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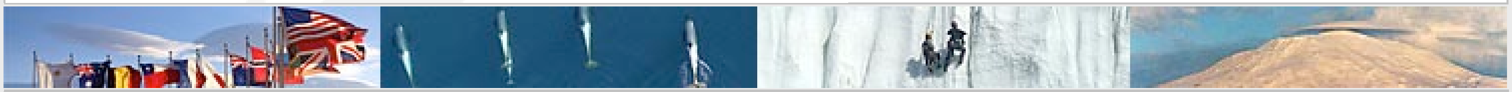

GEOLOGY AND GEOPHYSICS

Mt. Erebus is the southernmost active volcano in the world. At 3,794 meters in height, it forms the summit of Ross Island at the southwestern corner of Ross Sea. It was named by Captain James Clark Ross in 1841 for his ship, the Erebus. (*NSF photo by Jerrod Clausen*)

In this section:

Overview

Antarctica is not only one of the world's seven continents, it also comprises most of one of a dozen major crustal plates, accounting for about 9 percent of the Earth's continental (lithospheric) crust. Very little of this land is visible, however, covered as it is by the vast East Antarctic Ice Sheet and the smaller West Antarctic Ice Sheet. These ice sheets average some 3 kilometers deep and form a virtual vault; 90 percent of the ice on Earth is here. And it is heavy, depressing the crust beneath it some 600 meters (m). These physical characteristics, while not static, are current. Yet Antarctica is also a time machine, thanks to the sciences of geology and geophysics, powered by modern instruments and informed by the paradigm of plate tectonics/continental drift.

Geologists have found evidence that there was once a forested supercontinent, which they call Gondwanaland, in the Southern Hemisphere. Before the Earth's shifting plate movement began to break the continent up 150 million years ago, Antarctica was a core piece of this assembly; the land adjoining it has since become Africa, Madagascar, India, Australia, and South America. Though the antarctic plate has drifted south only about a centimeter a year, geologic time eventually yields cataclysmic results. The journey moved the antarctic plate into ever-colder, high-latitude climates, at a rate of about 4°C for each million years; eventually conditions changed dramatically, and Antarctica arrived at a near polar position. This astounding story—written in the language of rocks and fossils—is locked in beneath the ice and the sea, and in the bedrock below them both.

As the ice sheets developed, they assumed, through their interaction with oceanic and atmospheric circulation, what has become a key role in modulating global climate. As a bonus, the South Pole presents a strategic point to monitor the Earth's seismic activity. Antarctica is the highest continent on Earth (about 2,150 m above sea level), with its fair share of mountains and volcanoes; thus, many generic questions of interest to Earth scientists worldwide also apply to this region. Some specific issues of interest to the Antarctic Geology and Geophysics Program include the following:

- exploring new horizons in geology with discoveries that range from new dinosaur fossils to meteorites from Mars;
- determining the tectonic evolution of Antarctica, from its central role in the breakup of the Gondwana supercontinent to the active deformation driving present-day volcanism, rifting, and orogenesis;
- observing unique geologic processes, such as the mysterious formation of subglacial lakes or the aeolian sculpting of the Dry Valleys, in action;
- determining Antarctica's crustal structure;
- determining how the dispersal of antarctic continental fragments may have affected the paleocirculation of the world's oceans, the evolution of life, and the global climate (from prehistoric times to the present);
- reconstructing a more detailed history of the ice sheets, identifying geological controls to ice-sheet behavior, and defining geological responses to the ice sheets on regional and global scales; and
- deciphering paleoenvironmental records, through drilling of the continental margin, to understand Antarctica's role in global climate, ocean circulation, and the evolution of life.

These issues will all become clearer as scientists improve their models of where, when, and how crustal plate movement wrought Antarctica and its surrounding ocean basins. The Antarctic Geology and Geophysics Program funds investigations into the relationships between the geological evolution of the antarctic plate and the life and processes that can be deduced to accompany it—the paleocirculation of the world's oceans, the paleoclimate of the Earth, and the evolution of high-latitude biota. A current emphasis is the West Antarctic Ice Sheet Program, focused on the smaller of the continent's two ice sheets and conducted jointly with the Antarctic Glaciology Program. Several important research support activities are underway as well:

- **Meteorites:** In partnership with the National Aeronautics and Space Administration and the Smithsonian Institution, the program supports meteorite collection through the antarctic search for meteorites (ANSMET) and chairs an interagency committee that is responsible for curating and distributing samples of antarctic meteorites.
- **Mapping and geodesy:** In partnership with the U.S. Geological Survey, the program supports mapping and geodetic activities as an investment in future research in earth sciences. The U.S. Antarctic Resources Center (USARC) constitutes the U.S. Antarctic Program's contribution to the Scientific Committee on Antarctic Research library system for earth sciences; housed here is the largest collection of antarctic aerial photographs in the world, as well as many maps, satellite images, and a storehouse of geodetic information.
- **Marine sediment and geological drill cores:** In partnership with Florida State University's Antarctic Marine Geology Research Facility, the program manages and disseminates marine sediment and geological drill cores mined in Antarctica. The collection includes an array of sediment cores as well as geological drill cores from the Dry Valley Drilling Project, the Cenozoic Investigations of the Ross Sea Drilling Program, and the Cape Roberts Drilling Project. The facility fills requests for samples from researchers worldwide and also accommodates visiting researchers working onsite.

ANDRILL.

