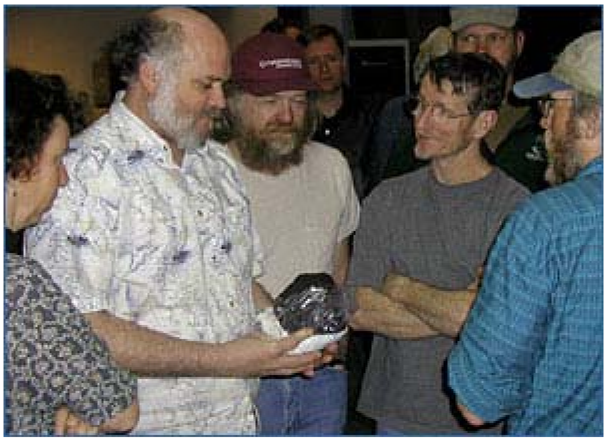
GEOLOGY AND GEOPHYSICS

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.



Steve Presher, left, a chef at McMurdo Station, inspects a meteorite recovered by the Antarctic Search for Meteorites team during the austral 2002-03 summer season.

NSF photo by Mark Sabbatini

Geologists have found evidence that there was once a forested supercontinent, which they call Gondwanaland, in the Southern Hemisphere. Before the Earth's constantly 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 rock 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:

- determining the tectonic evolution of Antarctica and its relationship to the evolution of the continents from Precambrian time (600 million years ago) to the present;
- 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
- determining the evolution of sedimentary basins within the continent and along the continental margins.

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 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) [http://www.nsf.gov/cgi-bin/good-bye?http://usarc.usgs.gov/] 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 the Antarctic Marine Geology Research Facility [http://www.nsf.gov/cgi-bin/good-bye?http://www.arf.fsu.edu/] at Florida State University, 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.

Antarctic mapping, geodesy, geospatial data, satellite image mapping, and Antarctic Resource Center management.

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

Antarctic mapping, geodesy, geospatial data, satellite image mapping, and the Antarctic Resource Center (ARC) constitute some of the activities necessary for the successful operation of a multifaceted scientific and exploratory effort in Antarctica. Year-round data acquisition, cataloging, and data dissemination will continue in the ARC 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 as funding permits 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 a continent-wide geodetic infrastructure (GIANT) that 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; NSF/OPP 02–33246)

The antarctic search for meteorites (ANSMET).

Ralph Harvey, Case Western Reserve University.

Since 1976, ANSMET (the antarctic search for meteorites program) has recovered more than 12,000 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 a meteorite 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 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 2003–2004 field season, ANSMET's main field party (8 people) will work at the LaPaz icefields, approximately 250 miles from Amundsen-Scott South Pole Station. More than 200 meteorites were recovered from the site during reconnaissance visits in 1991 and 2002. This year's field team will begin systematic searches of the icefields in an effort to recover a representative sample of the extraterrestrial material falling to Earth.

A second team consisting of 4 people will conduct high-level reconnaissance at a number of icefields throughout the mid Transantarctic Mountains, from the Miller Range in the north to Roberts Massif in the south. This reconnaissance team will visit poorly known or previously unvisited icefields, recovering meteorites and identifying their potential for more detailed searches during future seasons. (G-057-M and G–058–M; NSF/OPP 99–80452)

Evolution and biogeography of Late Cretaceous vertebrates from the James Ross Basin, Antarctic Peninsula.

Judd Case, Saint Mary’s College of California, and James Martin, South Dakota School of Mines and Technology.

We plan to investigate the Late Mesozoic vertebrate paleontology of the James Ross Basin. The Campanian through the Maastrichtian Ages (80 to 65 million years ago) are important in the history of vertebrate biogeography (dispersals and separations due to moving landmasses) and evolution between Antarctica and the rest of the Southern Hemisphere. Moreover, the dispersal of terrestrial vertebrates such as dinosaurs and marsupial mammals from North America to Antarctica and beyond to Australia via Patagonia and the Antarctic Peninsula, as well as the dispersal of modern birds from Antarctica northward, are unresolved questions in paleontology. These dispersals include vertebrates in marine settings as well. Both widely distributed and localized marine reptile species have been identified in Antarctica, creating questions about their dispersal in conjunction with terrestrial animals.

