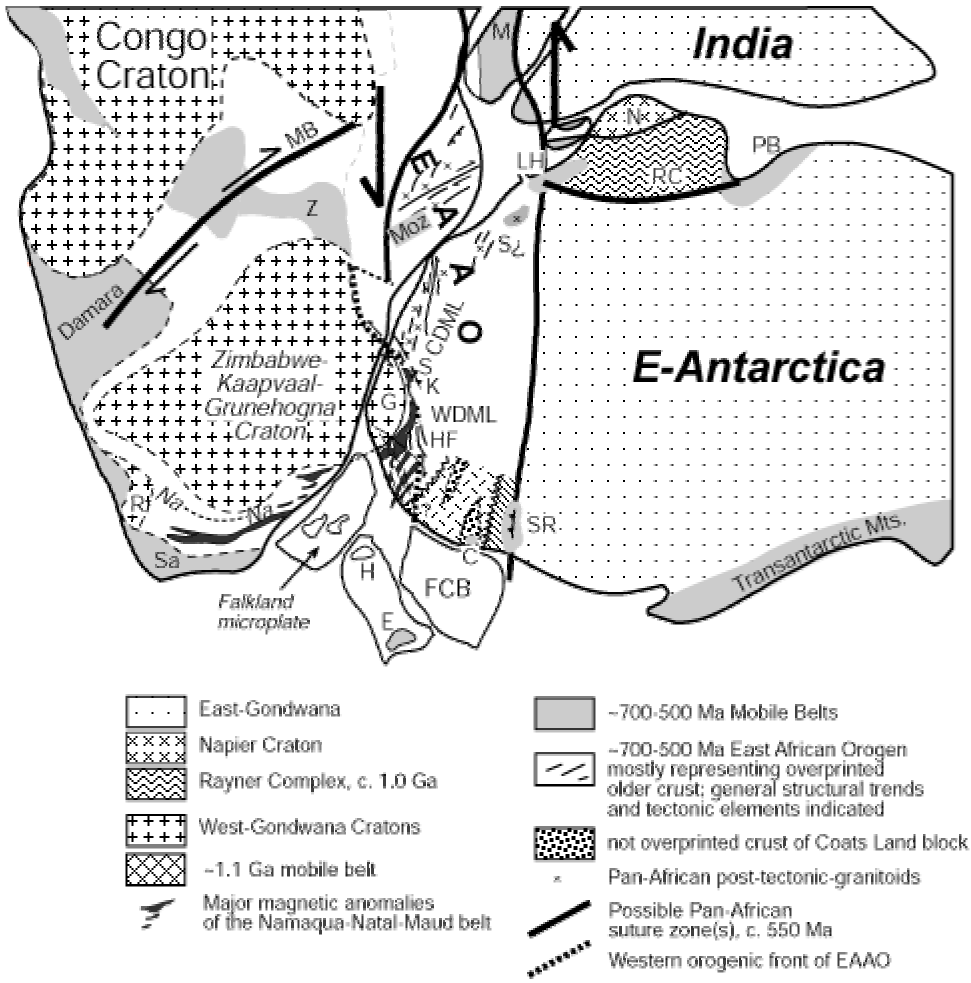

Fig. 1: Location of the study area in a Gondwana reconstruction after Lawver & Scotese (1987) and Grunow *et al.* (1996) with major Pan-African belts indicated. Abbreviations: C - Coats Nunataka, CDML - central Dronning Maud Land, EAAO – East African/Antarctic Orogen, EM - Ellsworth Mts, FCB - Filchner Crustal Block, G - Grunehogna Archean cratonic fragment, H - Haag Nunatak, HF – Heimefrontfjella, K - Kirwanveggen, LH - Lützow Holm Bay, M - Madagascar, MB - Mwembeshi Shear Zone, Moz - Mozambique Belt, N - Napier craton, Na-Na - Namaqua-Natal Belt, PB - Prydz Bay, R - Richtersveld Craton, RC - Rayner Complex, S - Sverdrupfjella, Sa - Saldania Belt, SL - Sri Lanka, Sø - Sør Rondane, SR - Shackleton Range, WDML - western Dronning Maud Land, Z - Zambezi Belt.

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Antarctic drilling, coring, and logging: how and why?

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In academia as in industry, the most effective exploration technique is usually to combine regional geophysical surveys with one or more drillholes. Drillholes are expensive, but they provide a ground-truth bridge between local geology and geophysics that minimizes the inherent ambiguity of geophysical surveys and constrains 2-D and 3-D geologic models. Drilling without site surveys is almost never cost-effective; this scarce resource needs to be guided. Antarctic drilling requires both coring (continuous or spot) and downhole logging; the incremental savings of skipping either are trivial in comparison to information loss. Drilling technique is more dependent on location than on scientific objectives. Present and future Antarctic drilling systems include, from offshore to on-ice: (1) ODP and IODP (offshore, nearly ice-free, 100-1500 m holes in 80-4000 m water, continuous coring and logging); (2) SHALDRIL (offshore, moderately ice-free, 50-100 m holes in <600 m water, continuous coring and limited logging, 2005 trials); (3) ANDRILL/CRP/other (nearshore through fast ice and coastal onshore, ≤1 km holes in <1 km water, continuous slimhole coring and logging, many previous McMurdo Sound holes, ANDRILL starts in 2005?); (4) hot-water drills (~1 km ice, spot coring and logging); (5) FASTDRILL (through-ice drilling, ≤4 km ice and <100 m bedrock, probably coiled-tubing drilling, spot coring and logging, geology/glaciology/climate, 2005?); (6) ice-core drilling (≤4 km ice, large-diameter continuous coring and logging, glaciology/paleoclimate, ex. Vostok).

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"Structure and Evolution of the East Antarctic Lithosphere " Geoscience Program,

- Outline and Scientific Significance -

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Lithospheric evolution and deep structure viewed from East Antarctic Shield are summarized relating to the continental growth process in the Earth's evolution. First, the lithospheric structure of Antarctica is discussed by comparing deep seismic probings of the other Precambrian continents. Next, we focus on the subsurface structure and the lithospheric evolution of the early-Paleozoic crust of the Lützow-Holm Complex (LHC), around Syowa Station (39°E, 69°S), East Antarctica. LHC is considered to be one of the collision zones between the East and the West Gondwanaland during the formation of a paleo supercontintnt when the Pan-African orogeny. The "Structure and Evolution of the East Antarctic Lithosphere (SEAL)" project has been carried out since 1996-1997 austral summer season in the framework of the Japanese Antarctic Research Expedition (JARE). Several geophysical studies and deep seismic refraction / wide-angle reflection surveys have been conducted at LHC. Air-borne surveys for geomagnetic, gravity and rader-echo soundings are also planning to be carried out within a few years future by making a cooperative study with AWI, using Twin Otter platforms. The main target of the SEAL geotransect is to obtain a whole lithospheric section in the different geological terrains from the Archean (Napier Complex) to the early-Paleozoic ages (LHC) between Western Enderby Land and Eastern Queen Maud Land. In the austral summer season in 2000, and 2002, deep seismic probing were conducted on ice sheet in the northern Mizuho Plateau, of LHC by JARE-41, and –43, respectively. In the JARE-41 surveys, more than 170 plant-type 2 Hz geophones were set along the Mizuho route 190 km in length. A total of 5,000kg dynamite charge at seven sites along the route gave information concerning the deep structure of a continental margin of the LHC. Continental evolution from the Archean ages to the present stage would be clarified by combining the geoscientific results from East Antarctic shield and those from the other cratonic terrains of the Earth's continent in the next step. Lithospheric structure of the Pan-African belt will be clarified by making deep seismic surveys and the other related geophysical approach to cross over the continental segments in the southern hemisphere that once were the fragments of a Gondwanaland. Deep seismic profiling by LEGENDS (Lithospheric Evolution of Gondwana East iNterdisciplinary Deep Surveys) project is expected to reveal the architecture and lithospheric evolution of these regions. SEAL transect has also been carrying out as a main contribution for LEGENDS, to delineate a crustal section in different geological terrains from Western Enderby Land to Eastern Queen Maud Land.

