National Science Foundation

U.S. Antarctic Program
1999-2000

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During the 1999-2000 austral summer and the 2000 austral winter, the U.S. Antarctic Program will support more than 800 researchers and other participants in the U.S. Antarctic Program at three year-round stations (McMurdo, Amundsen-Scott South Pole, and Palmer), aboard two research ships (*Laurence M. Gould* and *Nathaniel B. Palmer*) in the Ross Sea and in the Antarctic Peninsula region, at remote field camps, and in cooperation with the national antarctic programs of the other Antarctic Treaty nations. These projects, funded and managed by the National Science Foundation (NSF), are part of the international effort to understand the Antarctic and its role in global processes. NSF also supports research that can be best or only performed in Antarctica.

The scientists who will conduct the projects described in this book come primarily from U. S. universities and have won NSF support in response to *Antarctic Research Program Announcement and Proposal Guide* (NSF 99-93; http://www.nsf.gov/cgi-bin/getpub?nsf9993). Operational resources in Antarctica also are used to support scientists from other Federal agencies.

Highlights of this year's austral summer research include:

- the first year of the 5-year multi-disciplinary International Trans-Antarctic Expedition, which integrates meteorology, remote sensing, ice coring, glaciology, and geophysics to learn more about West Antarctica's role in the global change
- a 52-day Antarctic Pack Ice Seal research cruise to study how changes in the environment cause fluctuations in the abundance, growth patterns, life histories, and behavior
- a study of microbes found in snow samples from the South Pole to determine if they are indigenous to the interior of Antarctica and to learn more about their biology and ecology
- continued support of the Center for Astrophysical Research in Antarctica at the geographic South Pole
- measuring, monitoring, and studying atmospheric trace gases associated with the annual depletion of the ozone layer above Antarctica.
- the third year of drilling and related geological work at Cape Roberts near McMurdo Station by a team of scientists from the United States, New Zealand, Italy, Australia, the United Kingdom, and Germany
- long-term ecological research in the McMurdo Dry Valleys and in the Palmer Station region of the Antarctic Peninsula

Science teams also will use networks of automatic weather stations, automated geophysical observatories, ultraviolet-radiation monitors, and a high-altitude, long-duration balloon that will circumnavigate the continent and carry instruments for an optical investigation of solar activity.

Eight teachers from U.S. elementary, middle, and high schools will join researchers on eight projects this austral summer as part of NSF's Teachers Experiencing Antarctica (TEA) project. TEA immerses teachers in research as part of their professional development and to create a polar learning community of teachers, students, school districts, and researchers. U.S. Antarctic Program investigators volunteer to include TEA participants in their field parties; NSF selects the teachers competitively.

The Antarctic Artists and Writers Program provides opportunities for painters, photographers, writers, and others to use serious writing and the arts to increase understanding of the Antarctic and America's heritage there. The 1999-2000 austral summer includes a novel on science and scientists for middle-grade children; a photographic book; natural sound recordings; and underwater photography in McMurdo Sound.

Logistics to support these projects includes heavy-lift, ski-equipped C-130 airplanes operated by the New York Air National Guard, ski-equipped Twin Otter airplanes chartered from a Canadian firm, and C-141 and C-5 air-planes provided by the U.S. Air Force between New Zealand and McMurdo Station. Contract helicopters are headquartered at McMurdo to provide operational and close science support. Ground vehicles operated and maintained by an NSF contractor, provide specialized science support and other services. Annually, a U.S. Coast Guard icebreaker opens a channel to McMurdo and provides science support. A tanker and a cargo ship, operated by the Military Sealift

Command, bring fuel, cargo, and equipment each January.

Continuing the modernization and improvement of Amundsen-Scott South Pole Station, crews will prepare the foundations for a replacement laboratory that will be built on supports above the icey plateau and will begin the exterior of a new power plant, the interior of which will be completed over the austral winter. The South Pole Safety and Environmental Project (a $25-million undertaking) and the South Pole Station Modernization Project (a $128-million initiative) will replace the existing 24-year-old station by 2005.

This book is arranged by scientific discipline, except for sections focused on multi-investigator, multi-disciplinary research projects and a short list of technical projects in the table below. The order reflects the organization of the Antarctic Sciences Section of NSF's Office of Polar Programs, which funds projects in biology, medical research, ocean sciences, climate studies, geology and geophysics, glaciology, aeronomy, astronomy, and astrophysics.

Related information products that are produced or funded by NSF include:

- Press releases issued by the Foundation's Public Affairs Office to describe specific research progress. See the NSF World Wide Web page at http://www.nsf.gov or call 703-306-1070.
- *Antarctic Journal of the United States* review issues, which contain short reports by investigators about research recently performed in Antarctica. These issues are online (http://www.nsf.gov/od/opp/antarct/journal) and are available in print from the Office of Polar Programs (dfriscic@nsf.gov).

Technical projects supporting the 1999-2000 USAP antarctic field program

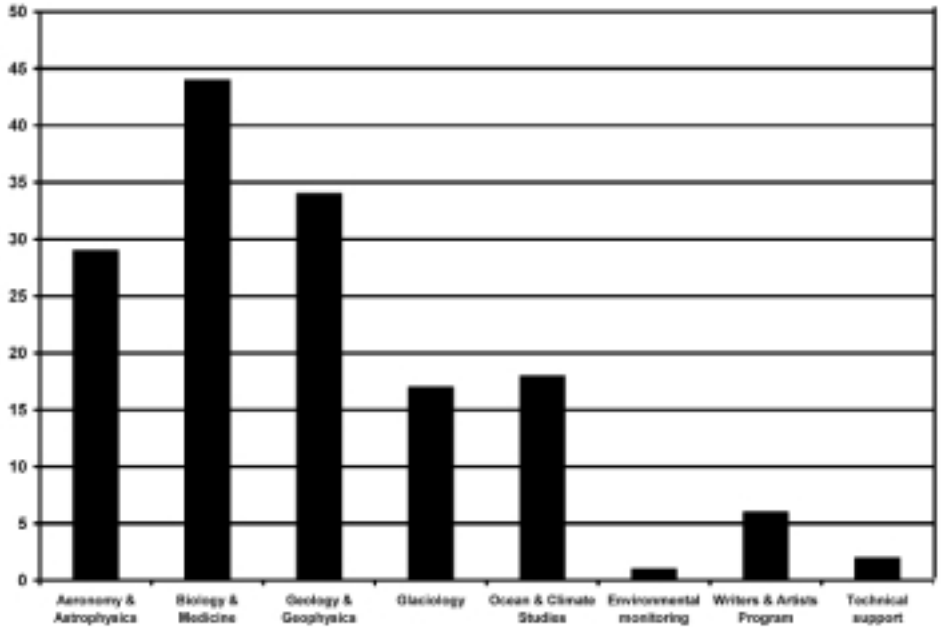
Project title	Project manager, affiliation
Polar Ice Coring Office(PICO) Hot-water drilling at the South Pole for the AMANDA project (TA-150-A)	*Karl Kuivinen,* *University of Nebraska*
PICO ice-core drilling at Siple Dome (TI-150-B)	*Karl Kuivinen,* *University of Nebraska*
Automatic Geophysical Observatory (AGO)—servicing and installation (TO-296-O)	*Jay Burnside,* *Antarctic Support Associates*
Synthetic Aperture Radar project; (TO-308-O)	*Steve Currier,* *NASA Wallops Flight Facility*
McMurdo Sound Metsat Station—refurbishment of Terascan satellite reception & processing system at Palmer Station (TO-312-O)	*Robert Whritner,* *Arctic and Antarctic Research Center, Scripps Institution of Oceanography*
UV-monitoring network (TO-513-O)	*Charles Booth,* *Biospherical Instruments, Inc.*

Artists and Writers Program projects, 1999-2000 U.S. Antarctic Program

Project title	Participant
Novel for middle-grade children on science and scientists (WO-007-O)	*Lucy Jane Bledsoe,* *Berkeley, California*
Photography book documenting the U.S. Antarctic Program (WO-009-O)	*Stuart Klipper,* *Minneapolis, Minnesota*
Natural sound recordings (WO-004-O)	*Douglas Quinn,* *Petaluma, California*
Underwater photography, McMurdo Sound (WO-317-O)	*Norbert Wu,* *Pacific Grove, California*

U.S. Antarctic Program, 1999-2000
Sites of major activities

Number of projects to be supported
during 1999-2000



AERONOMY AND ASTROPHYSICS

The polar regions have been called Earth's window to outer space. Originally, this term applied to aurora and other dynamic events staged as incoming solar plasmas encountered the Earth's geomagnetic fields. Because of its unique properties, the polar upper atmosphere becomes a virtual screen on which the results of such interactions can be viewed (and through which evidence of other processes can pass). More recently, this concept has been extended to refer to the "ozone hole" in the polar atmosphere. As scientists have verified an annual loss of ozone in the polar stratosphere, a window previously thought "closed" (stratified ozone blocking the sun's ultraviolet rays) is now known to "open" in certain seasons.

For astronomers and astrophysicists, the South Pole presents unique opportunities. Thanks to the relative lack of environmental pollution and anthropogenic "noise," the unique pattern of light and darkness, and the geomagnetic force field properties, scientists staging their instruments here can probe the structure of the sun and the universe with unprecedented precision. Studies supported by the Aeronomy and Astrophysics program probe three regions:

- The stratosphere and the mesosphere: In these lower regions, current research focuses on stratospheric chemistry and aerosols, particularly those implicated in the ozone cycle.
- The thermosphere, the ionosphere, and the magnetosphere: These higher regions derive many characteristics from the interplay between energetically-charged particles (ionized plasmas in particular) and geomagnetic/geoelectric fields. The upper atmosphere, particularly the ionosphere, is the ultimate sink of solar wind energy transported into the magnetosphere just above it. This region is energetically dynamic, with resonant wave-particle interactions, and Joule heating from currents driven by electric fields.
- The universe beyond, for astronomical and astrophysical studies: Many scientific questions extend outside the magnetosphere, including a particular interest in the sun and cosmic rays. Astrophysical studies are primarily conducted at Amundsen-Scott South Pole Station or on long-duration balloon flights launched from McMurdo.