David M. Harwood, University of Nebraska–Lincoln; Robert M. DeConte, University of Massachusetts; Thomas R. Janecek, Florida State University; Terry J. Wilson, Ohio State University; and Ross D. Powell, Northern Illinois University.

ANDRILL (Antarctic Drilling), an international program representing over 150 scientists from Germany, Italy, New Zealand, the United Kingdom, and the United States, is designed to investigate Antarctica's role in Cenozoic global environmental change. ANDRILL will obtain a record of important Eocene, Neogene, and Holocene stratigraphic intervals in high southern latitudes and will address four themes:

- the history of the antarctic climate and ice sheets,
- the evolution of polar biota,
- antarctic tectonism, and
- Antarctica's role in the Earth's ocean-climate system.

This research will lead to insights into

- the development of the antarctic cryospheric system (ice sheet, ice shelf, and sea ice);
- the magnitude and frequency of cryospheric changes;
- the influence of ice sheets on Eocene to Holocene climate, the modulation of thermohaline ocean circulation, and eustatic change; and
- the evolution and timing of major tectonic episodes and the development of sedimentary basins.

The successful retrieval of cores and excellent depth of penetration from fast-ice, ice-shelf, and land-based platforms is ensured by the improved drilling system. The program will provide new, seismically linked and well-constrained Cenozoic stratigraphic records from locations proximal to the antarctic cryosphere. Empirical data garnered from these records will calibrate numerical models and will allow new constraints to be placed on estimates of ice volume variability, marine and terrestrial temperatures, the timing and nature of major tectonic episodes, and the development of Antarctica's marine, terrestrial, and sea-ice biota.

This research will contribute to the development of strategies to cope with future climate change, provide insight into relationships between ice-sheet fluctuations and volcanic and seismic hazards, and improve models of glacially influenced sedimentary rift basins.

The project will also contribute to other international science goals, bring together international teams, and provide opportunities to share antarctic earth science with the global community. ANDRILL will foster strong partnerships with established educational programs to develop a broad array of activities designed to educate policymakers, K–12 teachers, students, and the community at large. (G–049–M; NSF/OPP 03–42484, NSF/OPP 03–42407, NSF/OPP 03–42408, NSF/OPP 03–42436, and NSF/OPP 03–42445)

Antarctic mapping, geodesy, geospatial data, and satellite image mapping.

Jerry L. Mullins, U.S. Geological Survey.

The U.S. Geological Survey collects data from several instruments such as the Global Navigation Satellite System to provide mapping, geodesy, geospatial data, and satellite image mapping to the U.S. Antarctic Resource Center (USARC). Year-round data acquisition, cataloging, and data dissemination will continue in the USARC in support of surveying and mapping. Field surveys are planned as part of a continuing program to collect the ground control data required to transform existing geodetic data into an Earth-centered system suitable for future satellite-mapping programs and to reinforce extant control of mapping programs to support future scientific programs. Landsat (Land Remote-Sensing Satellite) data will be collected to support satellite image-mapping projects. These maps will provide a basis for displaying geologic and glaciologic data in a spatially accurate manner for analysis. They will also support future expeditions by providing a basis for planning scientific investigations and data collection. In addition, spatially referenced digital cartographic data will be produced from published maps.

Geodetic projects are planned as part of a continuing program aimed at building the continent-wide GIANT (Geodetic Infrastructure for Antarctica) system, which will support a wide range of U.S. and international scientific research objectives by

- establishing and maintaining a framework of permanent geodetic observatories,
- extending and strengthening the existing network of stations linked to the International Terrestrial Reference Frame,
- establishing geodetic coordinates at identifiable points for georeferencing satellite image-mapping projects,
- maintaining and calibrating tide-gauge instrumentation,
- carrying out absolute gravity measurements,
- applying new high-accuracy remote-sensing measurement technologies such as airborne laser altimetry and digital cameras, and
- expanding the online geodetic database with new and historical data.

The geodetic field program is supported by a cooperative arrangement with Land Information New Zealand. (G–052–M/P/S; NSF/OPP 02–33246)

The antarctic search for meteorites (ANSMET).

Ralph P. Harvey, Case Western Reserve University.

Since 1976, ANSMET (the antarctic search for meteorites program) has recovered more than 14,000 meteorite specimens from locations along the Transantarctic Mountains. Antarctica is the world's premier meteorite hunting ground for two reasons:

- First, although meteorites fall at random all over the globe, the likelihood of finding one is enhanced if the background material is plain and the accumulation rate of terrestrial sediment is low; this makes the East Antarctic Ice Sheet the perfect medium.
- Second, along the margins of the sheet, iceflow is sometimes blocked by mountains, nunataks, and other obstructions; this exposes slow-moving or stagnant ice to the fierce katabatic winds, which can deflate the ice surface and expose a lag deposit of meteorites (a representative portion of those that were sprinkled throughout the volume of ice lost to the wind). When such a process continues for millennia, a spectacular concentration of meteorites can be unveiled.

The continued recovery of antarctic meteorites is of great value because they are the only currently available source of new, nonmicroscopic extraterrestrial material. As such, they provide essential "ground truth" about the composition of asteroids, planets, and other bodies of our solar system. ANSMET recovers samples from the asteroids, the Moon, and Mars for a tiny fraction of the cost of returning samples directly from these bodies.