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The paradoxical gravity anomaly of the Ross Sea, Antarctica

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Tectonic reconstructions of Antarctica and Australia suggest that the Ross Sea basins were formed in the late Cretaceous. The adjacent Transantarctic Mountains are often explained in terms of the uplift and flexural adjustment of the lithosphere to extension in the Ross Sea. As such, the high average elevation of the mountains requires significant extension, presumably the late Cretaceous event. However, the exhumation of the mountains occurred significantly after late Cretaceous rifting. Fission-track data suggest that the main period of denudation is in the mid-Tertiary, but geological evidence for significant mid-Tertiary deformation is lacking. Gravity anomalies in the Ross Sea are unusual in that positive gravity anomalies exist over the basins and negative anomalies over the basement highs. Analysis of these anomalies provides new constraints on the evolution of the Ross Sea basins and the dilemma of Tertiary denudation in the absence of significant Tertiary tectonics. We demonstrate that the gravity relationship is the consequence of a relatively low flexural strength of the lithosphere during rifting and higher flexural strengths significantly later during sedimentation. This relationship requires a delay in the infilling of the basins relative to late Cretaceous extension, as evidenced by the Oligocene-Neogene infill of the Ross Sea basins. The time delay between late Cretaceous uplift of the Transantarctic Mountains and mid-Tertiary exhumation requires the Paleogene climate to be ineffective in producing clastics until the early Oligocene.

Integrated geological and geophysical investigations of the oceanic crust–Analogs for Antarctic Investigations

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Investigations of the Antarctic continent have many parallels with marine geological and geophysical investigations of the oceanic crust. In both cases a substantial thickness of liquid or solid water separates observers from most outcrops. From limited outcrops and drill holes, interpolations and extrapolations are made to hidden areas with the aid of broader-scale, remotely sensed, geophysical data. In this way integrated geological and geophysical data sets provide a means of interpreting the geology of very large regions. The geological structure of the oceanic crust, along with the results of investigations of active spreading centers, contribute to the current understanding of processes at accreting plate boundaries. In the next generation of investigations of the Antarctic continent, it is worth considering the how marine geological and geophysical investigations have developed over the past two decades.

Recent studies of oceanic crust and spreading centers employ techniques that mirror those used on land. Satellite gravity and magnetic data provide synoptic views of the morphology of the seafloor. Regional-scale bathymetry, gravity and magnetic data are now widely available for most parts of the Mid-Ocean Ridge system and other areas of interest. On a finer scale, side-scan sonar studies provide images that are analogous to satellite images or air photographs in terrestrial environments with resolution of a few meters to kilometers. These types of data provide a framework for more detailed geological investigations. These include detailed imaging on the scale of meters to tens of meters with remotely operated vehicles (ROV's) and autonomous underwater vehicles (AUV's). Direct observations and sampling of major outcrops is accomplished with submersible craft such as DSRV Alvin. It is now possible to collect high-resolution, near-bottom potential field data as well as quantitative structural data. Compared to on-land geology, only reconnaissance-scale maps have been produced to date. Ocean Drilling Program (ODP) projects have provided drill holes into the oceanic crust on the order of a few tens to hundreds of meters deep. Only one hole (ODP Hole 504B) has penetrated as much as 2000 m into the upper crust (only about one-third of the total crustal thickness). Very substantial compositional and structural variations have been documented downhole as well as among closely spaced (few hundred meters) holes.

In the ongoing investigation of oceanic crust and oceanic spreading centers, regional-scale geophysics and geological investigations have expanded over the past 4 decades in a complex way with new results from both geological and geophysical perspectives redirecting the course of the other as new data have been acquired. The relative influence of different types of data has been strongly influenced by innovations in technology; and these developments have not been systematic with respect to scale. For example, detailed submersible studies preceded the availability of multibeam bathmetric maps in many areas. Unfortunately, different types of data sets have been collected independent of one another and commonly in widely separated geographic locations. The result has been a patchwork of different types of data that can be related to one another only through a series of poorly justified assumptions. It is very difficult to compare the details of the geology from one study area with the potential field data or seismic data from crust formed in a very different setting or even at a different spreading rate. Data from very different spreading environments have been lumped together resulting in the current "textbook" version of oceanic crust and seafloor spreading. This view is so highly generalized that it does not represent any part of the mid-ocean ridge system and it obscures important geological relationships that inform our view of spreading processes. For example, it is now clear that processes at fast- and slow-spreading ridges, and the crust they produce, are vastly different and require very different research approaches to constrain their respective processes.

One of the most important lessons learned from these studies is that no single geological or geophysical approach is capable of fully describing the nature of oceanic crust or its evolution. Data from only a single perspective commonly result in non-unique interpretations that can be more misleading than constructive. Regional-scale geophysical surveys need to be tied to key geological study sites. The most important breakthroughs in the understanding of the nature of oceanic crust, and by inference seafloor spreading, are likely to come from the integration of geological and geophysical data across different scales.

Several major initiatives in marine geology and geophysics have interfaced to varying degrees. These include the RIDGE Program, MARGINS Program, and the Ocean Drilling Program (ODP). Although each of these and other programs has contributed substantially to the current understanding of the oceanic crust, they all have different objectives and capabilities. For example, the focus of RIDGE is active spreading centers but ODP has only been able to drill into relatively old oceanic crust relatively far from spreading centers. The evolution of the RIDGE Program in particular provides food for thought regarding how to organize regional scale surveys and multidisciplinary investigations of remote regions of our planet.

While there is no denying that substantial progress has been made in the understanding of oceanic crust and the processes that create it, there are clearly some important lessons to consider for future investigations. Collecting comprehensive data sets from limited areas based on clearly defined scientific priorities requires compromises, is time-consuming, and may present logistical challenges, but this approach is likely to yield the most meaningful results. Although these points may seem obvious, they are commonly ignored.

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Structure of the seafloor north of the Ross Sea, Antarctica

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The Adare Trough is a prominent N-NW trending extensional feature that is aligned with sedimentary basins in the western Ross Sea and is located roughly 100 km NE of Cape Adare, Antarctica. The Adare Trough was first identified by Ewing et al. (1969) and Houtz & Davey (1973). More recently, satellite gravity data and a geophysical study aboard the Nathaniel B. Palmer have revealed that the trough is 40 km wide, is bounded by normal faults, has over 1 km of topographic relief from peak to trough, and is characterized by a free air gravity anomaly of approximately 110 mgal. A distinct series of magnetic lineations has been identified on either side of the Adare Trough indicating that this structure was actively spreading during Eocene and Oligocene time until approximately 28 Ma, producing seafloor that accounts for roughly 180 km of separation in the western Ross Sea embayment (Cande et al. 2000).

We analyze multibeam bathymetry data collected on the RV/IB Nathaniel B. Palmer in 1997 in order to better understand the formation, history, and tectonic role the Adare Trough has played in the Cenozoic history of the Antarctic Region. Analysis of multibeam data reveal seafloor spreading fabric on the flanks of the Adare Trough that is aligned parallel to its NW trending axis. Seafloor fabric is visible throughout most of the eastern part of the Adare Basin, the area of seafloor that was generated by spreading along the Adare Trough. Seafloor spreading fabric in the deeper parts of the western Adare Basin is obscured by thick sediment cover, suggesting that the Adare Trough has served as a barrier to eastward sediment transport from the Antarctic continental margin. The eastern margin of the Adare Basin is characterized by a change in the trend of seafloor spreading fabric from NW to NE. There is also an increase in depth across the boundary which is most pronounced to the south and is related to a change in seafloor age between the Adare Basin and the seafloor to the east which was created by spreading along the Southeast Indian Ridge. Statistical analysis of seabeam data in this region quantifies our observations of seafloor fabric orientations. Observed seafloor fabric orientations and the location of the eastern boundary of the Adare Basin are in agreement with the magnetic model of Cande et al. (2000).