Virtually all research projects sponsored by this program benefit from (indeed most require) the unique physical conditions found only in the high latitudes, yet their ramifications extend far beyond Antarctica. High-latitude astrophysical research contributes to the understanding of Antarctica's role in global environmental change, promotes interdisciplinary study of geosphere/biosphere interactions in the middle and upper atmosphere, and improves understanding of the critical processes of solar energy in these regions. Life exists on earth in a balance – not only because of the critical distance from the sun — but also because of numerous chemical and atmospheric phenomena peculiar to our atmosphere. The 20th century expansion of traditional astronomy to the science of astrophysics, coupled with the emerging discipline of atmospheric science (See also the Ocean and Climate Systems program), is nowhere better exemplified than in Antarctica.

AMANDA—Antarctic Muon and Neutrino Detector Array.

Robert Morse, University of Wisconsin.

Neutrinos are elementary particles: With no electrical charge, and believed to have very little or no mass, they can take any of three forms. Coursing through the universe, they interact only rarely with other particles. AMANDA's primary objective is to discover the sources – both within our galaxy and beyond – of the shower of very-high-energy neutrinos descending on (and usually passing through) the Earth.

AMANDA uses an array of photomultiplier tubes embedded between 1 and 2 kilometers in the ice near the South Pole to create a Cherenkov detector out of the natural ice. This system will detect high-energy neutrinos originating off the planet that have passed through Earth. Such sources of origin could be diffuse, made up of contributions from

many active galactic nuclei (AGNI); or they could be point sources of neutrinos – coming from supernova remnants (SNRs), rapidly rotating pulsars, neutron stars, individual blazars, or other extragalactic point sources.

Recently, new sources of high-energy gamma rays have been discovered, such as the source Mrk-421 discovered by NASA's Compton Gamma-Ray Observatory (CGRO) and Mt. Hopkins Observatory. AMANDA is designed to study just such objects, which are believed to emit high-energy neutrinos copiously. To date, neutrino astronomy has been limited to the detection of solar neutrinos, plus one brief, spectacular burst from the supernova that appeared in the Large Magellanic Cloud in February 1987 (SN-1987a). Only now is it becoming technically feasible to build large neutrino telescopes. As one of the first-generation detectors, AMANDA promises to make seminal contributions to this new branch of neutrino astronomy. (AA-130-0)

South Pole Air Shower Experiment–2.

Thomas Gaisser, University of Delaware.

As cosmic rays from space arrive at the Earth's upper atmosphere, molecules begin to feel the impact. The South Pole Air Shower Experiment-2 (SPASE-2) deploys a sparsely filled array of 120 scintillation detectors over 15,000 square meters at South Pole. This instrument array detects energetic charged particles (primarily electrons) that are produced in the upper atmosphere by cosmic rays. To detect the Cherenkov radiation produced in the high atmosphere by the same showers, a subarray called VULCAN has been constructed of nine photodetectors. The SPASE array is located less than half a kilometer from the top of AMANDA; this low-energy collector is designed to complement AMANDA's neutrino detecting capacity. [Described in the previous project summary (AA-130-0)]

SPASE-2 has two goals:

- To investigate the high-energy primary cosmic radiation, by determining the relative contribution of different groups of nuclei at energies above approximately 100 teraelectronvolts. This can be done by analyzing coincidences between SPASE and AMANDA. Such coincident events are produced by high energy cosmic-ray showers with trajectories that pass through SPASE (on the surface) and AMANDA (buried 1.5 to 2 kilometers beneath it). AMANDA detects the high energy, penetrating muons in those same showers for which SPASE detects the low energy electrons arriving at the surface. This is meaningful because the ratio of muons to electrons depends on the mass of the original primary cosmic ray nucleus. VULCAN adds two other ratios that also depend on primary mass in readings from the showers it detects.
- To use the coincident events as a tagged beam, which will permit investigation and calibration of certain aspects of the AMANDA response. This project cooperates with the University of Leeds in the United Kingdom.

(AO-109-0)

Magnetometer data acquisition at McMurdo and Amundsen-Scott South Pole Stations.

Louis Lanzerotti, AT&T Bell Laboratories, and Alan Wolfe, New York City Technical College.

The magnetosphere is that region of space surrounding a celestial object (such as the Earth or the Sun) where the object's magnetic field is strong enough to trap charged particles. Magnetometers have been installed at selected sites in both polar regions to measure changes in the magnitude and direction of Earth's magnetic field (in the frequency range from 0 to about 0.1 hertz). The unique climatic conditions in Antarctica also permit scientists to view the atmosphere optically and to correlate such hydromagnetic-wave phenomena with particle-precipitation measurements.

In this project we are measuring such variations with magnetometers installed at conjugate sites in both hemispheres; at McMurdo and Amundsen-Scott South Pole Stations, Antarctica, and at Iqaluit, in the Northwest Territories in Canada. Our data are also being analyzed and associated with similar data

acquired from several automatic geophysical observatories comprising the PENGUIN program [polar experiment network for geophysical upper-atmosphere investigations, (AO-112-O)].

Using all of these systems, we are deriving information about the causes and propagation of low-frequency hydromagnetic waves in the magnetosphere, as well as the coupling of the interplanetary medium into the dayside magnetosphere.
(AO-101-O)

An investigation of magnetospheric boundaries using ground-based induction magnetometers operated at manned stations as part of an extensive ground array.

Roger Arnoldy, University of New Hampshire.

The poles of the Earth – the points marking the axis around which the planet rotates – experience unique magnetic phenomena. By measuring magnetic pulsations at these high geomagnetic latitudes, scientists can study the plasma physics of some of the important boundaries of the magnetosphere. Geophysicists refer to the continuous stream of highly-charged particles emitted by the Sun as the solar wind. Two of the important areas of the magnetosphere are the area through which the solar wind enters and the area where its energy is transferred to the Earth's atmosphere in the form of aurora and similar phenomena.

This study employs an array of induction-coil magnetometers located at high geomagnetic latitudes in both north and south polar regions; in the Arctic at Sondre Stromfjord, Greenland, and Iqaluit, Northwest Territories, Canada, and in the Antarctic at Amundsen-Scott South Pole and McMurdo Stations. The data collected here is also being analyzed in the context of that from similar magnetometers in the U.S. and British automatic geophysical observatory (AGO) networks and the MACCS array in Canada. (The project is jointly supported by the U.S. Arctic and Antarctic Programs.)
(AO-102-O)

Antarctic auroral imaging.

Stephen Mende, Lockheed Palo Alto Research Laboratory.

Scientists are only beginning to try to perform quantitative studies on the dynamic behavior of the magnetosphere. In the past, detail-oriented explorations by space satellites have enabled them to map the average distribution of magnetospheric energetic particle plasma content. But the dynamics of auroral phenomena – when particles from the magnetosphere precipitate into the atmosphere, producing fluorescence – have been hard to quantify through optical means. Amundsen-Scott South Pole Station is uniquely situated to observe aurora because the darkness of polar winter permits continuous optical monitoring; in most other sites, the sky becomes too bright near local mid-day.

The aurora can actually be regarded as a two-dimensional projection of the three-dimensional magnetosphere because particles tend to travel along the magnetic field line. By observing the dynamics and the morphology of the aurora, scientists get a reliable glimpse into the dynamics of the region of the three-dimensional magnetosphere associated directly with it. This method relies on knowledge relating the type of aurora to specific energies of precipitation and to specific regions of the magnetosphere.

In this study, an intensified optical, all-sky imager, operating in two parallel wavelength channels – 4,278 and 6,300 Ångstroms – will be used to record digital and video images of aurora. These wavelength bands allow us to discriminate between more- and less-energetic electron auroras and other precipitation. The South Pole Station observations of the polar cap and cleft regions entail measuring auroral-precipitation patterns and then interpreting the results in terms of the coordinated observations of (magnetic) radio-wave absorption images as well as (high-frequency) coherent-scatter radar measurements.

This work should provide insight into the sources and energization mechanisms of

auroral particles in the magnetosphere, as well as other forms of energy inputs into the high-latitude atmosphere.
(AO-104-O)

A study of very high latitude geomagnetic phenomena.

Vladimir Papitashvili, University of Michigan.

This project continues a joint U.S./Russian program to operate an Antarctica-based array of automated magnetometers. As the only land mass at very high latitudes, the antarctic continent is uniquely suited to these instruments, providing an excellent and stable location for magnetometric investigations of the polar cap current systems in the Earth's magnetosphere.

Such studies are particularly important to the understanding of how the energy and momentum from the solar wind becomes coupled to the magnetosphere, ionosphere, and upper atmosphere. They also provide an excellent point of reference for other satellite-based experiments (both currently in progress and planned for the near future).

The specific tasks to be undertaken include design improvements in the digital geomagnetic data-acquisition systems at Vostok and Mirnyy, as well as continued operation and maintenance of autonomous stations along the Russian traverse route to Vostok. One aspect of the study that should enhance our results is the new satellite data-transmission capability at Vostok. This will provide a near-real-time polar cap magnetic index for space, weather and research applications.
(AO-105-O)

Global thunderstorm activity and its effects on the radiation belts and the lower ionosphere.

Umran Inan, Stanford University.

Tracking dynamic storms is a challenge, but lightning associated with thunderstorms can provide scientists an indirect way of monitoring global weather. This project employs very-low-frequency (VLF) radio receivers at Palmer Station, Antarctica, operated in collaboration with the British and Brazilian Antarctic Programs, both of which operate similar receivers. All are contributors to the Global Change Initiative.