The Weddellian Paleobiogeographic Province extends from Patagonia through the Antarctic Peninsula and western Antarctica to Australia and New Zealand. Within this province lie the dispersal routes for interchanges of vertebrates between South America and Madagascar and India, and also Australia. On the basis of our previous work, we theorize that an isthmus between more northern South America and the

Antarctic craton brought typical North American dinosaurs, such as hadrosaurs (duck-billed dinosaurs) and presumably marsupials traveling overland while marine reptiles swam along coastal waters, to Antarctica in the late Cretaceous. This region also served as the cradle for the evolution, if not the origin, of groups of modern birds, and the evolution of typical Southern Hemisphere plants.

To confirm and expand on these hypotheses, we will continue our investigations into late Cretaceous marine and terrestrial deposits in the James Ross Basin. We have previously recovered the following vertebrates from these sedimentary deposits: plesiosaur and mosasaur marine reptiles; plant-eating dinosaurs; a meat-eating dinosaur; and a variety of modern bird groups, including shorebirds, wading birds, and lagoonal birds.

Our research will result in important insights about the evolution and geographic dispersal of several vertebrate species. We will collaborate with scientists from the Instituto Antártico Argentino and with vertebrate paleontologists from the Museo de La Plata, both in the field and at our respective institutions in Argentina and in the United States. (G–061–E; NSF/OPP 00–03844 and NSF/OPP 00–87972)

Calibration of cosmogenic argon production rates in Antarctica.

Paul R. Renne, Berkeley Geochronology Center.

We intend to establish the systematics of cosmogenic argon production required to establish its measurement as a routine surface exposure dating tool analogous to existing methods based on helium-3, beryllium-10, carbon-14, neon-21, and aluminum-26. Cosmogenic argon offers advantages over existing cosmogenic chronometers in that it is stable (hence applicable to long-term or ancient exposure dating) and less prone to diffusive loss than helium or neon.

Argon-38 is produced principally by spallation of calcium and (probably) potassium, and it is most easily measured using neutron-irradiated samples, as has been done routinely on extraterrestrial samples for decades. Our initial measurements on antarctic samples demonstrate the viability of this method for terrestrial samples and suggest an average production rate of more than 100 atoms/gram-calcium/year. Existing data suggest that argon-38/calcium exposure ages younger than 105 years can be accurately determined by this method.

Further work on calcic minerals (apatite, sphene, clinopyroxene, plagioclase, calcite) whose exposure histories are constrained by helium-3 and neon-21 concentration data will be used to determine the calcium-derived production rate. Analogous work on potassium-rich minerals (potassium-feldspars, micas) will be used to constrain the production of argon-38 from potassium, which should theoretically be comparable to that from calcium when the same neutron-activation method is used.

To maximize cosmic radiation dosage for calibration purposes, our analytical work will use existing samples plus new ones to be collected from the McMurdo Dry Valleys of Antarctica. Laboratory studies of the retentivity of argon-38 in appropriate minerals will be used to help evaluate our results and guide future applications. (G–064–M; NSF/OPP 01–25194)

Global climate change and the evolutionary ecology of antarctic mollusks in the Late Eocene.

Daniel Blake, University of Illinois–Urbana, and Richard Aronson, Marine Environmental Science Consortium.

Global climate change in the late Eocene had an important influence in Antarctica. This was the beginning of the transition from a cool-temperate climate to the current one. The cooling trend strongly influenced the structure of shallow-water and antarctic marine communities, and these effects are evident in the ecological relationships among modern species. Cooling reduced the abundance of fish and crabs, which in turn reduced skeleton-crushing predation on invertebrates. Reduced predation allowed dense populations of ophiuroids (brittlestars) and crinoids (sea lilies) to appear in shallow-water settings at the end of the Eocene. These low-predation communities appear as dense fossil echinoderm assemblages in the La Meseta Formation on Seymour Island.