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Airborne Lidar Topographic Mapping of the Dry Valleys

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NSF, USGS, and NASA have collaborated on a lidar topography mapping project during the 2001-2002 field-season to test NASA's Airborne Topographic Mapper (ATM) scanning laser altimeter in the vicinity of McMurdo station. The data collected will be used by NSF projects studying biology, geology, and glaciology; by the NASA ICESat team to assist in the calibration of their data; and provide base layers for much of the Dry Valleys LTER that exceed the resolution and accuracy of existing data by more than a magnitude. The ATM sensor collected in excess of 800 million laser elevation measurements in the Dry Valleys and surrounding sites of geologic interest, including the caldera of Mt. Erebus.

The NSF research applications include characterization and modeling of complex surfaces in the Beacon Valley; modeling of glaciers and soils of the Taylor Valley; volcanic cone morphology of the north slopes of Mt. Morning and Mt. Discovery; relation between bedrock structure and ice flow in the Radian Glacier – Portal corridor; front structure in the Transantarctic Mountains; neotectonic fault structure and landscape analysis from Denton Hills to the Garwood Valley; and subglacial volcanic cones studies on White Island.

The McMurdo Dry Valleys comprise a primary site for calibration and validation of NASA's ICESat satellite, scheduled for launch in December 2002. The primary sensor on ICESat is a laser altimeter, designed to measure very precisely the surface elevation within the 70-meter footprint of the laser. Because the altimeter will be operated with off-nadir pointing, mounting angle calibration is equally important with range calibration. A calibration site for such a sensor requires precise knowledge of local topography for a region consisting of a stable, snow-free surface with minimal vegetation. To facilitate angle calibration, it is also highly desirable to have variable surface slopes of moderately large amplitude (10-20 deg). With accurately measured surface elevations, the Dry Valleys provide a near ideal calibration site for ICESat. Furthermore, the Dry Valleys are in the region of the maximum height above the earth for the orbit of ICESat, allowing verification of any measurement errors that may have a scale factor component by comparisons with measurements from other parts of the world. There is no other site in the world that can provide this unique combination of features.

The project was conducted on a Twin Otter aircraft in the 2001-2002 Antarctic Field Season. Flying at the normal altitude of 500 m, the scanning laser system collects an average of about 1 elevation measurement per 3 square meters of area, even without accounting for overlap of flight lines. Examples of various data sets will be presented.

An airborne geophysical survey of the Amundsen Sea Embayment, Antarctica

David L. Morse, Jack Holt, Don Blankenship

UTIG

The West Antarctic Ice Sheet (WAIS) is the only "marine" ice sheet that remains from the last glacial period. The WAIS has been the subject of intensive interdisciplinary study by both the European and U.S. scientific communities since it was recognized to be a potential source for up to 5 meters of sea level rise, possibly on short timescales. Of its three primary drainages, the Ross Sea and Weddell Sea embayments have been the primary focus of attention, while the Amundsen Sea Embayment (ASE) has been comparatively unstudied, primarily due to its remoteness from logistical centers. However, satellite remote sensing studies, combined with limited ice thickness data, indicate that the ASE discharges the largest ice flux in West Antarctica; furthermore, of all the major drainage basins in Antarctica, it is the only one to exhibit significant elevation change over the period of recent satellite observations.

At present, our knowledge of the ice thickness and subglacial boundary conditions in the ASE are insufficient to understand its evolution or sensitivity to climatic change. Stimulated by observations of its non-steady behavior and its dominant role in WAIS net mass balance, the glaciers of the ASE have become a focus for future integrated studies by both the U.S. and European scientific communities with the overarching objectives of assessing the present and predicting the future behavior of the ice sheet in the ASE. The US community has now generated a plan to achieve these objectives through coordinated satellite, airborne, marine and ground based observations.

UTIG has proposed to perform comprehensive aerogeophysical surveys of the two major drainage basins within the Amundsen Sea Embayment by joining forces with the British Antarctic Survey (BAS) to use both US and UK aircraft with the UT and BAS aerogeophysical instrumentation. We have designed survey that can be accomplished in two field seasons that will achieve the fundamental objectives of the ASE Science Plan as well as guide future surface-based research. I will present the scientific motivations for coordinated research in the ASE and discuss how the design of our proposed survey will achieve its objectives.

Marie Byrd Land, West Antarctica: evolution of Gondwanaland's Pacific margin constrained by zircon U-Pb geochronology

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The Paleozoic and Mesozoic development and subsequent fragmentation of Gondwanaland's Pacific margin is recorded in igneous and metamorphic rocks cropping out in the Marie Byrd Land (MBL), West Antarctica, recognized on geologic1,2 and paleomagnetic3,4 grounds to comprise a discrete crustal block. Widespread occurrence of metaluminous granitoids dated by the zircon U-Pb method as mid- to Late Paleozoic shows that convergence-related magmatism dominated the early evolution of this margin. Dates for granodiorites, monzogranites and granites from the Ruppert and Hobbs Coasts of western MBL reveal a prolonged period of subduction-related calc-alkaline magmatism between at least 320 ± 3 Ma (age of the oldest granodiorite dated) and 110 ± 1 Ma (the age of the youngest I-type granitoid in the area. The latter, known as the Mt. Prince granite is intruded by swarms of mafic and intermediate dikes believed to record the onset of rifting that led to separation of the New Zealand microcontinent. The dikes have been dated by zircon U-Pb at 101 ± 1 Ma. Thus, the regime along the Ruppert and Hobbs Coasts had shifted from subduction-related to rift-related magmatism within a mere ~9 m.y. period. In the Kohler Range and the Pine Island Bay areas of eastern MBL, the calc-alkaline magmatism did not terminate until 96 ± 1 Ma, based on U-Pb dating of zircons from one granitoid sample, or 94 ± 3 Ma based on zircons from another. This evidence requires that subduction shut off from west to east as suggested previously on the basis of geophysical models5. No continental separation occurred to the east of MBL. The margins of the Thurston Island and Antarctic Peninsula crustal blocks went directly from convergent to inactive, except at the northernmost tip of the peninsula where the South Shetlands Island block is still actively separating.

With their zircon U-Pb ages clustering around 100 ± 2 Ma, dike-free "anorogenic" syenites and quartz syenites along the Ruppert and Hobbs Coasts show that the transition to extensional magmatism was rapid in the west. This is also reflected by the fact that from the onset of rifting at 101 ± 1 Ma to formation of oceanic crust between MBL and Greater New Zealand (Campbell Plateau, Chatham Rise, North Island and South Island) prior to chron 33o at ~81 Ma required only 20 m.y. For comparison, this is only two thirds of the ~30 m.y. it took for the Central Atlantic to open after initial rift-related magmatism6. The swiftness of the separation between MBL and Greater New Zealand demonstrated by our data is consistent with ridge-trench interaction rather than a mantle plume as the primary cause of the break-up, as is the west to east diachroneity in the cessation of subduction.

Exposures of host rocks to the erosion-resistant plutons are scarce in mostly snow- and ice-covered MBL. The occurrence in the zircons of widely separated granitoids of discordant U-Pb patterns we attribute to inheritance. The best-constrained upper concordia intercepts are as high as 1576 ± 55 Ma. This suggests either that stretched Precambrian basement underlies most of MBL, or that clastic sedimentary sequences with Precambrian detrital zircons underlie much of the margin.

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Potential contaminates of Late Cenozoic volcanism in South Victoria Land, Antarctica: a geochemical view of the deep crust

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Recent work on Late Cenozoic volcanism within the West Antarctic Rift System (WARS) have focused primarily on the geochemical characterization of magma sources and the influence of mantle plumes on rifting. These studies rely on rock compositions that approach primary magmas (i.e. Mg # $\geq$ 65 and Ni $\geq$ 300 ppm) in order to ensure minimal crustal input. However, the "contamination" of basaltic magmas by crust does occur and can yield valuable information on the type of rock assimilated. This information, coupled with other lines of evidence (xenolith studies and geophysical data), can be used to interpret the composition and structure of the crust beneath volcanic regions.