During the 2004–2005 field season, ANSMET's main field party (eight people) worked at the LaPaz icefields, approximately 250 miles from Amundsen–Scott South Pole Station. More than 1,000 meteorites were recovered from the site during visits in 1991, 2002, and 2003. The field team continued systematic searches of the icefields in an effort to recover a representative sample of the extraterrestrial material falling to Earth.

This year's fieldwork will focus on a full-scale meteorite recovery in the Miller Range icefields. A detailed reconnaissance of these icefields in 2003 yielded 200 specimens, including a Martian meteorite, and demonstrated that a systemic survey would be valuable. (G–057–M and G–058–M; NSF/OPP 99–80452)

The timing of the Holocene climate change in the McMurdo Dry Valleys, Antarctica.

Carolyn B. Dowling, Arkansas State University; Glen T. Snyder, Rice University; W. Berry Lyons, Ohio State University; and Robert J. Poreda, University of Rochester.

The McMurdo Dry Valleys of southern Victoria Land constitute the largest ice-free region in Antarctica. Because most of the perennially ice-covered lakes there have closed basins, small changes in climate can have profound effects on water levels and aqueous chemistry. The limnology of these lakes has revealed important details about climate change in this region, which is affected by both the West and East Antarctic Ice Sheets and the Ross Ice Shelf. The lakes in the Dry Valleys, despite their geographic proximity, have not experienced the same drawdown and refilling history during the Holocene. In addition, the gain or loss of ice cover on the lakes is important because ice restricts the exchange between lake water and the atmosphere, limits lake circulation, and offers organisms a defense against the harsh winter.

We will provide information about the overall climate history of the McMurdo Dry Valleys, including data about lake levels, the timing of hypolimnia formations, and the presence or absence of ice cover. Data from dissolved gases, helium and other isotopes, and tritium from Lake Joyce (Pearse Valley), Lake Vanda (Wright Valley), and Lake Garwood (Garwood Valley) will impose new constraints on the Holocene climate history of the Dry Valleys. The data we collect, coupled with information from marine sediments, ice cores, and lakes, will provide a more complete picture of the climate history of the McMurdo Dry Valleys through the Holocene.

Our research will also improve understanding of the origin of cryogenic brines in polar regions. Isotope analyses will significantly influence our understanding of how these brines develop and how they migrate over time.

Students working on this research will gain experience both in the laboratory and in the field. In addition, an online limnology module, describing the physical, chemical, and biological aspects of lakes (with special emphasis on Dry Valley lakes), will be created for classes throughout the United States to use. Interpretive material and teaching and study guides will accompany the material. (G–060–M; NSF/OPP 04–40892, NSF/OPP 04–40686, NSF/OPP 04–40709, and NSF/OPP 04–40672)

Deducing the climate in late Neogene Antarctica from fossil-rich lacustrine sediments in the Dry Valleys.

David R. Marchant, Boston University, and Allan C. Ashworth, North Dakota State University.

Ancient lake sediments deposited alongside former outlet and alpine glaciers in the Dry Valleys are sensitive indicators of past climate and ecological change. We will analyze 17 former lake sites above 1,000 meters on the north wall of central Taylor Valley and in north-facing valleys of the Asgard and Olympus Ranges. Chronological control comes from argon isotope analyses of interbedded volcanic ash. Lake sediments over 13 million years old contain layers of well-preserved pleurocarpous mosses, diatoms, woody stems, and insects; younger sediments lack such fossils. The fossil-rich lacustrine sediments of the Dry Valleys contain the only known in-situ tundra-type flora and fauna in the Transantarctic Mountains outside the Beardmore Glacier region.

Our objectives include

- developing a better characterization of the distribution of ancient lakes and their flora and fauna,
- securing a more refined chronology,
- producing a geochemical signature for glass within ice-marginal lakes, and
- providing a comparison for previously mapped terrestrial vegetation in the central Transantarctic Mountains.

Our results will help place the modern Dry Valley lakes in a long-term framework and will facilitate dating among deposits across the Transantarctic Mountains. Moreover, our work will improve dating in nearby marine cores (Cape Roberts).

The key questions we will address are as follows:

- When did the polar desert replace the Neogene tundra?
- Was the climate change that caused the biotic turnover unidirectional and permanent, or did short-lived, warmer climatic conditions, supporting tundra, return to the Dry Valleys after the mid-Miocene?
- Were warmer conditions regional or continental?
- What variation is there in species content and richness among Neogene fossil sites in the Transantarctic Mountains?
- Was the extinction of Gondwanaland biota gradual, or were there dispersal episodes during warmer intervals that replenished the biota from South America, New Zealand, and Tasmania, thus delaying extinction until the Pliocene?

This research will introduce students to a unique synthesis of the Dry Valleys; results will be disseminated in scientific journals and in a special volume of the American Geophysical Union's Antarctic Research Series. (G–063–M; NSF/OPP 04–40711 and NSF/OPP 04–40761)

Collection of marine geophysical data on transits of the *Nathaniel B. Palmer*.

Joann M. Stock, California Institute of Technology, and Steven C. Cande, University of California–San Diego, Scripps Institution of Oceanography.

Well-constrained plate reconstructions of the antarctic region are critical for examining a number of problems of global geophysical importance. During this 3-year project, we are addressing questions about the motion history of the antarctic and other plates and improving plate reconstructions by surveying gravity, magnetics, and swath bathymetry on selected transit cruises by the U.S. research icebreaker *Nathaniel B. Palmer*.