Today, dense ophiuroid and crinoid populations are common in the shallow waters of Antarctica but have generally disappeared from similar habitats at temperate and tropical latitudes. Although the influence of declining predation on antarctic ophiuroids and crinoids is well documented, the effects of cooling on the more abundant mollusks have not been investigated. We will therefore examine the evolutionary ecology of gastropods (snails) and bivalves (clams) in the late Eocene.

We will test a series of hypotheses based on the predicted responses of mollusks to declining temperature and changing levels of predation:

- First, defensive features of gastropod shells, such as spines and ribbing, should decline as the temperature and, therefore, the activity of skeleton-crushing predators declined.
- Second, drilling of bivalve prey by predatory gastropods should increase, since the drillers should themselves have been subject to less predation as the temperature declined. Drilled shells should become more common.
- Third, patterns in the thickness of shells will make it possible to separate the direct physiological effects of temperature (shells are harder to produce at cooler temperatures and so should be thinner) from the indirect effects of temperature (increased drilling predation should result in thicker shells).

Seymour Island contains the only readily accessible fossil outcrops from this crucial period in Antarctica. Global climate change will probably increase upwelling in some temperate coastal regions. Evidence suggests that the resulting decline in sea temperatures could lower predation in those areas. Understanding the response of the La Meseta fauna to cooling in the late Eocene will provide direct insight into the rapidly changing structure of modern benthic communities. (G–065–E; NSF/OPP 99–08856 and NSF/OPP 99–08828)

Boron in antarctic granulite-facies rocks: Under what conditions is boron retained in the middle crust?

Edward Grew, University of Maine.

Trace elements provide valuable information on the changes sedimentary rocks undergo as temperature and pressure increase during burial. One such element, boron, is particularly sensitive to increasing temperature because of its affinity for aqueous fluids, which are lost as rocks are buried. The boron content of unmetamorphosed pelitic sediments ranges from 20 to over 200 parts per million, but rarely exceeds 5 parts per million in rocks subjected to the conditions of the middle and lower crust. Devolatization with loss of aqueous fluid and partial melting with removal of melt have been cited as primary causes for boron depletion in granulite-facies rocks. Despite the pervasiveness of both of these processes, rocks rich in boron are locally found in granulite-facies in the Larsemann Hills along Prydz Bay. More than 20 lenses and layered bodies containing four borosilicate mineral species crop out over a 50-square-kilometer area.

While most investigators have focused on the causes of boron loss, we will use field observations and mapping, chemical analyses of minerals and their host rocks, and microprobe age-dating to investigate how boron is retained during high-grade metamorphism. Our working hypothesis is that a high initial content facilitates retention of boron during metamorphism. For example, in a rock with large amounts of the borosilicate tourmaline (such as strata-bound tourmalinite), the breakdown of tourmaline to melt could result in the formation of prismatine and grandidierite, two borosilicates found in the Larsemann Hills. This situation is rarely observed in rocks with a modest boron content, in which tourmaline breakdown releases boron into partial melts, which in turn remove it when they leave the system.

Strata-bound tourmalinite is associated with manganese-rich quartzite, phosphorus-rich rocks, and sulfide concentrations that could be indicative of a tourmalinite protolith in a highly metamorphosed complex where sedimentary features have been destroyed by deformation. Because partial melting plays an important role in the fate of boron, our research will focus on the relationship between borosilicate units, granite pegmatites, and other granitic intrusives. Our results will provide information on boron cycling at deeper levels in the Earth's crust and on possible sources of boron for granites originating from deep-seated rocks. (G–067–E; NSF/OPP 02–28842)

Improved Cenozoic plate reconstructions of the circum-antarctic region.

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

Well-constrained Cenozoic plate reconstructions of the circum-antarctic region are critical for examining a number of problems of global geophysical importance, among them

- relating plate kinematics to geological consequences in various plate circuits (Pacific–North America, Australia-Pacific);

- understanding what drives plate tectonics (which requires well-constrained kinematic information to distinguish between different geodynamic hypotheses); and

- understanding the rheology of the plates themselves, including the amount of internal deformation they can support and the conditions leading to the formation of new plate boundaries through the breakup of existing plates.

By obtaining better constraints on the motion of the antarctic plate with respect to other plates, and by better quantifying the internal deformation within Antarctica, we can contribute to understanding these fundamental issues.