Here we present trace element and isotopic data from a suite of Neogene basalts (14-0.25 Ma) collected from the foothills of the Royal Society Range (RSR) in South Victoria Land. The RSR basalts (basanite and alkali basalt) were erupted on the western shoulder of the WARS between the thick crust (40-45 km) of the Transantarctic Mountains and the thin crust (15-20 km) of the Victoria Land Basin. The basalts are primitive (Mg # 55-65, Ni 100-300 ppm), have trace element concentrations that are akin to ocean island basalts (Nb/U 40-50, Ba/Nb 5-8, Zr/Nb 4-6, Sm/Hf 1-2) and represent small degrees of melting (~2%) of a garnet-bearing mantle source (La/Ybn 9-17). Co-variation of MgO with compatible elements (Ni, Cr, Os) indicates fractionation of olivine and clinopyroxene (±Cr-spinel, ±sulfide). Isotopically, the RSR basalts show a narrow range in oxygen (δ18Oolivine 4.5-5.3 ‰), modest variations in 87Sr/86Sr (0.70315-0.70354) and 143Nd/144Nd (0.51273-0.51290), and large variations in 206Pb/204Pb (18-20) and 187Os/188Os (0.13-0.54) ratios.

Variations in Sr, Nd and Pb isotopes of WARS basalts have been explained by the mixing of different mantle components (e.g., HIMU, FOZO, MORB and EM sources). The new Os isotope data for RSR basalts reflect the addition of crust. Os isotopes are inversely correlated with Os concentrations, which is consistent with crustal assimilation accompanied by fractional crystallization. Higher 187Os/188Os ratios also correlate with higher 87Sr/86Sr and lower 143Nd/144Nd ratios.

Constraints on the type of assimilant will be made by modeling geochemical and isotopic variations using published data on lower crustal xenoliths collected from

McMurdo Group volcanics (including the RSR). Contamination by silicic upper continental crust is unlikely based on the low δ18Oolivine values and primitive bulk rock chemistry. The assimilation of lower crust is consistent with models for ponding and differentiation of magmas at that depth.

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Crustal and upper mantle structure beneath Antarctica and surrounding oceans

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We present a shear velocity model of the crust and upper mantle at high southern latitudes that is produced from a large, data set of fundamental mode surface wave dispersion measurements. The inversion breaks into two principal steps: (1) surface wave tomography in which dispersion maps are produced for a discrete set of periods for each wave type (Rayleigh group velocity, 18 - 175 s; Love group velocity, 20 - 150 s; Rayleigh and Love phase velocity, 40 - 150 s; and (2) inversion for a shear velocity model which culminates in a Monte-Carlo inversion yielding an ensemble of acceptable models at each spatial node. The middle of the ensemble, together with the half-width of the corridor defined by the ensemble, summarizes the results of the inversion. We refer to the features that appear in every member of the ensemble as "persistent". Some of persistent features are the following. (1) Crustal thickness averages about 27 km in West Antarctica and about 40 km in East Antarctica, with a maximum thickness approaching 45 km. (2) Although the East Antarctic shield displays variations in both maximum velocity and thickness, it appears to be a more or less average shield. (3) The upper mantle beneath much of West Antarctica is slow and beneath the West Antarctic Rift is nearly indistinguishable from currently dormant back-arc areas such as the Western Mediterranean and the Sea of Japan. The model is, therefore, consistent with evidence of active volcanism underlying the West Antarctic ice-sheet and we hypothesize that the West Antarctic Rift is the remnant of events of lithospheric rejuvenation in the recent past that are now quiescent. (4) The Australian - Antarctic Discordance is characterized by a moderately high velocity lid to a depth of ~100 km. (5) The strength of radial anisotropy in the uppermost mantle across the southern hemisphere averages about 4%, similar to PREM. Radial anisotropy appears to be slightly stronger in West than in East Antarctica and in the thinner rather than the thicker regions of the East Antarctic craton.

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Revealing Tectonic Domains: The Use of Large Scale Magnetic Anomaly Compilations

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Continent wide compilations of magnetic anomaly data provide effective tools for first order delineation of tectonic domains. Particularly in regions where sediments cover the bedrock, magnetic anomalies are an essential mapping tool. Based mainly on magnetic and gravity data, we have compiled a series of basement tectonic domain maps over western Canada, from Manitoba to the Rocky Mountains. This poster will show some of the techniques for semi-automated interpretation of magnetic anomalies used on this compilation, and display the resulting compilation map and interpretation.

Regional magnetic compilations are increasingly available to the scientific community. Examples include the latest compilation of Antarctic magnetic anomalies [1], the Arctic compilation [2] and the magnetic and tectonic map of Northeast Eurasia [3]. The strength of these compilations is not so much in resolution, but in the fact that they provide broad continuous coverage and are amenable to mapping of regional scale tectonic features.

The magnetic data over Canada have recently been re-compiled as part of the new magnetic compilation for North America [4]. As a result of reprocessing and better manipulation techniques, the new compilation is of much higher quality than the DNAG compilation, which is now almost 20 years old.

The new magnetic data set for western Canada, from Manitoba to northeastern British Columbia was then used, together with Bouguer gravity data, to refine the definition of Precambrian basement domains beneath the Western Canada Sedimentary Basin. Magnetic data are draped at a constant distance above the mapped basement surface to reduce the effects of varying magnetic source depths. Automated interpretation methods that effectively map outlines of magnetic sources are used to characterize the internal structure of the domains and to aid in their delineation. The basement domain map thus derived differs from previous interpretations in the extension of domains further to the southwest due mainly to the availability of new public-domain magnetic data, and the more precise definition of domain boundaries based on the magnetic source location maps.

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Structural analysis and geophysical investigations reveal extended crust on the eastern Ross Sea margin

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The Ford Ranges in Marie Byrd Land (MBL) form the eastern Ross Sea margin, and represent significant topography in continental crust thinned during two episodes of rifting in the Cretaceous. NE-SW extensional faulting occurred in response to separation between Australia-Antarctica, followed by NW-SE extension between New Zealand/Campbell Plateau and West Antarctica. Seismic stratigraphy in the eastern Ross Sea suggests late Early Cretaceous timing. 40Ar/39Ar thermochronometry and apatite fission track determinations record rapid cooling ascribed to tectonic exhumation between 105-98 Ma and 85-67 Ma.

Coordinated geological and geophysical exploration has addressed the prolonged history of extensional tectonics in western MBL, with implications for glacial dynamics in the region. The approach has been instrumental in a region lacking distinctive geological markers for definitive evidence of fault kinematics, and with major structures concealed by extensive ice cover.

On-land structural studies and aerogeophysical mapping (SOAR 1998-2000) locate the eastern boundary of extended crust in the northern Ford Ranges, 250-300 km northeast of the ice grounding line of Edward VII Peninsula. Gravity modeling suggests that the crust thins by 8 to 9 km between the Phillips Mountains and the eastern Ross Sea, with half of the thinning in the northern Ford Ranges. The remainder occurred between the southwest side of Edward VII Peninsula and the Ross Sea continental shelf.

The dominant brittle fault population is NW-striking with steep dips, and accommodated normal sense displacements. Regional NW- trending lineaments coincide with basins mapped in the sub-ice basement by airborne radar. The basins have topographic relief of >1 km and 20-30 km spacing, and are oblique to the trend of the modern passive margin. Steep E-W and NE-SW structures form other important elements of the brittle fault array. NE-SW faults show a consistent regional overprinting relationship, with shallow-plunging fault striae inscribed upon earlier, downdip, normal-sense striae. Thus strike-slip movements reactivate older normal faults, potentially during Cenozoic time, in response to N-S stretching. Presence of Pleistocene basalts at the juncture of NE and E-W structures suggests possible Neogene tectonic activity. Extension in the modern Ross Sea Rift, tectonic subsidence in the Eastern Basin during

Miocene time, doming in the central Marie Byrd Land volcanic province, and/or isostatic adjustments following Last Glacial Maximum could be responsible for modest differential movements. Locally glacial erosion has been significant, according to gravity models of the Hammond Glacier trough that indicate maximum depths of 2.1-2.4 km on the Sultzberger Ice Shelf.