The VLF receivers measure changes in the amplitude and phase of signals received from several distant VLF transmitters. These changes follow lightning strokes because radio (whistler) waves from the lightning can cause very energetic electrons from the Van Allen radiation belts to precipitate into the upper atmosphere. This particle precipitation then increases ionization in the ionosphere, through which the propagating VLF radio waves must travel. Because the orientations to the VLF transmitters are known, it is possible to triangulate the lightning sources that caused the changes, and thus to track remotely the path of the thunderstorms.
(AO-106-O)

Study of polar stratospheric clouds by lidar.

Guido Di Donfrancesco, Instituto De Fisica Dell'Atmosfere, Rome, Italy.

The appearance each spring of the stratospheric ozone hole above Antarctica is driven by chlorine compounds interacting on the surfaces of polar stratospheric clouds (PSCs) that formed the previous polar winter. This is one explanation for why ozone depletion is much more severe in polar regions than elsewhere.

This project uses light detection and range finding (lidar) to study the polar stratospheric clouds (PSCs), stratospheric aerosol, and the thermal behavior and dynamics of the atmosphere above McMurdo Station. Continuous lidar observations provide insight on PSC formation, evolution, and other peculiar characteristics. These data will provide a complement to the information gained from balloon-borne instruments in project AO-131-O, and thus collaborative activities will be coordinated with the University of Wyoming.
(AO-107-O)

Extremely-low-frequency/ very-low-frequency (ELF/VLF) waves at the South Pole.

Umran S. Inan, Stanford University.

Atmospheric scientists orient their studies around different strata, or regions, and the boundaries and interactions between these regions are of particular interest. How are the upper atmospheric regions coupled electrodynamically? What can we learn by measuring the energy that is being transported between the magnetosphere and the ionosphere? These are but two of the questions the U.S. Antarctic Program's automatic geophysical observatory program is designed to explore.

Plasmas occur in the magnetosphere and the ionosphere, and can be transported and accelerated by a variety of different wave-particle interactions. One important dynamic in this system is particle precipitation that is driven by extra-low-frequency/very-low-frequency (ELF/VLF) waves. Thus, measuring ELF/VLF waves from multiple sites provides a powerful tool for remote observations of magnetosphere processes.

This project maintains a system at Amundsen-Scott South Pole Station to measure magnetospheric ELF/VLF phenomena, and to correlate the data with measurements made by the automatic geophysical observatory system.
(AO-108-O)

High-latitude antarctic neutral mesospheric and thermospheric dynamics and thermodynamics.

Gonzalo Hernandez, University of Washington.

The antarctic region attracts atmospheric scientists for a number of reasons; a basic one is that measurements taken at the Earth's rotational axis are largely unaffected by planetary magnetic waves. This simplifies the study of the large-scale dynamics of the atmosphere.

For example, how do scientists measure the temperature and windspeed of the atmosphere? One primary method is by deduction, based on the emission spectra of certain trace gases as they are borne along in currents at predictable heights. Hydroxyl radicals (OH), for example, are confined to a fairly narrow band near 90 kilometers altitude.

This study uses a Fabry-Perot infrared interferometer (located at Amundsen-Scott South Pole Station, Antarctica) to make orthogonal observations of the band spectra of several trace species – most importantly the hydroxyl radical (OH). The doppler shift of the band lines provides an algorithm for researchers to measure the windspeed. The brightness and line ratios within the bands provide density and temperature information.
(AO-110-O)

Riometry in Antarctica and conjugate regions.

Theodore J. Rosenberg and Allan T. Weatherwax, University of Maryland at College Park.

The University of Maryland continues to conduct research into upper atmospheric processes; using photometry to take auroral luminosity measurements and riometry to make high-frequency cosmic noise absorption measurements. A primary focus of our analysis activities over the next several years will include coordinated ground- and satellite-based studies and Sun-Earth comparisons.

The latest work also involves extensive collaboration with other investigators using complementary data sets. Continuation of science activities into the 1998-2001 time frame will enable us to participate in, and contribute to, several major science initiatives, including the GEM, CEDAR, ISTP/GGS, and National Space Weather programs as we enter the next solar maximum period.

Riometers measure the relative opacity of the ionosphere. This work employs a new imaging riometer system called IRIS (imaging riometer for ionospheric studies). The first two IRISs were installed at Amundsen-Scott South Pole Station and Sondre Stromfjord, Greenland. A third IRIS has been installed at Iqiluit, Northwest Territories, Canada – the magnetic conjugate to South Pole. Broadbeam riometers also operate at several frequencies at South Pole, McMurdo, and Iqiluit; auroral photometers operate at South Pole and McMurdo. This

array of instruments constitutes a unique network for the simultaneous study of auroral effects in both magnetic hemispheres.

The focus of all of this work is to enhance understanding of the relevant physical processes and forces that drive the observed phenomena; this includes both internal (such as magnetospheric/ionospheric instabilities) and external forces, such as solar wind/IMF variations. From such knowledge may emerge an enhanced capability to forecast; many atmospheric events can have negative technological or societal impact, and accurate forecasting could ameliorate these impacts. (AO-111-O)

Polar experiment network for geophysical upper-atmosphere investigations (PENGUIN).

Theodore Rosenberg, University of Maryland at College Park.

The data obtained from automatic geophysical observatories (AGOs) help researchers understand the Sun's influence on the structure and dynamics of the Earth's upper atmosphere. The ultimate objective of this research into how the solar wind couples with the Earth's magnetosphere, ionosphere, and thermosphere is to be able to predict solar-terrestrial interactions that can interfere with long-distance phone lines, power grids, and satellite communications.

A consortium of U.S. and Japanese scientists will use a network of six AGOs, established on the east antarctic polar plateau and equipped with suites of instruments to measure magnetic, auroral, and radiowave phenomena. The AGOs are totally autonomous, operate year round and require only annual austral summer service visits.

When combined with measurements made at select manned stations, these arrays facilitate studies on the energetics and dynamics of the high-latitude magnetosphere on both large and small scales. The research will be carried out along with in situ observations of the geospace environment by spacecraft, in close cooperation with other nations working in Antarctica and in cooperation with conjugate studies performed in the Northern Hemisphere. (AO-112-O)

All-sky-camera measurements of the aurora australis from Amundsen-Scott South Pole Station.

Masaki Ejiri, National Institute of Polar Research, Japan.

Amundsen-Scott South Pole Station, located at the south geographic pole, is a unique platform from which to undertake measurements of the polar ionosphere, situated in such a way that dayside auroras can be viewed for several hours each day. Research has shown these auroras come from the precipitation of low-energy particles entering the magnetosphere in the solar wind.

Since 1965, data have been acquired at the South Pole using a film-based, all-sky-camera system. Using advanced technology, we can now digitize photographic images and process large amounts of information automatically. As this project continues to acquire 35-millimeter photographic images, American and Japanese researchers will collaborate in deploying a new all-sky-camera processing system developed at Japan's National Institute of Polar Research. This system displays data in a geophysical coordinate framework, and analyzes series of images over short and long intervals thus enhancing observations over discrete, individual photographs.

These studies should provide further insight into the physics of the magnetosphere, the convection of plasma in the polar cap, and solar winds in the thermosphere; specifically dayside auroral structure, nightside substorm effects, and polar-cap arcs. (AO-117-O)

Solar and heliosphere studies with antarctic cosmic-ray observations.

John Bieber, University of Delaware.

Cosmic rays – penetrating atomic nuclei from outer space that move at nearly the speed of light – continuously bombard the Earth.

Neutron monitors deployed in Antarctica provide a vital three-dimensional perspective on this shower and how it varies along all three axes. Accumulated neutron-monitor records (begun in 1960 at McMurdo Station and in 1964 at South Pole Station) provide a long-term historical record that supports efforts to understand the nature and causes of cosmic-ray and solar-terrestrial variations occurring over the 11-year sunspot cycle, the 22-year Hale cycle, and even longer timescales.

This project continues a series of year-round observations at McMurdo and Amundsen-Scott South Pole Stations, recording cosmic rays with energies in excess of 1 billion electronvolts. These data will advance our understanding of a number of fundamental plasma processes occurring on the Sun and in interplanetary space. At the other extreme, we will study high time-resolution (10-second) cosmic-ray data to determine the three-dimensional structure of turbulence in space, and to elucidate the mechanism by which energetic charged particles scatter in this turbulence.
(AO-120-O)

Rayleigh and sodium lidar studies of the troposphere, stratosphere, and mesosphere at McMurdo and Amundsen-Scott South Pole Stations.

Jim Abshire, National Aeronautics and Space Administration, Goddard Space Flight Center.

Each austral winter, polar stratospheric clouds (PSCs) form in the extremely cold polar stratosphere. Each spring, as the stratospheric ozone begins to degrade, one particular form of these PSCs, the Type 1, appear to have a particular role. This project's primary science mission is to detect, monitor and profile these Type 1 PSCs with the automated geophysical observatory (AGO) lidar. This is an ongoing, National Aeronautics and Space Administration (NASA)-funded project to develop and demonstrate a compact, low-power, and autonomous atmospheric lidar system for operation throughout the AGOs that have been established in Antarctica by the U.S. Antarctic Program.

Type 1 PSCs depolarize incident radiation. Because the laser transmitters in AGO lidar produce light that is highly linearly polarized, they can generate a depolarization signal of up to several percent. These data are stored in the lidar instruments and, at least once a day, AGO lidar transmits an atmospheric profile back to NASA's Goddard Space Flight Center in Greenbelt, Maryland.

This project also conducts continuous, long-term monitoring of atmospheric transmission and backscatter from the surface. These data are being compiled for use by the Geoscience Laser Altimeter System (GLAS), which produces specialized information on atmospheric conditions.
(AO-126-O)

Rayleigh and sodium lidar studies of the troposphere, stratosphere, and mesosphere at the Amundsen-Scott South Pole Station.

George Papen, University of Illinois.