In February 2006, during a transit cruise (NBP 06–02) from McMurdo Base, Antarctica, to Punta Arenas, Chile, we will do geophysical surveys of gravity, magnetics, and swath bathymetry in the Ross Sea and South Pacific Ocean, on the Antarctica plate, to study several major features of the plate that relate to its history of spreading away from other plates (including the easternmost piece of the Australia plate and the Pacific Plate).

These data will be used in combination with previously collected marine geophysical data from the Pitman fracture zone, at the southwestern end of the Pacific-Australia plate boundary, and magnetic anomalies from previous Palmer cruises on the Pacific and Antarctica plates near the Menard Fracture Zone to improve high-precision plate reconstructions and evaluate the limits of possible internal deformation of the Pacific and Antarctica plates in this sector. Our results will contribute to knowledge of plate kinematics and dynamics, and lithospheric rheology.

The ship schedule has not been finalized for August to October 2006. However, if we are able to sail on another cruise during that time, we will integrate research and education by teaching an on-board marine geophysics class to 30 graduate and undergraduate students (some of them minorities). Classes will consist of daily lectures about the instruments and the data they record. In addition, each student will spend several hours a day standing watch and processing data and will also work on an individual independent research project. (G–071–N; NSF/OPP 03–38317 and NSF/OPP 03–38346)

Stability of landscapes and ice sheets in the Dry Valleys, Antarctica: A systematic study of exposure ages of soils and surface deposits.

Jaakko Putkonen, University of Washington.

The near-perfect preservation of ancient, *in situ* volcanic ash and overlying sediments suggests that hyperarid cold conditions have prevailed in the McMurdo Dry Valleys for over 10 million years. The survival of these sediments also suggests that warm-based ice has not entered the valley system and that ice sheet expansion has been minimal. However, other evidence suggests that the Dry Valleys have experienced considerably more sediment erosion than is generally believed:

- The cosmogenic exposure ages of boulders and bedrock all show generally younger ages than volcanic ash deposits used to determine the minimum ages of moraines and drifts.
- There appears to be a discrepancy between the suggested extreme preservation of unconsolidated slope deposits (more than 10 million years) and adjacent bedrock that has eroded 2.6 to 6 meters during the same interval.

The fact that till and moraine exposure ages generally postdate the overlying volcanic ash deposits (a clear contradiction) could reflect expansion of the continental ice sheet into the Dry Valleys with cold-based ice, thus both preserving the landscape and shielding the surfaces from cosmic radiation. Another plausible explanation of the young cosmogenic exposure ages is erosion of the sediments and gradual exhumation of formerly buried boulders.

We will measure the accumulation of multiple cosmogenic isotopes in rock and sediment profiles to determine the minimum exposure ages, degree of soil stability or mixing, and shielding history of surfaces by cold-based ice to obtain unambiguous minimum ages for deposits. In addition, we should be able to identify areas disturbed by periglacial activity, constrain its timing, and account for the patchy preservation of important stratigraphic markers such as volcanic ash.

In a complex landscape such as the McMurdo Dry Valleys, individual exposure analyses will seldom give unambiguous ages for the surfaces. By contrast, our approach of looking at vertical profiles and multiple isotopes at a few sites will be considerably more informative. The result will be a better understanding of the stability of the East Antarctic Ice Sheet, which could fundamentally change how we view the dynamics of Southern Hemisphere climate on time scales of millions of years. (G–076–M; NSF/OPP 03–38224)

Dry Valley Seismic Project.

Robert C. Kemerait, U.S. Air Force Technical Applications Center.

One recurrent issue in seismography is noise: that is, background phenomena that can interfere with clear and precise readings. The Dry Valley Seismic Project, a cooperative undertaking with the New Zealand Antarctic Program, was established to record broadband, high-dynamic-range, digital seismic data from the remote Wright Valley, a site removed from the environmental and anthropogenic noise that is ubiquitous on Ross Island.

The Wright Valley site provides one of the few locations on the continent with direct access to bedrock. The station there consists of a triaxial broadband borehole seismometer [100 meters (m) deep] and a vertical short-period instrument at 30 m. The seismological data are digitized at the remote location, telemetered by repeaters on Mount Newall and Crater Hill, and received eventually by the recording computer at the Hatherton Laboratory at Scott Base, where a backup archive is created.

From Hatherton, they pass along a point-to-point protocol link to the Internet at McMurdo Station and thence to the Albuquerque Seismological Laboratory for general distribution to the international seismological community. This data set has beautifully complemented the data from other seismic stations operated by the Albuquerque Seismological Laboratory at Amundsen–Scott South Pole Station, Palmer Station, and Casey, an Australian base. (G–078–M; NSF/OPP DoD MOA)

Transantarctic Mountains Deformation Network: Global positioning system (GPS) measurements of neotectonic motion in the antarctic interior.

Terry J. Wilson and Dorota Brzezinska, Ohio State University, and Larry D. Hothem, U.S. Geological Survey–Denver.

We will conduct global positioning system (GPS) measurements of bedrock crustal motions in an extension of the Transantarctic Mountains Deformation Network (TAMDEF) to document neotectonic displacements caused by tectonic deformation within the West Antarctic Rift or mass changes in the antarctic ice sheets. By monitoring the U.S. and Italian networks of bedrock GPS stations along the Transantarctic Mountains and on offshore islands in the Ross Sea, we will tightly constrain horizontal displacements related to active neotectonic rifting, strike-slip translations, and volcanism. We will use GPS-derived crustal motions, together with information from other programs on the ice sheets and from ongoing structural and seismic investigations in Victoria Land, to model glacio-isostatic adjustments due to deglaciation and to modern mass changes in the ice sheets. The integrative and iterative nature of this modeling will yield a holistic interpretation of neotectonics and ice sheet history that will help us discriminate tectonic crustal displacements from viscoelastic/elastic glacio-isostatic motions.