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Aerogeophysics in Dronning Maud Land and the adjacent sea

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The geological structure of Dronning Maud Land is only along the coastal mountain chains of Maudheimvidda, Fimbulheimen and Wohlthat Massif directly for geological observations accessible. North and south of the mountains a thick cover of ice and the adjacent ocean prevent direct observation of the crust. However using airborne geophysics it is possible to fill gaps between geological survey sites and to reveal the structure of the earth's crust hidden either by the overlaying ice sheets or oceans.
Since 1994 the Alfred Wegener Institute operates a combined radio-echo sounding and magnetic sounding system on board of one of its two with ski equipped polar aircraft, of the type Dornier Do228-100, in Dronning Maud Land, Antarctica and Greenland as well. In 1996 the equipment of the aircraft has been supplemented with a gravitymeter and an altimeter. The range of the aircraft is approximately 5 hours and depends strongly on the installed geophysical equipment and on the altitude of the airstrip.
From 1994 to 1999 ice thickness of the area from the coast to 77° S and from Hally to Novolazarevskaya have been successfully mapped using airborne radio-echo sounding. For this survey wintering stations with prepared skiways as well as field camps with unprepared surfaces and elevations up to 3000 m height have been used. In total 89 measurements flights with nearly 400 h of flight time and a length of more than 90,000 km have been carried out, covering a area of roughly 1,000,000 km². Moreover the magnetic field has been mapped during these missions. Another extensive survey mapping magnetic and gravity anomalies along the marine shelf north of the coast of central Dronning Maud Land, the project East Antarctic Margin Aero Geophysical Experiment (EMAGE), has been carried out from 1996-2000 with in total more than 80 flights with cover a area of approximately 450,000 km² more than 80,000 profile kilometer. The aim of this project is to provide further constraints for the geotectonic interpretation of the Gondwana beak-up. For the evaluation of this data set several magnetic base stations and GPS reference stations have been set up at ice rises, grounded parts of the ice sheet and ice-free areas along the coast. Since the austral season 2000/01 a new survey has been set up, mapping magnetic and gravity field as well as the ice thickness along the flight track south of the coast of Dronning Maud Land.
In the talk we will present the aircraft and its capabilities, the measurements and a discussion of their corresponding resolutions. Furthermore we will present data examples, e.g. maps of ice thickness and subglacial topography as well as magnetic anomalies.
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Subice geology inland of the Transantarctic Mountains in light of new aerogeophysical data

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The extreme morphology of the Transantarctic Mountains (TAM) has inspired a variety of models as to their origin. A widely accepted model is that of a flexurally uplifted footwall of a stress-free plate edge bounded by high-angle normal faults. This model predicts a flexurally formed basin on the backside of the TAM: the Wilkes Subglacial Basin (WSB). A 1145-km-long and 116-km-wide aerogeophysical survey from McMudro to Dome C shows several characteristic terrains, however, we do not observe a topographic depression associated with the WSB. West of the TAM, the Bouguer gravity increases in a smooth slope from -150 mGal to -75 mGal. Along this slope, neither the Bouguer nor the free-air gravity show a negative anomaly which could be associated with the WSB. Thetopography, gravity and magnetic data consistently rule out the presence of a basin within our survey area.

We suggest the alternative possibility that the TAM were not uplifted in the rifting that formed the Ross Sea region, but that the Ross Sea region subsided during continental extension. The Ross Sea structure, geologic history and heat flow may be consistent with the collapse of a high plateu of thick crust. In the context of this idea the TAM would be a region on the edge of the plateau that was already high when the plateau extended and collapsed. We will present preliminary results of dynamical modeling using an explicit finite-element method and an elastic-visco-plastic rheology. Preliminary results of this modeling support the idea of a plateau collapse.

Geophysical Evidence for a Geologic Boundary within East Antarctica

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Kinematic and flexural modeling of new gravity data across Lake Vostok reveals a major tectonic boundary bisecting East Antarctica. The analysis of incoming seismic signals images thin crust beneath Lake Vostok consistent with predictions from flexural modeling. This tectonic boundary appears to be the result of thrust sheet emplacement onto a passive continental margin. No data exists to directly date either the timing of passive margin formation or the subsequent shortening phase. Minor normal reactivation of the thrust sheets offers a simple mechanism to explain the formation of the Lake Vostok Basin. A line of 5 earthquakes along this boundary indicates that active tectonics may continue today.

Ice flow, landscape setting, and geological framework of Lake Vostok, East Antarctica

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Lake Vostok, located beneath more than 4 km of ice in the middle of East Antarctica, is a unique subglacial habitat and may contain micro-organisms with distinct adaptions to such an extreme environment. Melting and freezing at the base of the ice sheet, which slowly flows across the lake, controls the flux of water, biota and sediment particles through the lake. The influx of thermal energy, however, is limited to contributions from below. Thus, the geologic origin of Lake Vostok is a critical boundary condition for the subglacial ecosystem. We present the first comprehensive maps of ice surface, ice thickness and subglacial topography around Lake Vostok. The ice flow across the lake and the landscape setting are closely linked to the geologic origin of Lake Vostok. Our data show that Lake Vostok is located along a major geologic boundary. Magnetic and gravity data are distinct east and west of the lake, as is the roughness of the subglacial topography. The physiographic setting of the lake has important consequences for the ice flow and thus the melting and freezing pattern and the lake's circulation. Lake Vostok is a tectonically controlled subglacial lake. The tectonic processes provided the space for a unique habitat and recent minor tectonic activity might have the potential to introduce small, but significant amounts of thermal energy into the lake.

Byrd Glacier Discontinuity: First-order geological and physiographic feature

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With the greatest discharge of ice of any outlet glacier in the Transantarctic Mountains (20.5 km3/yr), Byrd Glacier streams in a nearly straight line from the East Antarctic Ice Sheet to the Ross Ice Shelf, following a 25 km-wide furrow through the mountains. The catchment area of Byrd Glacier is estimated to be approximately 9.0 x 105 km3. A single radio-echo sounding flight up the axis of the glacier in 1978-79 indicated that it occupies a fjord whose bottom is 1.2-1.6 km below sea level. This tremendous breach in the Transantarctic Mountains coincides with the most significant discontinuity in the Neoproterozoic/early Paleozoic Ross orogen, which is exposed throughout the 3,500 km length of the Transantarctic Mountains. With one exception, to the south of Byrd Glacier the rocks are Cambrian age and either unmetamorphosed or metamorphosed to lower greenschist grade (Byrd Group: Shackleton Limestone, Douglas Conglomerate, Dick and Starshot Formations). At the mouth of Byrd Glacier at Mt. Madison, the rocks are the lower amphibolite grade Selborne Group, which is now correlated with the Byrd Group. Thus, it appears that all sedimentary and metasedimentary rocks for 150 km south of Byrd Glacier are Cambrian in age. With the exception of a small pluton at Mt. Madison, the rocks for 150 km south of Byrd Glacier also lack plutonic intrusions. North of Byrd Glacier the rocks are all crystalline, with the preponderance of outcrops plutonics of the Granite Harbour Intrusives, and to a lesser extent upper amphibolite grade metamorphics of the Horney Formation. The depositional age of the Horney Formation is unknown; however, the next outcrops of metasedimentary and volcanic rocks to the north are the Neoproterozoic Skelton Group, cross cut by plutons dated at 550 Ma. If correlation of Skelton Group and Koettlitz Group is correct, then there are no known sedimentary rocks younger than Neoproterozoic in all of southern Victoria Land. What is the true nature of the discontinuity in the Ross orogen across Byrd Glacier? Was it a boundary already at the time of Cambrian deposition to the south? Had it marked a boundary to tectonic activity to the north during the Neoproterozoic? Is there a deeper crustal signature inherited from blocks of different ages, Paleoproterozoic or Archean? One thing that is certain is that the north side of Byrd Glacier underwent significantly greater exhumation following the Ross orogeny, than did the rocks to the south. The Kukri erosion surface beneath basal Beacon Supergroup appears to be at approximately equal elevations across Byrd Glacier, so significant differential vertical offset is not indicated during uplift of the present day Transantarctic Mountains. However, strike-slip movement along Byrd Glacier has been postulated by several authors. Geophysical characterization of the crust underlying the Transantarctic Mountains to the north and south of Byrd Glacier, as well as in the adjacent regions beneath the East Antarctic Ice Sheet and Ross Ice Shelf may offer important constraints toward our understanding of the Byrd Glacier discontinuity.

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Lake Concordia: a second significant subglacial lake in East Antarctica?