The Earth's atmosphere is described by several stratified layers, each with distinctive structure, dynamics and characteristics. The stratosphere begins about 11 kilometers (km) above the surface; the mesosphere runs from about 50 km to its upper boundary, the menopause, where atmospheric temperature reaches its lowest point (about –80°C), before beginning to rise with increasing altitude through the outer layer, the thermosphere, which runs from 80 km to outer space.

This research deploys a sodium-resonance lidar at the South Pole to study the atmosphere's vertical structure and dynamics, from the lower stratosphere up to the menopause. As the project enters its third year, scientists will add an iron-resonance lidar, extending their ability to measure the air dynamics and temperature structure even higher, to about 100 kilometers. Another addition, an airglow imaging camera, will be used to study horizontal structure.

This final complement of instrumentation, used in conjunction with the normal balloon-borne radiosondes flown regularly from South Pole, will provide extensive data on:

- the temperature structure from the surface to 100 kilometers altitude;
- the nature of the polar stratospheric clouds (PSCs), which are important to ozone chemistry;
- the variability and frequency of occurrence of metallic layers in the mesosphere, which play roles in communications as well as atmospheric chemistry;
- atmospheric gravity waves; and
- many other phenomena, some of which are unique to the South Pole.

(AO-127-O)

High-latitude electromagnetic wave studies using antarctic automatic geophysical observatories.

James LaBelle, Dartmouth College.

Aurora are light shows (streamers and arches of light) created when electrons accelerated along Earth's magnetic field lines excite atoms in the atmosphere; they occur at the poles because of the peculiar magnetic flux generated there. The energy associated with this phenomenon is significant and complex; one small but distinctive aspect of that energy are radio emissions detectable at frequencies between 0.05 and 5.0 megahertz (MHz).

Scientists understand the phenomenon of auroral hiss that causes broadband noise at frequencies below 1 MHz. But two other radio phenomena attributable to auroras remain unexplained: Narrowband emissions near 2.8 and 4.2 MHz, and broadband noise bursts in the frequency range of 1.4 to 4.0 MHz.

Although these radio emissions constitute a small fraction of the total energy of the aurora, they may provide important clues to the more energetic processes; this possibility would mirror the use of radio emissions from the Sun to infer processes taking place in the solar corona.

Taking advantage of radio-quiet antarctic conditions, this project uses low-frequency/middle-frequency/high-frequency receivers in hopes of developing insights about these emissions from antarctic auroral zone and polar cap sites. The receivers will be installed at Amundsen-Scott South Pole Station, in three U.S. automatic geophysical observatories and in two British automatic geophysical observatories.

(AO-128-O)

In situ measurements of polar stratospheric clouds spanning the austral winter and of ozone from late winter to early spring.

Terry Deshler, University of Wyoming.

The appearance each spring of the stratospheric ozone hole above Antarctica is driven by chlorine compounds interacting on the surfaces of polar stratospheric clouds (PSCs) that formed the previous polar winter. This is one explanation for why ozone depletion is much more severe in polar regions than elsewhere.

This project uses balloon-borne instruments to provide detailed information on the clouds' particles, their distribution, and on ozone changes. Our measurements will provide vertical profiles of both the PSCs and ozone, size distributions of the PSC particles, and some information on their composition and physical state (liquid or solid). Our project is enhanced by a lidar system at McMurdo Station operated by the Instituto De Fisica Dell'Atmosfere [(Rome), see project AO-107-O]. The results contribute to the World Meteorological Organization/UNEP Network for the Detection of Stratospheric Change as well as to the Global Change Initiative.

(AO-131-O)

Trace gas measurements over the South Pole using millimeter-wave spectroscopy.

Robert L. de Zafra, State University of New York at Stony Brook.

Many atmospheric gases radiate millimeter-length radio waves, but each species has its own unique spectrum. These fingerprints not only identify the gas, but also provide information on its temperature and pressure. These properties enable scientists to use the millimeter-wave spectrum of the atmosphere to determine how abundantly and at what altitudes a number of trace species can be found.

This research uses a millimeter spectroscope to monitor the atmosphere above South Pole, Antarctica, for ozone, carbon monoxide, nitrous oxide, nitric acid, water vapor, and nitrogen dioxide, over the course of a year. Several of these gases have important roles in the formation of the annual antarctic ozone hole. Others – particularly water vapor and carbon monoxide – can provide information about the vertical transport and other dynamics of the upper stratosphere and the mesosphere.
(AO-138-O)

Cosmology from Dome-C in Antarctica.

Lucio Piccirillo, Bartol Research Institute, University of Delaware.

When the universe was created some 15 billion years ago in the Big Bang, matter began coursing outward. The general flux of that movement was discovered in 1965, and is known as thermal cosmic microwave background radiation (CMBR). Measurements of the CMBR provide the only direct evidence on the distribution of matter in the very early Universe.

Concordia is one of the highest and coldest sites presently occupied in Antarctica. These conditions minimize water vapor in the atmosphere, which can hinder accurate measurements of the CMBR, which is anisotropic; that is, its readings vary along the different axes. Thus the new French/Italian station on Dome C in Antarctica (Concordia Station) is a potentially superb place from which to make anisotropic CMBR measurements. This project involves an international collaboration between the United States, Italy, and France. We will also evaluate the site for other future uses.
(AO-140-O)

An optical investigation of the genesis of solar activity.

David M. Rust, Johns Hopkins University.

Energy stored in the Sun's magnetic fields is released in a number of dynamic phenomena, such as flares and coronal mass ejections. Scientists trying to model and understand these events face several hurdles: The Sun must be observed for long, continual periods, but the Earth's rotation limits unbroken observation from any fixed telescope to the length of a day; further, the required resolution can be achieved only by a telescope situated above most of the atmosphere. Thus far, only two solutions have been found. You can build a large, special purpose spacecraft for hundreds of millions of dollars, or launch a long distance balloon (LDB) from a polar site.

This study, The Flare Genesis Experiment, uses a high-altitude, long-duration balloon flying around the antarctic continent to deploy an 80-centimeter telescope that captures images and magnetograms of the solar photosphere and chromosphere; this instrument produces an unprecedented resolution of 0.2 arc-sec. The project is jointly sponsored by the National Science Foundation, the National Aeronautics and Space Administration, and the Air Force.
(AB-146-O)

Center for Astrophysical Research in Antarctica (CARA).

Stephan Meyer, University of Chicago.

Astronomers probe the infrared (IR) spectrum at submillimeter scales in search of data that could suggest answers to some of the seminal questions about the formation of the Universe; such as:

- How do stars form from interstellar gas?
- How did the planets form?
- What was the nature of primeval galaxies?
- How were matter and energy distributed in the early Universe?

Antarctica is an ideal spot for such research: The cold temperatures and lack of water vapor in the atmosphere above the polar plateau makes the infrared spectrum of sky in that region consistently clearer and darker than anywhere else on Earth. These conditions enable scientists to collect measurements that would be extremely difficult or impossible from other sites.

To capitalize on these advantages, the University of Chicago and several collaborating

institutions in 1991 established the Center for Astrophysical Research in Antarctica (CARA), one of 23 Science and Technology Centers funded by the National Science Foundation. CARA's scientific mission is to investigate the conditions for astronomy at the South Pole and other sites on the polar plateau, and to establish an observatory at the South Pole. Currently, CARA supports research using three major telescope facilities:

- The Astronomical Submillimeter Telescope/Remote Observatory (AST/RO) project uses a 1.7-meter (m) diameter telescope to survey interstellar gas in the galactic plane, the galactic center, and the Magellanic Clouds.
- The South Pole Infrared Explorer (SPIREX) project uses a 0.6-m diameter telescope to observe distant galaxies, cool stars, and heavily obscured star-forming regions.
- The Cosmic Background Radiation Anisotropy (COBRA) project helps researchers test current theories of the origin of the Universe.

In addition to projects using these three telescopes, CARA's Advanced Telescopes Project collects data on the quality of polar plateau sites for astronomical observations, and configures plans for future telescopes and facilities. The following projects and principal investigators are currently part of CARA:

CARA-wide operations and activities.

Stephan Meyer, University of Chicago.
(AC-370-O)

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) project develops studies on atomic and molecular gas in the Milky Way and nearby galaxies. Proposals to use their 1.7-m diameter telescope are invited from the astronomical community.
Antony Stark, Smithsonian Institution.
(AC-371-O)

The Advanced Telescopes Project (in addition to gathering measurements of "seeing" quality using the SPIREX telescope) also supports a number of other efforts including wide-field cameras, a near-IR sky brightness monitor (in collaboration with the University of New South Wales), and an instrument for monitoring mid-IR sky brightness and transmission (in collaboration with the National Aeronautics and Space Administration's Goddard Space Flight Center).
Bob Lowenstein, University of Chicago.
(AC-372-O)

The Degree Angular Scale Interferometer (DASI) is a 13-element interferometer designed to measure anisotropies in the Cosmic Microwave Background (CMB). Now in its final phase of construction, DASI will capture radiation readings over a large range of scales with very high sensitivity, and should be collecting data by Feb 2000. The instrument uses cooled HEMT amplifiers running between 26 and 36GHz, in five 2-GHz channels and will operate from the South Pole.
John Carlstrom, University of Chicago.
(AC-373-O)

The South Pole Infrared Explorer (SPIREX) project is ideal for extensive large-scale infrared and submillimeter surveys of star-forming regions in the Milky Way and Magellanic Clouds. The SPIREX telescope (60 centimeters in diameter) was built to exploit the unique observing conditions at the South Pole and to develop and demonstrate the technology needed to operate IR telescopes during the antarctic winter.

The telescope has been enhanced to lower total telescope emissivity to just 5 percent. The Abu camera is based on an Aladdin 1024x1024 pixel indium antimonide focal plane array and a set of broad- and narrow-band filters spanning the range between 2.4 and 5 millimeter (mm). It was developed at NOAO to test advanced focal-plane arrays. Combining this camera with the telescope permits wide-field (10.2 arc-minutes) astronomical imaging at wavelengths of 3-5 microns (μ); this region of the spectrum is where the advantages of the South Pole over temperate sites are greatest.