We will do repeat surveys of key sites southward about 250 kilometers along the Transantarctic Mountains. These measurements will cross gradients in predicted vertical motion due to viscoelastic rebound. The southward extension will also allow us to determine the southern limit of the active Terror Rift and provide a better baseline for constraints on any ongoing tectonic displacements across the West Antarctic Rift system as a whole. Further, we will investigate unique aspects of GPS geodesy in Antarctica to determine how the error spectrum compares with that found in mid-latitude regions and to identify optimum measurement and data processing methods.

The geodetic research will improve position accuracies within our network and will also yield general recommendations for other deformation-monitoring networks in polar regions.

An education and outreach program targeted at Ohio State University undergraduates who are not science majors will illuminate the research process for nonscientists. This effort will educate students about science and inform them about Antarctica and how it relates to global science issues. (G–079–M; NSF/OPP 02–30285 and NSF/OPP 02–30356)

Mount Erebus Volcano Observatory and Laboratory (MEVOL).

Philip R. Kyle and Richard C. Aster, New Mexico Institute of Mining and Technology.

Mount Erebus, Antarctica's most active volcano, is a rare example of a persistently active magmatic system. This volcano, which has a history of low-level eruptive activity associated with a highly accessible summit vent complex, also features one of Earth's few long-lived lava lakes. We are developing an interdisciplinary geophysics/geochemistry laboratory on Mount Erebus to pursue basic research on the eruption physics and associated magmatic recharge of active volcanoes. Erebus is especially appropriate because of its persistent open-conduit magmatic system, frequent eruptions, ease of access (by antarctic standards), and established scientific and logistical infrastructure, including real-time data links and relative safety.

The key integrated data-gathering components we will rely on include video surveillance and seismic, infrasound, Doppler radar, infrared, volcanic gas, and geodetic studies. To collect the data, a combination of core Mount Erebus Volcano Observatory and Laboratory (MEVOL)–supported personnel and their students (with specialties in seismology, gas studies, and general volcanology) will collaborate with internationally recognized volcano researchers (with specialties in infrared, Doppler radar, gas studies, and infrasound).

We will then develop quantitative models of the magmatic system of an active volcano, including eruptive energy balance (gravity; explosive gas decompression; and thermal, seismic, acoustic, and kinetic components) and magma recharge (volcanic tremor, convection, residence time, gas emissions, and deformation). We expect this research to contribute substantially to basic knowledge of active volcanoes around the world.

Our work also involves a project to develop and deploy integrated low-power, low-cost, real-time-telemetered volcano monitoring stations at Erebus and other active volcanoes. (Many volcanoes, particularly in the developing world, have little or no modern instrumentation.) The goal is to contribute to the development of low-power, low-cost interdisciplinary geophysical observatories within the larger seismology, geodesy, and geophysical communities.

Our work also includes the education of graduate and undergraduate students in volcanology and geophysics, the dissemination of information to high school audiences, and the provision of year-round monitoring information to the National Science Foundation and to McMurdo Station. Finally, to convey the excitement and relevance of volcanology and other aspects of earth science to society, we expect to continue public outreach through lectures, media interaction, and inquiry response. (G–081–M; NSF/OPP 02–29305)

SHALDRIL, a demonstration drilling cruise to the James Ross Basin.

John B. Anderson, Rice University; Patricia Manley, Middlebury College; and Sherwood W. Wise Jr., Florida State University.

For over three decades, U.S. scientists and their international colleagues exploring the shallow shelves and seas along the margins of Antarctica have been consistently frustrated by their inability to penetrate the overcompacted glacial diamictons encountered at shallow subbottom depths (within the upper 10 meters) over these terrains. This has been particularly frustrating because advanced high-resolution seismic reflection techniques clearly show the presence of older successions of Neogene and even Paleogene sequences lying just beneath this thin veneer of diamictons in many areas. Until the means to recover these sequences are developed, a detailed history of the antarctic ice sheets—an essential prerequisite to understanding Cenozoic paleoclimates and future climate change on a global scale—will remain an elusive and unobtainable goal.

A group of U.S. scientists called the SHALDRIL Committee has identified at least two diamond coring systems deemed suitable for use on existing U.S. Antarctic Research Program ships. We will use one of these systems on the research icebreaker *Nathaniel B. Palmer* to demonstrate the feasibility of both ship-based diamond coring and downhole logging. We will core along a high-resolution seismic reflection dip line off Seymour Island, Antarctic Peninsula, an area of high scientific interest in its own right. Here the well-defined geologic section is estimated to range from Eocene to Quaternary in age, effectively spanning the "greenhouse-icehouse" transition in the evolution of antarctic/global climate. A complete record of this transition has yet to be obtained from anywhere along the antarctic margin.