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We present evidence for a subglacial lake below the East Antarctica ice sheet, 120 km from Dome Concordia, with active basal processes at the ice/lake surface boundary. This is the first documentation of such processes in a subglacial lake other than Lake Vostok. This ~800 km2 subglacial lake, Lake Concordia, is substantially smaller in size than Lake Vostok which is ~10,000 km2, but is still one of the larger documented subglacial lakes. We have used gravity data to estimate the water depth of the lake to be <1000 m. The lake, the size of Lake Geneva, is situated in a northwest-southeast trending valley that extends to the east of Dome Concordia. The ice sheet flow is slightly oblique to the long axis of the lake. The ice sheet thins by 150 m as it traverses the lake creating a tilted ice ceiling. As the ice sheet thins there is evidence for basal freezing. The basal freezing is seen in increased elevation of internal layers in the lower 2 km of the ice sheet with respect to the lake surface in the north. Basal melting is also seen in the decreased elevation of internal layers in the lower 2 km of the ice sheet with respect to the lake surface in the south. The basal melting is coincident with a region of inferred grounding. Internal deformation is also observed coincident with the area of inferred grounding. The radar data suggest that Lake Concordia has active exchange with the ice sheet and may therefore be hospitable to biota and a viable site for future subglacial lake exploration.

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Integrating airborne and new satellite magnetic and gravity observations for lithospheric investigations of the Antarctic

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We investigate the utility of combining satellite and near-surface magnetic and gravity anomalies for enhanced studies of the Antarctic lithosphere. We process magnetic data from the Ørsted satellite launched in February, 1999 to confirm the veracity of the Antarctic lithospheric anomalies mapped by Magsat over twenty years ago. Our analysis reveals that core field model estimates between degree 11 and 13 can contain significant lithospheric components. To extract these components, we use the pseudo magnetic effect of a model of Antarctic crustal thickness variations that we obtain by spectrally comparing the terrain gravity to free-air gravity anomalies. By combining the crustal thickness effects with the degree 13 and higher anomaly components, we obtain comprehensive magnetic anomaly maps of the Antarctic lithosphere from the Ørsted and Magsat observations.

The comprehensive magnetic anomalies provide important constraints for estimating near-surface magnetic anomalies in the regional coverage gaps of the Antarctic magnetic anomaly map being produced by the Antarctic Digital Magnetic Anomaly Project (ADMAP). We develop an effective procedure for estimating near-surface values in unmapped areas from the joint inversion of satellite and available near-surface data. Relative to the Magsat data, we find that the Ørsted data offer significant advantages for this application because of their greatly enhanced measurement accuracy. However, even greater advantages are anticipated when the high-accuracy, lower altitude magnetic and gravity data become available from the CHAMP mission that was launched in July, 2001.

We extend the joint inversion of satellite and near-surface anomalies for modeling the crustal magnetic properties of the Maud Rise in the Southwest Indian Ocean off the coast of East Antarctica. We also find that the quantitative crustal model for the Maud Rise can be extrapolated via the satellite anomalies to the conjugate Agulhas Plateau off the South African coast for new tectonic perspectives on the Cretaceous breakup of Gondwana.

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Aerogeophysical polar explorer (APEX) for bi-polar lithospheric investigations

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Our poor knowledge of the geology of the polar regions contributes to significant gaps in our understanding of global tectonic and paleoenvironmental evolution. Recent advances in navigation technology permit us to efficiently map at high resolution the gravity and magnetic anomaly fields over the polar regions using long-range aircraft. For example, during a typical 2-3 month polar field season, an aircraft such as the CASA CN-235 or Fokker F-27 navigated by differential GPS can map over 200,000 sq km (an area about twice the size of Ohio) at a 20 km resolution. These data would provide the needed information to estimate the structure, age and evolution of the polar lithosphere and can be used to locate areas for further study by seismic, drilling, and other surface-based geophysical and geological programs.

A dedicated APEX aircraft can be implemented to service the requirements of both Arctic and Antarctic geoscientists because the two field seasons are complementary. Hence, a decade long APEX program could fulfill long term aerogeophysical objectives for Antarctica while mapping the unexplored and poorly understood regions of the Arctic. The APEX aircraft could be outfitted with radars to map the distribution, thickness and other properties of ice for various geological, glaciological, marine and climatological applications. The APEX could also be equipped with detectors to monitor the environment, and to provide ground truth information for satellite monitors, as well as additional information on atmospheric chemistry, biomass, ice and oceanic processes. The aircraft could also be utilized to deploy buoys and other monitoring devices along the survey route.

These considerations suggest that an APEX could well serve a considerable spectrum of polar interests in academia and the government agencies (e.g., NSF, USGS, NASA, NRL, NIMA, NOAA, EPA, etc.). Accordingly, it is recommended that the bi-polar community of geoscientists contribute to the planning, production, and implementation of an APEX with the goal of mapping the polar geopotential fields as a major contribution towards resolving the structure and evolution of the polar lithospheres.

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Thermal Regimes and Architecture of the Crust and Upper Mantle Inferred from Electrical Conductivity Investigations

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Deformation of the continents is heterogeneous and reflects the interplay between force and strength. Variations of strength in both brittle and ductile regimes have fluid content and thermal contrasts as primary controls. These physical properties and other geochemical fluxes can be mapped according to their electrical conductivity using electromagnetic (EM) survey methods, specifically magnetotellurics (MT). Constraints on crust/mantle composition and thermal history narrow the possible physical states and fluid compositions inferred from imaged geophysical structure. Geochemical flow paths implied from geophysical structure can provide insight to fluid/magma conduits and ore deposition. Other mechanisms of high conductivity such as graphite can be discriminated according to macro-scale textures and external constraints on temperature and oxidation state. Experiences in classic tectonic environments world-wide, including results from two successful deployments over thick ice sheets of the Antarctic interior, demonstrate the potential of deep conductivity surveying.

In active compressional regimes, lower crustal fluids can be created in zones of crustal thickening and root zone formation via conductive heating and radioactivity. The New Zealand South Island is a prime example that shows a highly conductive zone within the lower crustal root. High conductivity extends to the surface from the lateral limits of this deep zone and coincides with observed modern veining, high-temperature fluid flux, and gold deposition of lower crustal origin. Seismicity in the central South Island is low, compatible with a lack of stress buildup in fluidized, weakened lithologies. In active extensional regimes, lower crustal fluids can be produced only if deep, mantle derived magmatism occurs to release fluids via crystallization. Otherwise, extension per se actually cools the deep crust and uppermost mantle so that fluids should be resorbed and conductivity is not enhanced. Investigations in the magmatic, extending Great Basin of the western U.S. show strong correlations between degree of lower crustal conductivity and rate of extension within the province. The lower crustal conductor can be anisotropic with principal directions, and thus degree of fluid/melt interconnection, showing influence of pre-extensional, continental margin fabric. Numerous high-angle, crustal-scale, conductive fault zones connect the lower crust to the near surface. These may act to preserve the low effective elastic thickness of the Great Basin despite secular cooling and may exemplify the mid-crustal fault zones in which large earthquakes nucleate. In the quiescent Great Basin interior, relatively high upper mantle resistivities imply a geotherm that is near the average current mantle adiabat and is not plume-like. The transition to the stable Colorado Plateau to the east, often compared to the West-East Antarctic transition, suggests a mode of extension which is highly non-uniform with depth and is not due to simple gravitational collapse due to lateral warming.

Two successful deployments of deep conductivity profiling within the Antarctic interior using the MT method took place in the 1990's. Novel developments in electrode preamp design were required to overcome the high contact impedance (up to 2 M-ohm) at the electrode-firn interface for the electric field component. The first profile deployment took place out of the central West Antarctica (CWA) camp in concert with seismic and potential field studies to assess the thermal regime there in extended West Antarctica. High crustal and upper mantle resistivities were imaged which are consistent with extension that is long inactive or amagmatic. The second MT experiment took place across the South Pole Station area to assess crustal structure and thermal regime in this high-standing area of East Antarctica. A conductive sedimentary section, possibly the Beacon Supergroup, immediately under the 3 km ice sheet was inferred, which showed pronounced lateral variations in thickness reminiscent of horst-graben structure. The lower crust and upper mantle also are of high conductivity, which appears uniform over at least the 54 km profile length. This suggests an enhanced thermal regime for the South Pole region that may be influenced by plume processes implied in other studies. A strong, crustal-scale conductor running parallel to the acquired profile, and normal to the trend of the Trans Antarctic Mountains (TAM), also is imaged suggesting a fossil suture zone containing graphitized metasediments or perhaps sulfides. The principal difficulty in obtaining high-fidelity MT recordings in the Antarctic interior is electrostatic noise generated by blowing ice crystals, which may be overcome by lengthening the E-field bipoles and recording times. Recording times longer than those for equivalent surveying at mid-latitudes also are needed to robustly reject non-plane wave EM outliers due to ionospheric electric currents in the polar electrojet.