The Abu/SPIREX project is the result of unique collaboration: The National Optical Astronomy Observatories (NOAO) contributes the Abu, the best existing 3-5 micron camera; the United States Naval Observatory (USNO) and CARA commit to operating the SPIREX and conducting the science at the world's darkest 3-5 micron site, the South Pole. In addition to researchers at NOAO and USNO, the effort includes collaborators from Boston University (BU), Goddard Space Flight Center (GSFC), Ohio State University (OSU), Rochester Institute of Technology (RIT), the University of Chicago (UC), the University of New South Wales (UNSW), and the Universities Space Research Association (USRA).
Bob Lowenstein, University of Chicago.
(AC-374-0)

The Viper telescope is a 2-meter class telescope that will extend the observations (now being made with the 0.75-meter Python telescope) to structures in the cosmic microwave background having smaller angular scales. The primary goal of the Viper project is to determine the power spectrum of the CMBR anisotropy over the range of angular scales where cosmological models most differ in their predictions. Viper data should permit scientists to better discriminate among these models. Viper images will also be used to search for cosmological defect-imprints on the CMBR.
Jeffrey Peterson, Carnegie-Mellon University.
(AC-375-0)

The Submillimeter Polarimeter for Antarctic Remote Observing (SPARO), operating on the Viper 2-meter telescope is newly deployed to the Pole in 1999. SPARO is a 9-pixel, 450-micron polarimetric imager, which requires only infrequent cryogen refills, making maintenance easier during the winterover.

The South Pole offers superb conditions for SPARO observations, extending submillimeter polarimetry (measurement of the polarization of thermal emission from magnetically aligned dust grains) to regions of low-column density that cannot be studied from other sites. SPARO is similar to polarimeters in the University of Chicago array designed for other telescopes; but those instruments (for example, at the Caltech Submillimeter Observatory and the Owens Valley Radio Observatory) provide much better angular resolution. SPARO's geographic advantage, however, results in a much enhanced submillimeter sensitivity to extended emission.

The primary goal for the 1999-2000 phase of the project is to reveal the large-scale magnetic field in the nucleus of our Galaxy.
Giles Novak, Northwestern University.
(AC-376-0)

ANTARCTIC BIOLOGY AND MEDICINE

The Biology and Medicine program funds research to improve understanding of antarctic life forms and ecosystems – their physiology, behavior, adaptations, and relationships. Projects range across all organizational levels – from the molecule, cell and organism to relationships within communities and ecosystems, to the level of global processes. This is another area of inquiry where scientific goals extend far beyond learning (in this field, about flora and fauna) in the high latitudes.

Antarctica is a place like no other: as an intriguing habitat, a scientist's dream; a land where water is scarce – truly a desert – despite containing more than two-thirds of the world's freshwater supply trapped in the ice. Though it borders the world's major oceans, the Southern Ocean system is unique in the world, a sea where average temperatures don't reach 2°C in summer, where even the water itself is so unique that it can be identified thousands of miles away in currents that originated here. As the Earth makes its elliptical journey around the sun each year – tilted on its rotational axis – the sun "sets" in April, not to be seen again until September. And the ice – unimaginable, incomparable vastness of ice – in a dozen different varieties, at times and in places several thousand meters thick, two major ice sheets (the East larger than most countries), changing dynamically all the time.

Adaptations and behavior developed in response to these extreme conditions provide insight into the intricacies (as well as the fundamental processes) of evolution. These extremes have also driven the development of ecosystems simple enough to reveal wonderfully clear pieces of the web of life on Earth. Support is focused on the following areas:

- Marine ecosystem dynamics: Among the research topics are understanding the natural variability of marine ecosystems; correlating the structure and function of the marginal ice-zone ecosystem with oceanic and atmospheric processes; exploring the sources of nutrition and their influence on prey and on primary production; and the role of marine phytoplankton in carbon dioxide cycling.
- Terrestrial and limnetic ecosystems: Organisms in ice-free areas and in perennially ice-covered lakes show remarkable adaptations to extreme environments. Relatively few species thrive here, which facilitates the study of ecosystem dynamics and the interpretation of experiments, although much more remains to be learned about adaptive mechanisms and evolutionary processes.
- Population biology and physiological ecology: At the next level, looking at relationships among organisms, studies have focused on the variability and dynamics of populations of krill and other zooplankton; ecological relationships among and between fish species, marine mammals, and birds have also been the object of much research, with many issues still to be further explored. As organized programs of antarctic science enter their fifth decade (some even longer), data sets and ongoing observations are elucidating manmade as well as natural changes.
- Adaptation: Antarctic extremes present a fundamental research opportunity; topics include low-temperature photosynthesis and respiration, enzymatic adaptations and adaptive physiology such as the development in fish of antifreeze compounds and modifications to the circulatory system in seals; also continuing interest in the response of (and impacts upon) organisms to increased UV-B radiation from the ozone hole.
- Human behavior and medical research: Antarctica's extreme climate and terrain impose a quite spartan and unconventional existence upon scientists and others who live and work there. As people are subjected to social, psychological, and physiological stresses (exacerbated during the winter isolation) research opportunities arise. Studies focus on epidemiology, thermal regulation, immune system function, individual behavior, and group dynamics.

Life in Extreme Environments (LEXEN): Biology and ecology of South Pole snow microbes.

Edward J. Carpenter, State University of New York at Stony Brook.

Scientists have always portrayed Antarctica's interior ice sheets as a region extremely hostile to life. As arid as the world's severest desert, the heart of the continent has no water (H2O as a liquid), relentlessly low temperatures and long periods with minimal solar energy (darkness) – all conditions that undermine the viability of indigenous organisms. Move toward the fringes of the continent where these conditions moderate somewhat, and this picture begins to change, with numerous species of plants, protozoa, and bacteria.

In snow samples collected in January 1997 near the Amundsen-Scott South Pole Station, however, scientists have found microbes that contain two of the basics of biological life: DNA and pigments that result from photosynthesis. The snow was flown immediately to the Crary Laboratory at McMurdo Station, melted and examined by epifluorescent microscope. Based on their shape and fluorescence signatures, the particles appear to be cyanobacteria. Subsequent analysis using fluorescent DNA stains and scanning electron microscopy confirmed the presence of DNA-containing microbes with this same shape.

Formerly known as blue-green algae, cyanobacteria are now considered to be Monera: Ancient, often unicellular organisms that lack cell nuclei but which are basic to the carbon and nitrogen cycles, as many of them have photosynthetic properties.

Are these microbes indigenous to the antarctic interior? What can be learned about their biology and ecology? These questions will drive this research project, since the discovery of organisms capable of surviving in Antarctica's interior should provide us with new insight into how life forms can adapt to conditions previously believed incapable of supporting life. The biomolecules and metabolism of these creatures must be unique, and could prove valuable for molecular engineering research. (BO-004-O)

Role of antifreeze proteins in freezing avoidance in antarctic fishes: Ecological and organismal physiology, structure-function and mechanism, genetics, and evolution.

Arthur DeVries, University of Illinois.

Despite temperatures that can dip below 0°C, antarctic waters provide a life-sustaining environment for a number of fishes. Thus a basic question: Why don't these fish freeze when they take this water in through their gills? One primary reason seems to be the presence of biological molecules that work like antifreeze in an engine, so-called antifreeze glycopeptides (AFGPs) and antifreeze peptides (AFPs). By devising experiments that distinguish a number of factors, this project probes some interesting questions about how these fishes may have developed such systems.

How much ice – and as an adaptative response, how much "antifreeze" – is found in fish from more and less severe environments? Researchers will examine how much exogenous (imported into the body) and endogenous (manufactured inside the body) ice is found in fishes from two distinct environments. The McMurdo area fishes live in the coldest and most ice-laden waters of the antarctic region, while those living near the Antarctic Peninsula face a less severe marine environment. Studies will correlate the freezing extremes and compare the circulating levels of AFGPs in the fishes found in these two environments.

Other ongoing and new experiments will look for answers to a number of interesting and related questions: How does the fish organism respond to ice created inside the body? The antifreeze proteins: How do they function, what is their structure, how do their molecules actually adhere to the potential ice to inhibit its growth? What about the genes that code for these proteins: What is their structure; how are they organized; how might they have evolved? In what tissues in the fish's body is the AFGP gene expressed? (BO-005-M)

Use of a long-term database and molecular genetic techniques to examine the behavioral ecology and dynamics of Weddell seal *(Leptonychotes weddellii)* population.

Donald B. Siniff, University of Minnesota-Twin Cities.

The Weddell seal (*Leptonychotes weddellii*) is found in regions of pack ice or fast ice close to the antarctic continent. These seals are relatively long-lived, and the waters of McMurdo Sound have provided a continuous environment in which to study their survival and aquatic reproductive patterns. A series of long-term population studies, ongoing since the mid-1960s, have generated a rare and valuable set of data.

Recently developed molecular biology techniques, however, permit scientists to examine the DNA of individual seals as well as groups, and to gain insight into their genetic histories, breeding systems and reproductive fitness. Breeding males behave characteristically; looking at this behavioral ecology and their mating systems through the lens of their DNA can project backwards in time and correlate their reproductive success and the effective size of their populations.

Using and building on the long-term data set, the study will also examine how hypotheses can be tested and parameters can be estimated, in producing models and studies of population demographics. The population dynamics of the Weddell seal will also be explored though the lens of immigration and emigration into and out of the group.

As the southernmost breeding mammal in the world, the Weddell seal exemplifies the ability to adapt to environmental extremes. Understanding the mating strategies these seals employ should contribute to a deeper understanding of the evolution and population dynamics of the Pinnipedia (a suborder of aquatic, carnivorous mammals, including all the seals and walruses), as well as how marine mammals (more generally) compete. (BO-009-0)

Weddell seal foraging: Behavioral and energetic strategies for hunting beneath the antarctic fast ice.