We will correlate the record we obtain with detailed fluctuations of the ice margin recently recorded at higher latitudes in the eastern Ross Sea. If successful, SHALDRIL will be able to further explore the gap in our technical capability to study the antarctic shelves between the shoreline/fast-ice margin and the continental slope. This technological breakthrough will not only address major outstanding scientific issues of the past three decades, but will also favorably affect many other current antarctic or drilling-related initiatives. (G–083–N; NSF/OPP 01–25922, NSF/OPP 01–25480, and NSF/OPP 01–25526)

Integrated study of East Antarctic Ice Sheet tills (ISET): Tracers of ice flow and proxies of the ice-covered continental shield.

Kathy J. Licht and R. Jeffrey Swope, Indiana University, Purdue University–Indianapolis; John W. Goodge, University of Minnesota; and G. Lang Farmer, University of Colorado–Boulder.

Our interdisciplinary study of glacial deposits in the Ross embayment will help constrain Antarctica's Late Quaternary glacial history (about 18,000 years ago) and improve our knowledge of the rocks underlying the East Antarctic Ice Sheet. While constraining changes to till during transport, we will use till provenance to evaluate models for the last glacial maximum and to characterize rocks eroded from the East Antarctic Craton.

Although progress has been made in constraining the extent and timing of the last glacial maximum in the Ross Sea, reconstructions vary substantially. For example, some studies have concluded that ice streams derived from the west were dominant features of the Ross Ice Sheet during the last glacial maximum, while others show roughly equal inputs from east and west. Glacial sediments from the Ross embayment can be used to test these models.

Despite limited data, our previous work suggests that

- the east-to-west variations in the sand composition of Ross Sea till can be linked to eastern and western sources and that the ice sheets contributed equivalent volumes to the Ross Ice Sheet during the last glacial maximum,
- tills from West and East Antarctica are distinguishable and can be related to Ross Sea tills, and
- detritus from specific glaciers in the Transantarctic Mountains can be isotopically fingerprinted.

We will collect till samples from moraines at the heads and mouths of the Amundsen, Beardmore, Byrd, Liv, Nimrod, Reedy, Scott, and Shackleton Glaciers. We will then characterize particle size distribution, clast lithology, sand petrography, isotopic composition and elemental abundance of the silt/clay fraction, and ages of detrital zircons.

We will build predictions of the ice sheet's response to changing climate and rising sea level from models that accurately predict past configurations. Detailed sampling will allow us to characterize changes to till produced by the processes that modify sediment during transport and to determine constraints on the transport distances of eroded bedrock, as well as provide evidence of unmapped, buried rocks.

Also, we will host curriculum development workshops for 30 Indiana earth science educators, thus allowing us to reach over 600 students from diverse backgrounds. (G–084–M; NSF/OPP 04–40885, NSF/OPP 04-40160, and NSF/OPP 04-40177)

A global positioning system (GPS) network to determine crustal motions in the bedrock of the West Antarctic Ice Sheet: Phase I—Installation.

Ian W. Dalziel, University of Texas–Austin; Robert Smalley, University of Memphis; and Michael Bevis, University of Hawaii.

This project will initiate a global positioning system (GPS) network to measure crustal motions in the bedrock surrounding and underlying the West Antarctic Ice Sheet. Evaluating the role of both tectonic and ice-induced crustal motions in this bedrock is critical to understanding past, present, and future dynamics and the potential role of the ice sheet in future global change scenarios, as well as to improving our understanding of Antarctica's role in global plate motions. The extent of active tectonism around and under the West Antarctic Ice Sheet is largely speculative. Existing GPS projects are located on the fringe of the ice sheet and do not address the regional picture.

In the final season of this project, we will finish installing the GPS network at sites across the interior (approximately the size of the contiguous United States from the Rocky Mountains to the Pacific) and making initial measurements. We designed the network by using a multimodal occupation strategy in which a small number of independent GPS roving receivers make differential measurements against a network of continuous GPS stations for comparatively short periods at each site. This strategy, successfully implemented elsewhere, minimizes logistical requirements.

The GPS network is based on permanent monuments set in solid rock outcrops that have near-zero setup error for roving GPS occupations and that can be directly converted to a continuous GPS site when technology makes autonomous operation and satellite data linkage throughout western Antarctica reliable and economical. The network both depends on and complements existing and planned continuous networks.

Our work complements existing GPS projects by filling a major gap in coverage among the discrete crustal blocks making up western Antarctica. The network will yield increasingly meaningful results over time. We anticipate that these results will initiate an iterative process that will gradually resolve into an understanding of the contributions from plate rotations and viscoelastic and elastic motions arising from deglaciation and changes in ice mass. (G–087–M; NSF/OPP 00–03619; NSF/OPP 00-03834; NSF/OPP 00-03861)

Gneiss dome architecture: Form and process in the Fosdick Mountains, Antarctica.

Christine S. Siddoway, Colorado College, and Christian Teyssier, University of Minnesota–Twin Cities.

Gneiss dome formation involves material and heat transfer from middle or deep crustal levels and therefore represents a fundamental orogenic or mountain-forming process. Recent breakthroughs in understanding the role of migmatitic gneiss domes result from the geophysical exploration of contemporary mountain belts that reveal a thick, midcrustal layer of partially molten crust within the orogenic system. As middle crust exposures, gneiss domes offer the means to study structural and metamorphic processes that cannot be observed directly in contemporary orogens and to undertake a detailed analysis of structures beyond the resolution of seismic imaging.

