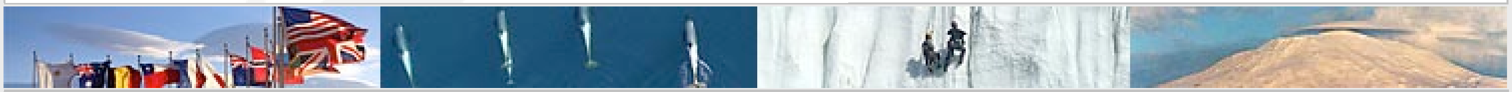

GEOLOGY AND GEOPHYSICS

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*)

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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.

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)