Randall Davis, Texas A&M University at Galveston.

Weddell seals, as carnivorous mammals, hunt underwater but breathe air. To thrive in their aquatic environment, they have developed some remarkable adaptations. Foraging efficiently deep beneath the extensive, unbroken fast-ice along the antarctic coast requires that they hold their breath for 20 minutes or longer (a feat comparable to a lion or other large terrestrial predator holding its breath while it locates, pursues, and captures its prey). Then at the end of a dive, to avoid drowning, the seals must either return to the same hole or know the location of other breathing holes.

What enables Weddell seals to live this remarkable life? Until now, detailed investigation of the foraging behavior of marine mammals has not been feasible. Working from an isolated ice hole in McMurdo Sound, Antarctica, this study will employ a small video system and data logger (attached to the seals' backs) to analyze their behavior and measure their consumption of oxygen during voluntary dives. We will measure the underwater behavior, locomotor performance (swimming velocity, stroke frequency and amplitude, and three-dimensional movements), and energy metabolism of Weddell seals during their foraging dives. We will test hypotheses on: General foraging strategies; the general behavior of "searching," as well as the mechanics; modes of swimming; the metabolic price of foraging; and how foraging efficiency varies, under different environmental conditions, and in pursuit of different types of prey.

Effective inquiry into foraging ecology in marine mammals requires these sorts of pioneering studies, focused on type of prey, energetics, and foraging behavior. Of all of the deep-diving Pinnipedae (other species of seal and also of walruses), the Weddell seal may provide the best opportunity to advance

knowledge of foraging ecology; because: We have data on their diving ability; the isolated-ice-hole protocol in McMurdo Sound enables recorders to be attached and recovered reliably; and, when placed in the isolated ice hole, the seals make daily foraging dives.
(BO-017-O)

The chemical ecology of shallow-water marine macroalgae and invertebrates on the Antarctic Peninsula.

James B. McClintock and Charles D. Amsler, U. of Alabama, Birmingham.

In a number of plant species, evolution has adapted the basic strategy of developing chemical substances designed to defend the organism. One general group of these substances are classified as defensive secondary metabolites. This project will probe three "cost/benefit" ideas that are often woven into viable theories on the evolution of chemical defenses.

- First, the Resource Availability Model of chemical defense. The proposed research will examine whether macroalgae grown under carbon limitation (reduced light) will produce quantitatively higher levels of defensive compounds than will those grown in an optimal light environment; also whether antarctic macroalgae found in the nutrient-rich peninsula region are likely to develop chemical defenses that include nitrogen compounds.
- Second, the Optimal Defense Theory in macroalgae and invertebrates. The proposed research will determine the extent to which chemical defenses are more abundant in tissues with a high energy content, such as reproductive tissue and offspring (larvae); also whether larvae relying on lecithin for nutrition have a higher incidence of chemical defense than do larvae relying on plankton.
- Finally, using previous work in the Ross Sea as a starting point, the investigation will map how chemical defenses may vary across different areas; if they do vary, we will seek out possible underlying evolutionary factors.

The program should advance our understanding of the evolution of chemical defenses in general, as well as the nature and role of bioactive agents in the specific ecology of antarctic marine benthos (organisms living at the bottom of, or in very deep, marine environments).
(BO-022-O)

The biogeochemistry of dimethylsulfide (DMS) and related compounds in a chemically stratified antarctic lake.

John C Priscu, Montana State University, and Giacomo R. DiTullio, Grice Marine Laboratory, University of Charleston.

The Earth's atmospheric cycle involves continuous transport of basic elements, one of which is sulfur. Dimethylsulfide (DMS) is the dominant volatile sulfur compound emitted from the ocean and may represent up to 90 percent of the sea-to-air biogenic sulfur flux. When these volatile sulfur molecules oxidize in the atmosphere, condensation nuclei can be released which, scientists hypothesize, may directly counteract the warming effects of anthropogenically produced CO_2. Aquatic systems – in particular the waters of the south polar regions – thus play a crucial role in one of the planet's basic transactions. Yet both the sources and the sinks of DMS and associated sulfonium compounds have yet to be fully identified and understood.

This research will examine the biogeochemistry of water column and sedimentary DMS/DMSP (dimethylsulfoniopropionate), and the role of associated compounds (e.g., dimethylsulfoxide, dimethylated polysulfides) in Lake Bonney. A relatively simple aquatic system, Lake Bonney provides a highly tractable environment for investigating the microbially mediated cycling of biogenic sulfur because there is no turbulence, no grazers and little atmospheric exchange.

Preliminary data suggest that maximum levels of DMS precursors may be found in the deep-chlorophyll layer of the lake, a zone dominated by cryptophyte algae. In addition, DMS concentrations deep in the lake, where there is very little light (i.e., in the aphotic waters), are

among the highest recorded in a natural aquatic system. These observations indicate that precursors produced by trophogenic zone phytoplankton sink to the aphotic waters and sediments, where microbes decompose them to DMS and other sulfur compounds. The proposed research will define the sources and sinks of DMS and associated compounds, and establish how they function in the overall ecosystem. We hope to develop a model describing the biogeochemical transformations of organo-sulfur compounds in Lake Bonney. (BO-025-O)

Factors regulating population size and colony distribution of Adélie penguins in the Ross Sea.

David G. Ainley, H.T. Harvey and Associates, California.

Over the past few decades, the Adélie penguin (*Pygoscelis adeliae*) colonies in the Ross Sea region have grown dramatically in size. What demographic mechanisms might account for this change? This collaborative project will investigate (in particular) the possible effects of documented changes in the region's climate. We will look at the nesting habitat as a function of access to food, and hope to distinguish the relative importance of the key resources that constrain the growth of colonies. A number of behavioral and demographic mechanisms may influence a colony's growth, relative to its initial size and distribution pattern – for example, a phenomenon known as philopatry: The interrelationship between the balance achieved by immigration/emigration and consequent breeding effort and success.

As the first empirical study to consider the geographic structuring of a seabird population, we expect our results to increase understanding of how populations regulate themselves, and the patterns they follow when they disperse. We also hope to elucidate the effects of climate change, mediated through changes in sea-ice cover, on penguin populations. The results should also provide a context in which to interpret conflicting data on penguin population trends from existing programs; in particular, Adélie penguins have been studied as an indicator of such anthropogenic impacts on antarctic resources as fishery catches and disturbances created by tourism.

Our 5 years of research include intensive field study of three Ross Island penguin colonies. We quantify reproductive effort and success, food availability (access to food), diet quality, habitat use, and immigration/emigration relative to colony size and environmental conditions (i.e., pack-ice cover). We employ several well-established techniques that have been successfully (but infrequently) used in antarctic biological research:

- Aerial photography: to evaluate the availability of nesting habitat,
- Microwave images of sea-ice concentration: to assess availability of feeding habitat,
- Analysis of stable isotopes: to evaluate food quality,
- Radio telemetry: to assess overlap in colony feeding areas, and
- Automatic systems: to log aspects of reproductive effort.

Landcare Research New Zealand (LCRNZ) has conducted two preliminary field seasons, including the testing of new equipment. This project will build on their results, and they will collaborate with us throughout the lifetime of the project. The LCRNZ work is independently funded. Researchers from the University of California-Santa Cruz, the University of Wisconsin, and Beigel Technology, will collaborate with those from H.T. Harvey and Associates and LCRNZ to accomplish the project's goals.
(BO-031-O)

Penguin/krill/ice interactions: The impact of environmental variability on penguin demography.

Wayne Trivelpiece, Montana State University.

As the environment fluctuates, there are direct effects on the structure and function of antarctic marine ecosystems. Three examples are the Adélie, gentoo, and chinstrap penguins of the antarctic, whose changing

numbers have been related to long-term changes in environmental conditions, in particular the possible effects of sea-ice coverage on the availability of prey (krill).

We will explore the demographics of colonies of those three species living in Admiralty Bay, King George Island, to test five hypotheses:

- The structure of the krill population is strongly affected by the extent of pack-ice, and its consequent impact on female fecundity and the survival of larvae.
- Recruitment of penguins to their respective populations is affected by the extent of pack-ice cover during the winter prior to the breeding season.
- The survival of penguin fledglings is correlated to the extent of pack ice cover during the winter following the breeding season.
- Adélie penguins return to the pack-ice habitat during their first two-week-long foraging trips following clutch competition to recover from prolonged fasting of the courtship period.
- Accessible pack ice in the early breeding season has led to the evolution of discrete population centers of Adélies from the Bellingshausen, Weddell, and Ross Sea populations.

The Pygoscelis species of penguins are the major upper trophic level predators of krill (*Euphausia superba*) in the Antarctic Peninsula region. In trying to assess the potential impacts of fishery activities in this area, it is imperative to first determine the distinct impact of a changing environment.
(BO-040-O)

Microbial mediation of trace metal cycling in four stratified antarctic lakes.

William Green, Miami University at Oxford, Ohio.

Aquatic environments often stratify; that is, boundaries at different depths indicate changes in the composition of the water. One of the basic processes in nature is reduction by oxidation (redox), and redox boundaries can be found at specific water depths where microbes are implicated in the cycle and fate of a large suite of chemical elements.

The proposed research will examine the role of microbial influences on metal cycling in four stratified lakes in the McMurdo Dry Valleys: Lakes Fryxell, Hoare, Joyce and Miers. These lakes are characterized by unusually stable redox transition zones, and are also especially amenable to a finely spaced sampling regime. Collectively, they represent a broad range of water chemistries.

The proposed research will test two hypotheses:

- In stratified water columns there should be a clear spatial difference between the onset of manganese reduction and the onset of iron reduction. Heavy metals and rare-earth elements will be seen to undergo co-cycling with manganese (Ma) rather than with iron.
- In all four lakes, Ma reduction will be associated with the presence of carnobacteria or other Ma-reducing organisms.