In the Fosdick Mountains of the Ford Ranges of western Marie Byrd Land are excellent three-dimensional exposures of an elongated migmatite dome derived from sedimentary and plutonic protoliths. Preliminary findings suggest that peak metamorphism occurred about 105 million years ago at depths of about 25 kilometers (km), followed by decompression as the Fosdick dome was emplaced to 16 to 17 km, or possibly 8.5 km, by 99 million years ago. Near-isothermal conditions, favorable for producing substantial volumes of melt, were maintained during ascent. Because mineral assemblages record decompression and because the ages of argon isotopes indicate rapid cooling, the gneiss dome has been interpreted as a product of extensional exhumation. This is a viable interpretation from the regional standpoint, because the dome was emplaced during the mid-Cretaceous with the rapid onset of divergent tectonics along the proto-Pacific margin of Gondwanaland.

However, the complex internal structures in the Fosdick Mountains have not been integrated into the extensional exhumation model, and alternative models have not been explored. Possible alternatives are upward extrusion within a contractional setting or lateral flow within a transcurrent attachment zone. To address this question, we will use detailed structural analysis, paired with geothermobarometry and geochronology, to determine the flow behavior and structural style that produced the Fosdick Dome. Our study will be relevant to research on the role of gneiss domes for material and heat transfer in orogeny and on mechanisms of gneiss dome formation.

In addition to multidisciplinary research, students will be involved in developing curriculum materials. (G–088–M; NSF/OPP 03–38279 and NSF/OPP 03–37488)

Global seismograph station at Palmer Station and the South Pole.

Rhett G. Butler, Incorporated Research Institutions for Seismology.

Seismology, perhaps as much as any other science, is a global enterprise. Seismic waves resulting from earthquakes and other events can be interpreted only through simultaneous measurements at strategic points all over the planet. The measurement and analysis of these seismic waves are not only fundamental to the study of earthquakes, but they also serve as the primary data source for the study of the Earth's interior. To help establish the facilities required for this crucial scientific mission, IRIS (the Incorporated Research Institutions for Seismology) was created in 1985.

IRIS is a consortium of universities with research and educational programs in seismology. Ninety-seven universities are currently members, including nearly all U.S. universities that have seismological research programs. Since 1986, IRIS, through a cooperative agreement with the National Science Foundation (NSF) and in cooperation with the U.S. Geological Survey (USGS), has developed and installed the Global Seismographic Network (GSN), which now has about 137 broadband, digital, high-dynamic-range seismographic stations around the world; most of these have real-time communications.

The GSN seismic equipment at Amundsen–Scott South Pole Station and at Palmer Station was installed jointly by IRIS and USGS, which continue to operate and maintain them. The GSN sites in Antarctica are vital to seismic studies of Antarctica and the Southern Hemisphere, and they contribute to the international monitoring system of the Comprehensive Test Ban Treaty. The state-of-the-art seismic instrumentation is an intrinsic component of the NSF effort to advance seismology and earth science globally.

In 2003, with the completion of the South Pole Remote Earth Science and Seismological Observation (SPRESSO) in the Quiet Sector, the GSN seismic instrumentation was moved to the SPRESSO site, 8 kilometers from the Pole, and deployed into 300-meter deep boreholes in the ice below the firn. The new GSN site, QSPA, achieves the quietest conditions on Earth at frequencies above 1 hertz. (G–090–P/S; NSF/EAR 00–04370)

Reconstructing the high-latitude Permian-Triassic: Life, landscapes, and climate recorded in the Allan Hills, southern Victoria Land, Antarctica.

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On the basis of fossil plants and paleosols recorded in the sedimentary rocks of the Transantarctic Mountains, a model of Permian to Triassic climate at high paleolatitudes is emerging: After continental glaciers melted in the early Permian, forests grew in the cold, wet climate. By the early Triassic, warmer, drier conditions inhibited prolific plant growth. A moister, but still warm climate allowed plants to flourish later in the Triassic.

We will test and refine this model and investigate the effects of climate change on Permian to Triassic landscapes and ecosystems. Using exposures in the Allan Hills, we will search for, describe, and interpret fossil forests, vertebrate tracks and burrows, arthropod trackways, and subaqueously produced biogenic structures, and document the end of glaciation and the importance of major episodic sedimentation. In so doing, we will address broader questions that will contribute to understanding

- the evolution of terrestrial and freshwater ecosystems and how they are affected by the end-Permian extinction,
- the abundance and diversity of terrestrial and aquatic arthropods at high latitudes,
- the paleogeographic distribution and evolution of vertebrates and invertebrates as recorded by trace and body fossils, and
- the response of landscapes to changes in climate.

The excellent record preserved by this Permian to Triassic sequence provides a unique opportunity to compare high-latitude forests and freshwater and terrestrial faunas with better-known low-latitude equivalents during an important period of their evolution.

We will also include two activities that we anticipate will have a strong impact on large audiences:

- A professional scientific illustrator has been engaged to paint reconstructions of Permian to Triassic high-latitude landscapes and ecosystems as interpreted by our research. In addition to synthesizing our results, these reconstructions will convey Earth's history to the public.
- A 10- to 15-minute video will chronicle the research. The video, which will be filmed in the field and edited by a professional, will accompany presentations to general audiences by our group and, perhaps more important, by former students and colleagues who have worked with us in Antarctica and have gone on in many cases to become educators. (G–093–M; NSF/OPP 04–40954, NSF/OPP 04–40889, NSF/OPP 04–40910, NSF/OPP 04–40919)

Paleohistory of the Larsen Ice Shelf System: Phase II

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Building on our previous work, we intend to test the hypothesis that the Larsen B Ice Shelf system has been a stable component of the cryosphere since it formed during rising sea levels 10,000 years ago. This conclusion would be an important step in establishing the uniqueness and consequences of the rapid warming taking place across the Peninsula. Our previous work on the Larsen A and B embayments taught us to recognize the signature and impact of past ice-shelf fluctuations. We have also overcome many of the limitations of radiocarbon-based chronologies in antarctic marine sequences by using geomagnetic-paleomagnetic intensity records for millennial-scale correlation and dating and by refining other dating techniques.