The Transantarctic Mountains Seismic Experiment (TAMSEIS): Investigating the Lithospheric Structure of the East-West Antarctica Boundary

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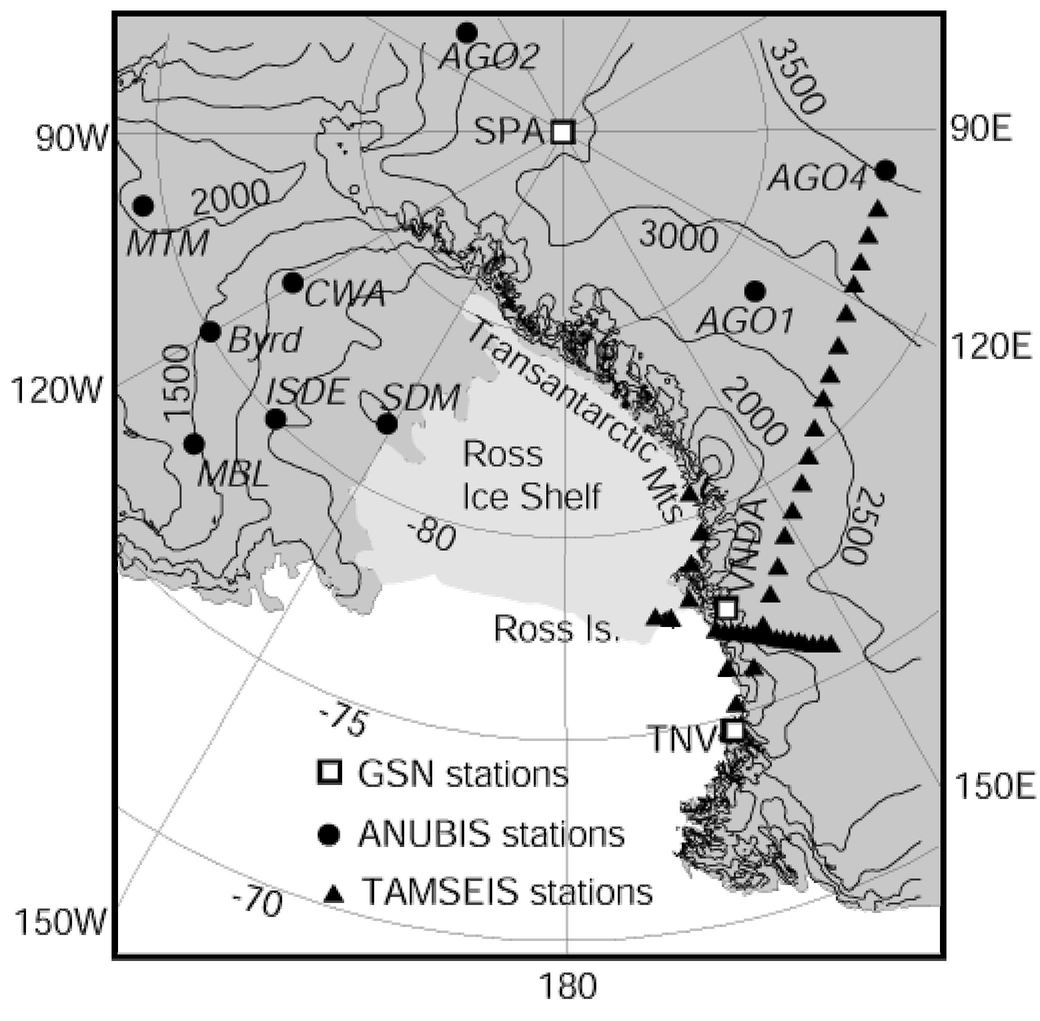
Although it has long been recognized that Antarctica is comprised of two distinct tectonic regions, East and West Antarctica, little is known about deep continental structure of the boundary dividing them. In November 2001, we installed 42 broadband seismic stations extending from the Ross Sea to the East Antarctic Plateau in order to investigate the lithospheric structure beneath the Trans-Antarctic Mountains and East Antarctica. The experiment consists of three major components (figure 1): 1) A 1400 km linear array of 17 broadband seismic stations extending from the high central regions of the East Antarctic craton to the Transantarctic mountains 2) An intersecting 400 km dense linear array of 16 broadband seismic stations extending from the coast across the Transantarctic mountains nearly perpendicular to the strike of the range in the Dry Valleys region. 3) 11 broadband stations in coastal regions around Ross Island and Terra Nova Bay. The seismographs will remain deployed until the 2003-2004 season. An aerogeophysical survey was also carried out by the SOAR group along the longest transect.

Data from this experiment will be used to address two outstanding questions: 1) What mechanism is responsible for the uplift of the Trans-Antarctic Mountains? Many mechanisms have been proposed, including delayed phase changes, simple shear, lithospheric flexure, and transform-flank uplift, all of which make assumptions about upper mantle structure beneath and adjacent to the mountain front. 2) What lithospheric structure is responsible for the topography and high modal elevations of the East Antarctic Craton? Previous proposals have included unusually thick continental crust and buoyant upper mantle.

Most of the stations were serviced in January 2002, and were operating well. Satellite ARGOS state-of-health telemetry from a subset of stations indicates that they operated reliably until about the end of March 2002. Preliminary receiver function analysis of data from stations near McMurdo indicates crustal thicknesses of about 20 km near Ross Island, 38 km in the Trans-Antarctic Mountains, and 34 km in the Wilkes Subglacial Basin.

Weins continued…



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The Prince Charles Mountains Expedition of Germany-Australia (PCMEGA) 2002-2003

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The Prince Charles Mountains are one of the few parts of east Antarctica with significant rock exposure of Precambrian geology and the only such region to occur substantially (>500 km) inland from the continental margins. Their current exposure above the ice plateau is related to relatively recent uplift along the flanks of the Lambert Graben, one of the most important crustal-scale structures in east Antarctica. This exposure reveals the best geological cross section through the east Antarctic shield. The rugged and remote nature of these mountain ranges, particularly in the southern Prince Charles Mountains (sPCMs), where elevations exceed 3300 m and the nearest permanent stations (Davis and Mawson) are ~750 km to the north, have restricted previous investigations to reconnaissance field programs. Past expeditions to the sPCMs have involved a small number of scientists from Russia (between 1983 to 1991) and Australia (1960/61; 1970-74; 1998/99). This critical region remains the most poorly understood outcrop area in east Antarctica. The overall aim of the PCMEGA expedition is to dramatically improve our knowledge of the sPCMs with a comprehensive international field program involving scientific personnel with a wide range of experience and expertise. This program will be divided into four principal sub-projects with the following objectives.

To establish the Phanerozoic to recent evolution of the sPCMs with an emphasis on the development of the Lambert Graben during the Cretaceous break-up of Gondwana, and subsequent episodes of uplift, denudation and glaciation.

To test recently proposed models suggesting that the Lambert Graben region is at the edge of a major Cambrian suture between at least two Precambrian blocks that collided at 550 Ma during the assembly of Gondwana.

To identify the principal Precambrian crustal blocks in the sPCMs and attempt to correlate them with other Precambrian crustal fragments in Antarctica, Australia, India and elsewhere.

To determine the regional crustal structure of the sPCMs using a combination of airborne geophysical surveys and isotope mapping of intrusive rocks to identify tectonic blocks and boundaries concealed beneath the present-day surface.