Dissolved and particulate metal profiles will be examined at depths from the ice-water interface at the top all the way down to the sediments. Profiles will be correlated with microbial Ma-reduction assays, and with the presence of Ma reducers; these can be detected by screening with Mn-oxide overlay agar plates and nucleic acid hybridizations that function as probes for known manganese reducers. The research will include significant involvement of undergraduates.
(BO-041-O)

Shell morphogenesis in giant agglutinated foraminifera.

Samuel S. Bowser and Charles R. Hauer, Wadsworth Center, New York State Department Health.

A dominant member of the cold, deep-sea sediments ecosystem is a group of giant protozoa, the agglutinated foraminifera, also known as forams. For protection, these single-celled organisms encase themselves in architecturally elegant shells that they con-

struct by collecting, sorting, and cementing together sediment grains. The unique occurrence of these giant cells (greater than 1 millimeter in size) in the shallow waters of McMurdo Sound, Antarctica, allows for the study of the cellular and molecular aspects of shell construction.

In our project, we will use novel light-microscopic methods to examine how agglutinated forams secrete and sculpt the adhesive matrix that binds sediment particulate in their shells. Comparative time-lapse photography of different foram species constructing shells will identify key steps in the processes that lead to the various shell morphologies. Peptide sequence analyses of the elastic proteins of the shells will provide valuable insight into the chemical nature of foram bioadhesives. From a practical standpoint, these cements may have important biotechnological and medical applications.

We will also continue a study of the effects of collection activities, as well as natural physical disturbances, in this unique environment. The interdisciplinary research conducted for this project has implications for a number of fields, including cellular development, evolution, paleontology, marine products chemistry, and ecosystem management.
(BO-043-0)

Microbial life within the extreme environment posed by permanent antarctic lake ice.

Christian H. Fritsen, Edward E. Adams, James A. Raymond, John C. Priscu, and Christopher P. McKay, Montana State University.

How does microbial life adapt to environmental extremes, such as those found in Antarctica? One strategy is by association with sediment aggregates, sites where physical, chemical, and biological interactions promote microbial growth under extreme conditions inherent to the ice environment. The 3-to-20-meter-thick permanent ice covers on the lakes of the McMurdo Dry Valleys, Antarctica, contain viable microbial cells in association with just such sediment aggregates. Specifically, certain ice aggregates (within the permanent ice covers on the lakes in the Taylor Valley) have been tentatively characterized in previous studies.

This interdisciplinary research program will use this background and context to explore specific processes that allow for:

- the creation of liquid water (the essential element for life) in the permanent ice,
- the survival and structuring of microbial populations subjected to freezing and thawing,
- the production of substances that alter the physical attributes of the ice-crystal habitat, and
- the nutrient supply to the microbial populations, which is essential for survival and whch largely determines net microbial growth and the accumulation of biomass.

Research on microbes in permanent ice provides information on the ecology of microbes in ice ecosystems and promises to have biotechnological implications. Furthermore, since water ice has been detected within and beyond our own solar system, these studies could provide insights into the conditions that might support extraterrestrial life.
(BO-044-0)

Influence of seasonal ice cover on pelagic and benthic communities: Long time-series studies.

Kenneth L. Smith, Scripps Institution of Oceanography.

The annual expansion and contraction of ice cover in the Southern Ocean – the largest seasonal process in the world ocean – causes primary biomass production to fluctuate extensively, and has a strong impact on both pelagic (open, upper sea) and benthic (deeper, at the bottom) communities of fauna. This study at Port Foster, Deception Island, will take advantage of a region that has seasonal ice cover and which supports a pelagic and benthic fauna that are representative of the antarctic coastal zone.

The study of the water column and seafloor will be structured as a long time-series, employing long-term, autonomous monitoring and sampling systems that were developed especially for use in Antarctica. We will deploy a bottom-moored, upward-looking acoustic instrument on the seafloor for 12 months to monitor the vertical distribution, abundance, and biomass of acoustically detectable macrozooplankton and micronekton in the water column. Collections will be made over this period using newly developed, vertically profiling pump sampling. Simultaneously, a time-lapse camera system will be moored on the seafloor to monitor the spatial distribution, sizes, and movements of the epibenthic megafauna component of the benthic community.

This deployment of instruments will allow us to focus on the effect of the seasonal sea-ice cycle on the distribution, abundance, and biomass of the macrozooplankton and micronekton in the water column. Similar questions about the deeper-dwelling epibenthic megafauna will focus on distribution, size, abundance, and movements. Results from this study should provide a valuable foundation database to evaluate the pelagic and benthic community responses to seasonal variability in the Southern Ocean.
(BO-050-O)

Biodiversity and biogeochemistry of antarctic photosynthetic bacteria.

Michael T. Madigan and Laurie A. Achenbach; Southern Illinois University, Carbondale.

Environments classified as "cold" (average temperature 5˚C or lower) comprise more than 90% of the earth's biosphere, yet relatively little is known about about the diversity and ecological activities of cold-adapted microorganisms – photosynthetic microorganisms, in particular. This research will explore the biodiversity of cold-adapted anoxygenic photosynthetic bacteria that are found in permanently cold antarctic habitats. The research takes a phased approach to biodiversity: Beginning with the enrichment and isolation of cultures of antarctic photosynthetic bacteria; then characterization in the laboratory of their major physiological, biochemical, and genetic features; finally, in situ study of biogeochemical reactions carried out in natural populations of these organisms.

Readily cultivable species of cold-adapted photosynthetic bacteria will be isolated in pure culture. The isolation methods to be used are not the classical ones of liquid enrichment but instead employ extincting dilution – this will ensure that rare as well as abundant cultivable species are obtained. Variations in the enrichment approach will be used to isolate those cold-adapted species with particularly well developed and/or specialized metabolisms. Examples are those capable of autotrophic carbon dioxide fixation, nitrogen fixation and the photocatabolism of aromatic compounds. Field research will include isolation of new cultures from stratified antarctic lakes in the McMurdo Dry Valleys. A series of enrichment cultures established at different temperatures and growth rate measurements will yield isolates that possess the ability to grow over a range of temperatures. The Isolates will be phylogenetically characterized by 16s rRNA sequencing. This will permit us to determine which species are merely psychrotrophic (cold-tolerant) and which are actually psychrophilic (cold-loving).

The results of the research should fortify the knowledge of photosynthetic diversity. We anticipate identifying novel organisms for agricultural and biotechnological use, and for the study of photosynthesis and related processes at low temperatures. Finally, we expect to broaden the diversity of known psychrophilic and psychrotrophic prokaryotes, and thus provide more data for the study of exobiology (the study of life beyond the planet).
(BO-195-O)

Diving biology of emperor penguins.

Paul J. Ponganis, Scripps Institution of Oceanography.

Because the emperor penguin (*Aptenoidytes forsteri*) lives within the pack ice zone of Antarctica, its advanced ability to dive has been the subject of interest for many years.

Emperor penguins routinely hunt for food for between 2 and 10 minutes, at depths ranging from 50 to 500 meters. These birds have reached a measured depth of nearly 550 meters. The longest dives are not the deepest, however; the recorded longest of twenty-two minutes was nowhere near that record depth.

This project will examine the diving physiology and behavior of emperor penguins in the Ross Sea region of Antarctica. We hope to elucidate both the physiological and behavioral mechanisms underlying the breath-holding capacity of these diving birds; also to understand how these physiological limits may affect the natural diving behavior and ecology of the penguins; and further, to use the unique adaptation of diving birds to explore how organs and tissue tolerate oxygen deprivation.

The emperor penguin provides an excellent model to investigate the physiology and behavior of diving birds and mammals; in this case, thermoregulation, underwater behavior and the homoeostatic regulation of myoglobin. We will focus on the role of decreased body temperature in extending the duration of aerobic metabolism during diving. The presence of a small camera will permit us to examine their behavior during their dives, and to correlate changes in core and muscle temperature with which prey they ingest as well as with their wing stroke frequency. At the molecular biology level, we will use the high myoglobin concentration in emperors and the large increases in myoglobin concentration during chick development to examine transcriptional control of the myoglobin gene. (BO-197-0)

Ultraviolet-radiation-induced DNA damage in bacterioplankton in the Southern Ocean.

Wade H. Jeffrey, University of West Florida.

Strong evidence now shows that ultraviolet (UV) radiation is increasing periodically over certain locations in Antarctica and the Southern Ocean – a result of ozone depletion. When ozone concentrations are diluted, the stratosphere is able to adsorb less UV radiation, permitting more of it to reach the Earth's surface. Although research on the impact of increased UV radiation due to ozone depletion has focused primarily on phytoplankton, a smaller effort is being directed to the impacts on other food sources.

During this collaborative project, we will explore the effects of UV radiation upon bacterioplankton. This involves the interactions between bacterioplankton and photochemical processes, as well as interactions with higher trophic groups such as phytoplankton and zooplankton. Several specific parameters will be explored:

- whether bacterial phytoplankton-coupling modifies bacterial response to UV radiation,
- how seasonal changes in UV radiation affect bacterial community dynamics, and
- how chemical photoproducts affect bacterial production.

We hope to elucidate the molecular determinants of changes in productivity, and also the molecular and physiological responses to changing UV radiation. The ultimate benefit would be a greater understanding of the potential impact that changes in UV radiation can have on marine microbial communities. (BO-200-0)

The role of oceanographic features and prey distribution on foraging energetics and reproductive success.

Daniel Costa, University of California at Santa Cruz.

The Southern Ocean enjoys a high seasonal productivity, in both coastal and pelagic environments. But observations over the last several decades show that behind this general productivity lies much variation – during the year, and from year to year. Thus the prey available to vertebrate predators can vary significantly over time, and from place to place.