We will analyze existing data to address several specific issues related to the motion of the antarctic plate. First, we will work on four-plate solutions of Australia–Pacific–West Antarctica–East Antarctica motion to constrain the rotation parameters for separation between East and West Antarctica by imposing closure on the circuit and using relevant marine geophysical data from all four of the boundaries. We will determine the uncertainties in the resulting rotation parameters based on the uncertainties in the data points. These can then be propagated in the plate circuit to address the issues listed earlier. Second, we will use well-navigated transit data from the icebreaking research ship *Nathaniel B. Palmer* to further quantify Pacific–West Antarctica rotation parameters for Tertiary time. These parameters and their uncertainties will be used to assess plate rigidity and will be included in the circuit studies.

We will collect new marine geophysical data (on underway gravity, magnetics, and swath bathymetric data) on *Nathaniel B. Palmer* transit cruises. On one of the cruises, we propose to teach a formal class in marine geophysics to graduate and undergraduate students to integrate teaching activities with the data collection objectives. (G–071–N; NSF/OPP 01–26334 and NSF/OPP 01–26340)

Dry Valley Seismic Project.
Robert 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.

These data will eventually reach the international seismological community; 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. 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 Wilson, Ohio State University; Larry D. Hothem, U.S. Geological Survey–Denver; and Dorota Brzezinska, Ohio State University.

We will conduct global positioning system (GPS) measurements of bedrock crustal motions in an extension of the Transantarctic Mountains Deformation Network (TAMDEF) in order 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 will 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 Kyle and Richard 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 will develop 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.

Another part of our work 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 societal relevance of volcanology and other aspects of earth science, we expect to continue public outreach through lectures, media interaction, and inquiry response. (G–081–M; NSF/OPP 02–29305)

A global positioning system network to determine crustal motions in the bedrock of the West Antarctic Ice Sheet.

Ian Dalziel and Frederick Taylor, Institute of Geophysics, University of Texas–Austin; Robert Smalley, University of Memphis; and Michael G. Bevis, University of Hawaii.

Motion in the bedrock that underlies the West Antarctic Ice Sheet is suspected from rifting, active volcanism, and uncertainties in global plate circuits, but it is unconstrained. Without reliable data on tectonic and ice-induced crustal motions, we will never be able to fully comprehend the ice sheet's past, present, and future dynamics. Without that knowledge, we can neither develop reliable global change scenarios for the future nor accurately factor the antarctic region into global plate movements. Currently, permanent global positioning system (GPS) networks that measure bedrock movement are established only on the fringe of the West Antarctic Ice Sheet; they cannot provide the data needed to understand subglacial volcanism, active tectonics, and ice streaming.

Our project is focused on establishing baseline, long-term, reliable geodetic measurements of the crustal motion in the bedrock beneath the West Antarctic Ice Sheet. We are building a West Antarctica GPS Network (WAGN) of at least 15 sites on nunataks across the interior—an area comparable to the area from the Rocky Mountains to the Pacific coast—over 3 years, beginning in the 2001–2002 austral summer.

The first season, we initiated the network and tested the precision and velocities at critical sites. The second season, we built monuments and made initial measurements. If crustal motions are relatively slow, meaningful results will begin to emerge only over the next 5 years or so. Once it is permanently established, however, the network should yield increasingly meaningful results. Indeed, the slower the rates turn out to be, the more important it is to start measuring early.

West Antarctic Ice Sheet bedrock is so scattered and remote that erecting a continuous string of permanent GPS stations is unrealistic. Instead, we are using roving receivers (based in permanent monuments set in solid rock outcrops) in place for only a short time at each site and providing data that can be ranged against continuous data acquired from permanent GPS stations elsewhere. Each of these bases can be converted to a permanent, autonomous station when more logistics and satellite data linkage are in place throughout West Antarctica. When detectable motions occur, we can reoccupy the most critical sites, obtain more reliable velocities, and possibly reoccupy the entire network.

We expect this project to establish important early indicators of crustal plate dynamics beneath the West Antarctic Ice Sheet. As scientists take these into account in refining their models, future measurements and a time-series of the geodetic data should gradually produce a more constrained picture of plate rotations and elastic and viscoelastic motions caused by deglaciation and changes in ice mass in the West Antarctic Ice Sheet. (G–087–M; NSF/OPP 00–03619)

A broadband seismic experiment to investigate deep continental structure across the east-west antarctic boundary.