The geophysical program within this expedition will be to investigate the multidimensional subsurface structures in the sPCMs. The program will involve collaboration between the Australian Antarctic Division (AAD), Bundesanstalt für Geowissenschaffen und Rohstoffe (BGR), The University of Melbourne and other invited participants. The BGR will supply the ice radar unit for the expedition. A geophysical company has been contracted to supply the aeromagmetic and gravity equipment and provide 2 staff for the program. This company would also be responsible for the initial processing of the data in the field which will be collected at a line spacing of 5km. The AAD will be supplying a Twin Otter aircraft for this program and will supply all the logistic support. The geophysical equipment will be fitted and tested in the aircraft before it flies to Antarctica. This equipment would then be transported to Antarctica by ship.

The geophysical work envisaged for this program will target the critical transitions that are believed to exist in the Archaean and Proterozoic sequences, their boundary with the ~500 Ma zones and the extent of the Lambert Graben. Aeromagnetics will be the key technique to identify such boundaries and can resolve key focal problems such as whether the marginal faults of the graben are controlling the distribution of the glacial drainage systems. Of further interest is the question whether the faults have a strike-slip component and whether there is a direct relationship to regional transform faults that could control the geometry of the Amery-Lambert Glacier system and the bathymetry of Prydz Bay. This new geophysical data will be integrated with the existing 5 and 20 km spaced Russian data sets and the AAD glaciological ice-radar data sets.

Mesozoic-Cenozoic Geology of Antarctica: Progress and Unknowns

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Mesozoic-Cenozoic continental rifting, block translations, uplift of the Transantarctic Mountains, and widespread magmatism, are the results of intraplate processes associated with progressive breakup of Gondwanaland to form the Antarctic plate. Geophysical and geological studies over the last decade have improved our understanding of the crustal structure of some sectors of the Ross Sea and its margins, of central West Antarctica, and of the Antarctic Peninsula-Weddell Sea sector. Yet, enduring questions remain concerning the kinematic histories and structural boundaries of West Antarctic crustal blocks, and the tectonic segmentation of East Antarctica remains virtually unknown. Better delineation of structural boundaries is required to improve continental reconstructions, unravel the intraplate motions of crustal blocks as Mesozoic-Cenozoic breakup progressed, and to map the lithospheric template that exerts influence on modern intraplate deformation.

New aeromagnetic surveys and regional magnetic compilations are providing new insights into the position and extent of major crustal boundaries and the magmatic architecture of arc and rift terranes. Nevertheless, much ambiguity about the age and nature of features remains because key ancillary data sets required to reach unique geological interpretations are lacking.

The increasing archive of thermochronological data for the Transantarctic Mountains has documented regional Cretaceous and Cenozoic uplift phases. The paucity of age control for on land structures and for offshore rift basin strata in the Ross embayment continues to impede progress in understanding the time-space linkages between mountain uplift and rifting episodes. Tantalizing new data on Eocene-Oligocene spreading in the Adare Trough, on Oligo-Miocene rifting in the Victoria Land Basin (Cape Roberts Project drilling results), on Cretaceous and Neogene rift history and volcanism in eastern Ross Sea/Marie Byrd Land, and on the nature/existence of basins on the 'backside' of the Transantarctic Mountains, all provide isolated pieces in the regional puzzle. Little information exists on regional structure in the central and southern Transantarctic Mountains, beneath the Ross Ice Shelf, at junctions between major West Antarctic crustal blocks, and across East Antarctica.

There is increasing interest in the extent and nature of neotectonic activity in Antarctica, currently being investigated by a variety of new geodetic, seismic, geomorphic, structural and volcanological studies. There is major global interest in the feedback mechanisms between climate, landscape and geodynamic processes and Antarctica provides a unique laboratory to investigate the relationship between intraplate deformation and the evolution of polar climate and ice sheets. Better information on the thermomechanical properties of the Antarctic crust and mantle, the subglacial landscape and its evolution through the Cenozoic, the geological controls on ice dynamics, and the influence of the ice sheets on volcanism, erosion, and the continental stress regime are required.

Advancing our understanding in all of these realms will require a new era of integrated, interdisciplinary research. Land-based and airborne geophysical surveys studies must be linked, integrated with data from satellite remote sensing, coordinated with topical geological studies, and tied to targeted drilling programs to provide essential age constraints.

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Exploration of Antarctic Lithosphere: Neotectonic Objectives

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Antarctica provides a unique laboratory to explore the influence of tectonics on ice sheets, sea level and climate processes and, conversely, the influence of the ice sheets on continental-scale crustal motions, on the stress and strain regimes in the lithosphere and on rates and volumes of magmatism. Active crustal deformation (uplift, faulting) and active volcanism (plume-related?) are widespread in West Antarctica and may occur beneath the ice sheet in East Antarctica where subglacial mountains and basins are present. Antarctica is also undergoing active glacial loading and unloading, which induces isostatic motions and applies unusual stresses to the crust. Active tectonic processes may influence the stability of the Antarctic ice sheets. The Scientific Committee for Antarctic Research (SCAR) sponsors the ANTarctic NeoTECtonic (ANTEC) program to improve understanding of the unique character of the neotectonic regime of the Antarctic plate. The ANTEC program is promoting interdisciplinary research aimed at addressing a range of questions, such as:

Where are active tectonics occurring?

- Where are there crustal boundaries - active or ancient?
- What is the extent of the West Antarctic Rift system?
- How integral is the East Antarctic craton?
- Are there unique Antarctic driving forces?
- What is the interplay between ice sheets and tectonics?

What is the nature of feedback between mantle processes, crustal structure, glacial dynamics and magmatism?

- What are the mantle processes (thermal anomalies/mantle plumes) controlling magmatism?
- What is the relationship between tectonism and magmatism?
- What is the nature of active volcanism (volcano dynamics)?
- What is the relationship between glaciation and volcanism?

What are the feedback mechanisms between geodynamics, climate and ice sheets?

- What is the interplay between tectonic, climatic and glacial influences during landscape evolution?
- What is the role of plate configuration, vertical tectonics, and paleotopography in glacial inception?
- What are the rates, styles, and mechanisms of uplift and erosion around Antarctica?

- What is the history of Cenozoic landscape evolution?
- What are the neotectonic landscape features?
- What are modern uplift and erosion patterns?

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Lateral Variations in the Guided Wave Attenuation in the Eurasian Crust with Tectonic Implications

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The seismic Lg wave train can be treated as guided waves traveling in the continental crust. The Lg attenuation rate, or its inverse, the Lg Q, reflects the crustal average of shear wave Q. Lg Qo (Lg Q at 1 Hz) is strongly dependent on the temperature or fluid content in the crust. Over the past two years we have been mapping lateral variations in Lg Q in eastern Eurasia using data from various permanent and passive seismic stations. Research so far reveals that Lg Qo is higher than about 550 is stable regions including eastern Europe and much of Siberia and Mongolia. These values are similar to those found in the stable eastern U.S. In central Asia and northern China Lg Qo decreases into the range of 400-500. In eastern China which is characterized by recent rifting, Qo is about 200 which is compatible to that in the Basin and Range province in the U.S. The most striking low Qo is found in the Tibetan plateau, where the crustal temperature and/or fluid content should be higher than normal. The measured Qo is about 126 in southeastern Tibet and drops to below 100 in central Tibet. Qo becomes even lower (60-90) in southern Tibet. In the vicinity of the Yalung-Tsangbu Suture just behind the High Hymalayas, we mapped a zone of low Qo of 60 which causes the Lg to disappear after a propagation distance of about 100 km. The area where the lowest Lg Qo is found coincides with the prominent mid-crust reflectors found during an active-source PASSCAL experiment. Those reflectors were interpreted as being the top of a molten layer. Hence the low Qo of 60 is likely caused by a prominent mid-crustal melting.

The factor of 10 variations in Lg Qo provide a good indicator of the past tectonic history and current tectonic processes in eastern Eurasia. Work is underway to complete a large-scale Lg Qo tomography. The measurements of Lg Qo, if combined with surface wave inversion for depth-varying shear wave Q structures, will likely provide similar constraints on the temperature and fluid content in the crust under other continents, such as Antarctica.

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Appendix IV

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