We will pursue these advances and extend our sediment core stratigraphy to areas uncovered by the most recent collapse of the Larsen B Ice Shelf and areas immediately adjacent to the Larsen C Ice Shelf. In addition to the core recovery program, we will use our access to the ice-shelf front to continue our observations of firn/ice stratigraphy, oceanographic character, and ocean floor characterization.

We will also conduct marine process studies across the Vega Drift in the Erebus and Terror Gulf. The Vega Drift—the largest Holocene deposystem on the antarctic margin—contains an exceptional paleoenvironmental archive for the northwest Weddell Sea. We will install a 1-year instrumented mooring and conduct other process-related observations that will facilitate the optimum interpretation of a drill site to be recovered from the drift in 2005.

This 3-year, multi-institutional, international effort combines expertise in a variety of disciplines and integrates the research plan into undergraduate, graduate, and postdoctoral education. The work will extend over two primary field seasons to accommodate the as yet undetermined schedules for the research ships *Nathaniel B. Palmer* and *Laurence M. Gould*.

The Antarctic Peninsula is undergoing greater warming than almost anywhere on Earth, perhaps because of greenhouse effects. Since these changes will increasingly affect life on Earth, our work will contribute to understanding them where they are occurring first and with the greatest magnitude and impact. (G–096–L; NSF/OPP 03–38142, NSF/OPP 03–38101, NSF/OPP 03–38109, NSF/OPP 03–38163, and NSF/OPP 03–38220)

UNAVCO global positioning system support.

Bjorn Johns, UNAVCO.

UNAVCO is a nonprofit, membership-governed consortium funded through the National Science Foundation and the National Aeronautics and Space Administration (NASA) to support and promote high-precision measurement techniques for the advancement of earth sciences. UNAVCO provides complete support for permanent stations, surveying, mapping, and other applications of the global positioning system (GPS) to U.S. Antarctic Program investigators and maintains a satellite facility with a full range of geodetic GPS equipment and support services at McMurdo Station during the austral summer research season.

A large pool of high-precision GPS receivers and associated equipment is provided for short-term surveys through multiyear data collection in Antarctica. Regular equipment upgrades ensure a steady influx of modern equipment, including

- state-of-the-art dual-frequency GPS receivers,
- power and communication systems for remote locations,
- GPS monument and antenna mount options, and
- accessories for kinematic and real-time kinematic (RTK) surveys.

UNAVCO staff provides year-round support to help ensure the success of field projects and subsequent data management. The level of support is scalable and includes

- survey planning,
- field survey and data processing training,
- custom engineering solutions,
- system integration,
- field assistance,
- GPS station maintenance, and
- data retrieval, flow monitoring, processing, and archiving.

UNAVCO also operates a community RTK GPS base station that covers McMurdo Station and provides maintenance support to the NASA GPS Global Network station MCM4 at Arrival Heights. (G–295–M; NSF/EAR 03–21760)

Controls on sediment yields from tidewater glaciers from Patagonia to Antarctica.

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Glacial erosion is a principal issue in contemporary research on landscape evolution and high-latitude climate change. In the Himalayas, for example, the spatial pattern and rapid rates of tectonic rock uplift correspond closely to patterns and rates of erosion by ice and water. On a global scale, the onset of widespread glacial erosion is often viewed as responsible for the increase in sedimentation that coincided with a change to a cooler, more variable climate at the onset of late Cenozoic glaciation (about 2 to 4 million years ago). At high latitudes, this increase in sedimentation created clastic wedges up to 5 kilometers thick on continental margins; these sediments contain a rich history of climate change recorded in proxy climate data (ice-rafted debris, foraminifera) and sediment accumulation rates that reflect the production of glacial sediment.

Our aim is to define an empirical relationship between glacial erosion rates and ice dynamics. We will use glaciologic and marine geologic techniques to examine the role of glacier dynamics in determining glacial sediment yields. We hypothesize that glacial erosion rates are a function of sliding speed and will therefore diminish sharply as basal temperatures drop below the melting point. To test this hypothesis, we will study six tidewater glaciers ranging from fast-moving temperate glaciers in Patagonia to slow-moving polar glaciers on the Antarctic Peninsula. For each system, we will

- use seismic profiles and core data to assess yields and, by inference, erosion rates by determining sediment accumulation rates in the fjords, and
- measure the dynamic properties and basin characteristics of each of the glaciers, which have different ice fluxes and basal thermal regimes.

We will base our work in Patagonia and the Antarctic Peninsula because

- the large latitudinal range provides for a wide range of precipitation and glacier thermal regimes over relatively homogeneous lithologies and tectonic settings,

- earlier studies have noted a significant decrease in the accumulation of glaciomarine sediment in the fjords along a southward transect, and
- the fjords constitute accessible and nearly perfect natural sediment traps. (G–435–N; NSF/OPP 03–38137 and NSF/OPP 03–38371)