Douglas Wiens, Washington University, and Andrew Nyblade and Sridhar Anandakrishnan, Pennsylvania State University.

Antarctica's outline looks generally like that of Australia, though half again as large; but beneath its enormous ice sheet lies evidence of its origin. East Antarctica has a bedrock continent-like foundation, while the ice sheet over West Antarctica—a third the area—in fact covers a series of islands. West Antarctica shares a geologic history with the Andes Mountains, the result of plates colliding and subducting. East Antarctica is more like a large chunk that broke free of the supercontinent Gondwanaland and drifted to a new position at the bottom of the world. The boundary between these two regions (with their disparate geologic pedigrees) is called the east-west antarctic boundary, and the crust and upper mantle here reveal many important and interesting distinctions that tell the basic story of the tectonic development of Antarctica.

In November 2000, we began making seismic measurements using 3 different arrays and 44 seismic stations, all geared to evaluating geodynamic models of the evolution of Antarctica. To analyze the data, we use a variety of proven modeling techniques, including body- and surface-wave tomography, receiver function inversion, and shear-wave splitting analysis.

One basic question is, How were the Transantarctic Mountains formed? Though widely considered a classic example of rift-flank uplift, there is little consensus about the exact mechanism. Many theories have been proposed, ranging from delayed-phase changes to transform-flank uplift. All of these make assumptions about the upper mantle structure beneath and adjacent to the rift-side of the mountain front.

Another focus will be the structure of the east antarctic craton, the highest ice block in the world. Was this anomalous elevation a prime driver in the onset of glaciation there? More to the point, how did it arise? Proposed models include isostatic uplift from thickened crust, anomalously depleted upper mantle, and thermally modified upper mantle, as well as dynamic uplift. How far the old continental lithosphere extends is also uncertain. In particular, it is not known whether the old lithosphere extends to the western edge of East Antarctica beneath the crustal rocks deformed during the Ross Orogeny (formation).

When completed and analyzed, this comprehensive set of data and theory testing will enable new maps of the variation in crustal thickness, upper mantle structure, anisotropy, and mantle discontinuity topography across the boundary of East and West Antarctica, providing a much enhanced foundation for understanding the geodynamics of the region. (G–089–M; NSF/OPP 99–09603, NSF/OPP 00–09648, and NSF/OPP 02–26538)

IRIS—Global seismograph station at South Pole.

Rhett 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 for 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 126 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 together 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. (G–090–S; NSF/EAR 00–04370)

Neotectonic structure of Terror Rift, Western Ross Sea.

Terry Wilson, Ohio State University, and Lawrence Lawver, University of Texas–Austin.

Displacements between East and West Antarctica have long been proposed based on global plate circuits, apparent hot-spot motions, geologic grounds, seafloor magnetic anomalies, or paleomagnetism. Such motions require plate boundaries that cross Antarctica, yet these boundaries have never been explicitly defined.

We will attempt to delineate the late Cenozoic boundary between East and West Antarctica along the Terror Rift in the western Ross Sea by using marine and airborne geophysical data to map the fault patterns and volcanic structure along the eastern margin. We will also map the orientations of volcanic fissures and seamount alignments on the seafloor. The volcanic alignments will show the regional extension or shear directions across the rift and the orientations of associated crustal stresses.

Delineation of neotectonic fault patterns will demonstrate whether the eastern margin of the rift forms a continuous boundary and whether the rift itself can be linked with postulated strike-slip faults in the northwestern Ross Sea. We will combine seafloor findings with fault kinematic and stress field determinations from the surrounding volcanic islands and the Transantarctic Mountains.

Over 3 years, we will complete a collaborative structural analysis of existing multichannel and single-channel seismic profiles and aeromagnetic data over the Terror Rift, locating volcanic vents or fissures and any fault scarps on the seafloor and making a preliminary determination of the age and kinematics of deformation in the Terror Rift. We will then carry out multibeam sonar mapping of selected portions of the seafloor and use these data to map the orientations and forms of volcanic bodies and the extent and geometry of neotectonic faulting associated with the Terror Rift.

In summary, we will

- complete a map of neotectonic faults and volcanic structures in the Terror Rift,
- interpret the structural pattern to derive the motions and stresses associated with the development of the rift,
- compare rift structures with faults and lineaments mapped in the Transantarctic Mountains to improve age constraints on the structures, and

- integrate the late Cenozoic structural interpretations from the western Ross Sea with Southern Ocean plate boundary kinematics. (G–099–N; NSF/OPP 01–25624 and NSF/OPP 01–26279)

Geology and geochronology of the Byrd Glacier discontinuity, Antarctica: A pilot study.
Edmund Stump, Arizona State University.

The East Antarctic Ice Sheet breaches the Transantarctic Mountains by way of a handful of outlet glaciers; Byrd Glacier is the largest of these, contributing about a quarter of all the ice moving from there to the Ross Ice Shelf. A major geological discontinuity in the Ross Orogen of the Transantarctic Mountains has been discovered beneath Byrd Glacier.

We will continue the probe into this area by mapping the Byrd Group (Early Cambrian Shackleton limestone and younger Douglas conglomerate) for structure and by trying to develop a basis for understanding its kinematic evolution. Another target of interest is Mount Madison; its geochronology and structural and metamorphic history should be revealed from samples of outcropping, amphibolite-grade metamorphic rocks (Selbourne marble).

Using snowmobiles and supported by helicopters, we will also collect igneous and high-grade metamorphic rocks (Horney Formation) in the Britannia Range and will investigate Shackleton limestone. We hope to determine the thermochronology of Selbourne marble and to further constrain the provenance and age of the Douglas conglomerate.

All rock samples will be subjected to followup studies. Structural data will be reduced at Arizona State University, metamorphic studies of Selbourne marble will be conducted at the University of Siena, and isotopic studies will be done at both Ohio State University (argon-40/argon-39, Sm-Nd) and the University of Kansas (U-Pb). (G–116–O; NSF/OPP 99–09463)

Geomagnetic field as recorded in the Mount Erebus Volcanic Province: Key to field structure at high southern latitudes.
Lisa Tauxe, Hubertus Staudigel, Catherine Constable, and Anthony Koppers, Scripps Institution of Oceanography, University of California–San Diego; and Philip Kyle and William McIntosh, New Mexico Institute of Mining and Technology.

We aim to use lava flows from the Mount Erebus Volcanic Province to study the magnetic field of the Earth over the past 5 million years in order to test models of its geomagnetic dynamo. Paleomagnetic data (directions of ancient geomagnetic fields obtained from rocks) play an important role in a variety of geophysical studies of the Earth, including plate tectonic reconstructions, magnetostratigraphy, and studies of the behavior of the ancient geomagnetic field (called paleogeomagnetism).

Over the past four decades, the key assumption in many studies has been that the average direction of the paleomagnetic field corresponds to one that would have been produced by a geocentric axial dipole (analogous to a bar magnet at the center of the Earth) and that paleoinclinations (the dip of magnetic directions from rocks) provide data of sufficient accuracy to enable them to be used in plate reconstructions. A recent reexamination of the fundamental data underlying models of the time-averaged field has shown that the most glaring deficiency in the existing database is a dearth of high-quality information, including paleointensity data, from high latitudes.

We will therefore undertake a sampling and laboratory program on suitable sites from the Mount Erebus Volcanic Province in order to produce the quality data from high southern latitudes that are essential to an enhanced understanding of the time-averaged field and its long-term variations. (G–182–M; NSF/OPP 02–29403 and NSF/OPP 02–29604)

Shackleton Glacier area: Evolution of vegetation during the Triassic.
Edith Taylor and Thomas Taylor, University of Kansas–Lawrence.

The rocks of the central Transantarctic Mountains have been a source of fossil discoveries over the past 30 years. The rare juxtaposition of sites that include many different types of plant preservation, the exceptional quality of the fossils, and the biodiversity of the sites make this area unique. The Paleozoic/Mesozoic transition is a critical time in plant evolution. A unique variety of seed plant groups existed, and several have been suggested as the ancestors of flowering plants. There was also a massive floral change from the Permian to the Triassic.

While most fossil plants occur as disarticulated leaves, stems, and reproductive organs, many in the Shackleton Glacier area are partially articulated, thus making it possible to gain a more accurate picture of the entire plant and its place in the ecosystem. We will examine Triassic floras from two sites in the Shackleton Glacier area (Collinson Ridge and an unnamed ridge southeast of Schroeder Hill). In addition to compression fossils, the latter also includes some permineralized peat and fossil stumps. The Collinson Ridge site is important because it contains fossil peat and logs in presumably Lower Triassic rocks. Preliminary analysis of petrified material collected during the 1995–1996 field season, however, suggests that perhaps it is Late Permian rather than Early Triassic, as would be expected. It is therefore important to elucidate the biostratigraphy of this area because the position of the Permian-Triassic boundary is crucial in understanding the timing of terrestrial extinctions around it. Further collecting at both of these sites and analysis of the fossil material in the laboratory will address these discrepancies and yield important new information about Triassic plant evolution.

Paleobotany is ideally suited to education and outreach. Workshops and temporary exhibits on antarctic science have been developed through programs sponsored by the University of Kansas Natural History Museum and Biodiversity Research Center, and we will continue this activity. Student involvement has also been extensive and will be continued. (G–293–M; NSF/OPP 02–29877)

University NAVSTAR Consortium (UNAVCO) global positioning system survey support.
Bjorn Johns, University Navstar Consortium (UNAVCO/UCAR).

UNAVCO provides year-round support for scientific applications of the global positioning system (GPS) to the U.S. Antarctic Program, which is supported and managed by the National Science Foundation's Office of Polar Programs. This support includes preseason planning, field support, and postseason followup, as well as development work for new applications. UNAVCO maintains a satellite facility at McMurdo Station during the austral summer research season, providing a full range of support services, such as geodetic GPS equipment, training, project planning, field support, technical consultation, data processing, and data archiving.

UNAVCO also operates a community differential GPS base station that covers McMurdo Sound and Taylor Valley, provides maintenance support to the MCM4 continuous GPS station as contractual support to the National Aeronautics and Space Administration's GPS Global Network, and supports remote continuous GPS stations for scientific investigations.

Using GPS, vector baselines between receivers separated by 100 kilometers or more are routinely measured to within 1 centimeter (that is, 100 parts per billion). UNAVCO is also able to support researchers who are investigating global, regional, and local crustal motions where maximum accuracy (in the millimeter range) of baseline measurement is required. GPS measurements using portable equipment can be completed in a few hours or less. Such expediency lends itself to research applications in global plate tectonics, earthquake mechanics, volcano monitoring, and regional tectonics. (G–295–M; NSF/EAR 99–03413)

Vertebrate paleontology of the Triassic to Jurassic sedimentary sequence in the Beardmore Glacier area of Antarctica.
William Hammer, Augustana College.

During a 3-year study, we will investigate fossils from Triassic and Jurassic dinosaurs and other vertebrates in the central Transantarctic Mountains. A field program to search for Upper Triassic to Jurassic fossil vertebrates in the Beardmore Glacier region will be carried out in the 2003–2004 austral summer. Initially, we will concentrate our efforts on the Hanson Formation, which has produced the only Jurassic dinosaur fauna in Antarctica. We will then further excavate the Hanson dinosaur locality on Mount Kirkpatrick and will follow that with an extensive search of other exposures of the Hanson, Falla, and Upper Fremouw Formations in the Beardmore area.

Our field party will operate for 3 to 4 weeks out of a small helicopter camp in the Beardmore area. The field party will consist of six persons, to allow two groups of three to work independently at different sites. One group will excavate the Mount Kirkpatrick site, while the other reconnoiters. In addition to collecting new specimens, we will interpret the depositional settings for each of the vertebrate sites. Our second and third years will be dedicated to preparing and studying the vertebrates.

Antarctic vertebrates provide a unique opportunity to study the evolutionary and biogeographic significance of high-latitude Mesozoic fauna, and this project should result in significant advances in knowledge. (G–298–M; NSF/OPP 02–29698)