Since the late 1980s, scientists have recorded this spatial and temporal variability for the northern South Shetland Islands region of the Antarctic Peninsula. The antarctic fur seal [*Arctocephalus gazella*], a subpolar migratory

otariid with a short lactation period, is an increasingly dominant marine predator of the South Shetlands region. Its life-history pattern is characterized by foraging trips alternating with short visits to provide for a single offspring; this pattern allows scientists to measure both maternal investment and the distribution/abundance of prey, on the same temporal and spatial scales.

This project will quantify the foraging costs and maternal investment associated with different strategies observed in populations of South Shetland antarctic fur seals. Using state-of-the-art techniques, we will determine the costs and benefits of different foraging patterns correlated to: Energy expenditure, food intake, dive depth, dive duration, time of day, dive frequency, swim speed, and foraging location. These measurements will coincide with small- and large-scale oceanographic surveys to be conducted by the National Oceanic and Atmospheric Administration's Antarctic Marine Living Resources program, which also contributes to the support of this project.

The research will provide scientists a clearer picture of the life of a free-ranging marine vertebrate predator. The data should reveal patterns linking the biological characteristics of the prey (composition, distribution, and abundance) and the physical characteristics of the foraging environment with foraging success, maternal investment, and reproductive success.
(BO-267-O)

Surface UV irradiance and PAR variability over Antarctica

Paul J Ricchiazzi and Catherine Gautier, University of California, Santa Barbara.

Since discovery of the antarctic ozone hole in the early 1980s, concerns have grown about whether the consequent increase in ultraviolet (UV) radiation reaching the Earth's surface has a negative impact on the Southern Ocean ecosystem. While subsequent photobiology research has shown there are negative effects on photoplankton, zooplankton and fish larvae from the increased UV radiation, it is difficult to extrapolate localized studies to a broad spatial scale.

One way to extend the results of photobiology point-measurement to large spatial scales is by applying PAR (photosynthetically active radiation) mapping techniques to the UV radiation data gained by satellites. The mapping algorithm developed to date uses specific satellite images of cloud and ozone distribution to estimate UV and PAR irradiance levels over large areas of the Earth's surface. This work is underway, thanks to prior research support; the goal of the current project is to improve performance of the UV and PAR mapping algorithm. Since a significant fraction of overall biological productivity occurs in waters near the coast, we will focus special attention on improving the performance of the mapping technique in those regions.

Simulations made with Monte Carlo radiative transfer models suggest that these coastal regions are subject to significantly greater UV surface irradiance. The field study will deploy a newly modified surface radiometer with spectral sensors; this device optimizes retrieval of cloud optical depth and surface albedo. This superior system should significantly enhance our ability to test the accuracy of PAR, the mapping algorithm.

We will also investigate how the new AVHRR-3A satellite sensor might be used to improve the algorithm. It appears that information from this new sensor could be useful for obtaining more frequent and accurate surface albedo maps, information vital to the mapping algorithm.

We expect the development of these new approaches to interpreting satellite and surface measurements to provide information critical for interpreting the impact of ozone reduction on the biological communities in Antarctica.
(BO-279-O)

Planktonic invertebrate larvae and biogeography of Antarctica.

Rudolf Scheltema, Woods Hole Oceanographic Institution.

Because continental drift has isolated antarctic ecosystems since the Early Oligocene (about 40 million years ago), most inverte-

brate fauna commonly found there are native only to that region. Despite this extensive isolation, however, some benthic groups consist of significant proportions of non-native species – from 20 to more than 50 percent. To account for such species, scientists have proposed that intermittent reciprocal exchange must occur between populations resident on South America and Antarctica.

One hypothesis is that geographical distribution could be maintained and genetic exchange accomplished through the passive dispersal of planktonic larvae. This project is targeted at this hypothesis; our objective is to show that this dispersal actually occurs. We must demonstrate two facts:

- larvae of sublittoral species actually can be found across the Drake Passage; further, that these do belong to species that can be found in south american and antarctic faunas, and
- a hydrographic mechanism exists that can explain how passive transport of larvae occurs between the two continents.

To address these two requirements we will make transects of plankton samples across the Drake Passage and examine the possibility of cross-frontal exchange of larvae at the subantarctic and polar fronts of the Antarctic Circumpolar Current; we will also explore the possible transport of larvae in mesoscale rings. Our results should demonstrate that other species may be profitably examined using molecular techniques that compare individuals from bottom populations of South America and Antarctica.
(BO-281-O)

McMurdo Station biology course; Integrative biology and adaptation of antarctic marine organisms.

Donal Manahan, University of Southern California.

This international, advanced-level, graduate training course will be organized and taught in Antarctica for one month during the austral summer of 1999-2000. The course introduces students to the diversity of biological organisms in antarctic regions, and allows them to study unique aspects of biology that permit life in such extreme environments.

Long-standing questions in evolution and ecology (such as cold adaptation and food limitation) about the biology of antarctic organisms are examined through physiological experiments with organisms, studies of isolated cells and tissues, experiments on protein structure and function, and molecular analysis of genetics systems. Lectures emphasize physiological, biochemical, and molecular biological approaches to understanding the ecology and biological adaptations of antarctic organisms.

Student research projects follow these interwoven themes. The students should gain a rigorous understanding of the power – as well as the limitations – of physiological, biochemical, and molecular biological methods that are currently being used to answer research questions in environmental science and the biology of adaptation.

The course will be held in the Crary Science and Engineering Center at McMurdo Station, Antarctica. This modern research facility provides state-of-the-art laboratory facilities a short distance from the marine and freshwater environments where biological observations are made and material is collected. The course will be taught in four modules:

- Biological diversity of antarctic organisms: Evolution and molecular phylogeny;
- Ultraviolet radiation: Effects on antarctic organisms;
- Invertebrates: Physiology, energy metabolism, and development; and
- Fish: Biochemical adaptations.

By attracting an extremely competitive group of young scientists, this course introduces new researchers to Antarctica and teaches students the modern research methods currently being deployed to study mechanisms that are unique to biology in Antarctica.
(BO-301-O)

Bentho-pelagic coupling on the west Antarctic Peninsula shelf: The impact and fate of bloom material at the seafloor.

Craig R. Smith, University of Hawaii Manoa; and David DeMaster, North Carolina State University.

Primary production in antarctic coastal waters is highly seasonal; each spring/summer, an intense pulse of biogenic particles is delivered to the floor of the continental shelf. This seasonal pulse may have major ramifications for carbon cycling, benthic (seafloor) ecology and the nature of material buried on the west Antarctic Peninsula (WAP) shelf. This project brings several disciplines together in an effort to evaluate the bloom material – its fate, accumulation on the seafloor, and impact on the benthic community.

We will work along a transect of three stations crossing the antarctic shelf in the Palmer Long Term Ecological Research study area. During five cruises throughout the 1999-2000 research season, we will test the following hypotheses:

- A substantial proportion of spring/summer export production is deposited on the WAP shelf as phytodetritus or fecal pellets.
- The deposited bloom production is a source of labile particulate organic carbon (POC) for bottom-dwelling organisms (benthos) for an extended period of time (i.e., months).
- Large amounts of labile bloom POC are rapidly subducted into the sediment column by the deposit-feeding and caching activities of benthos.
- Macrobenthic detritivores undergo rapid increase in numbers and biomass following the spring/summer POC pulse.

To test these hypotheses, we will evaluate seabed deposition and POC lability, patterns of POC mixing into sediments, seasonal variations in macrofaunal and megafaunal abundance, biomass and reproductive condition, and rates of POC and silica mineralization and accumulation in the seabed. We will contrast the fluxes of biogenic materials and radionuclides (into midwater particle traps) with seabed deposition and burial rates; this data should permit us to establish water-column and seabed preservation efficiencies for these materials.

A better understanding of the spring/summer production pulse on the WAP shelf should enhance our understanding of the impact of such fluctuations on seafloor communities, as well as carbon cycling in Antarctic coastal systems.
(BO-303-O and BO-313-O)

Control of denitrification in a permanently ice-covered antarctic lake: Potential for a regulation by bioactive metals.

Bess B Ward, Princeton University.

Denitrification driven by bacteria is the process by which nitrogen is lost from ecosystems, and thus its rate and regulation may directly affect both primary biological production and carbon cycling, over both short and long time scales. This research investigates a natural experimental system to be found in permanently ice-covered Lake Bonney in the Taylor Valley of East Antarctica to ask: What is the role of bioactive metals in regulating denitrification?

Lake Bonney has two distinct lobes, but in only one does denitrification occur. Previous study has ruled out most of the obvious biological and chemical variables – which usually influence denitrification – that might account for the difference between the two lobes. Denitrifiying bacteria are present in both lobes of the lake, where tests of both temperature and salinity reveal conditions they can thrive. Thus a paradox presents itself: Despite apparently favorable conditions, what is inhibiting denitrification in one lobe and not the other?

Our study entails a combination of culture experiments and field work to examine this paradox:

- experimenting with the denitrifying isolates to determine metal tolerances and requirements for growth,

- measuring metal concentrations and metal speciation in surface transects and depth profiles, and
- probing how denitrifying bacteria respond to alterations in the availability of certain metals.

By elucidating the relationship between microbial activity and metal distributions in Lake Bonney, we hope to add to scientific knowledge about the cycling of elements in other aquatic systems. We also expect to develop insights useful for evaluating the proposed use of paleo-denitrification indicators for past climate-reconstructions. Finally this research may shed light on the potential significance of the global marine denitrification/nitrogen fixation ratio to atmospheric carbon dioxide levels.
(BO-310-0)

PACK-ICE SEALS

At least half of the seals in the world inhabit the pack ice around Antarctica. Six of the known 31 species are here, including about 80 percent of the world's total pinniped (carnivorous, aquatic mammals, including the walrus and all seals) mass. As a group, these seals are one of the the dominant predators in Southern Ocean ecosystems. Changes in population size, growth patterns, life histories, and behavior provide a rich source of potential information, about not only seal/pinniped biology, but also the history of their environment in time and space. The Antarctic Pack Ice Seals (APIS) program is designed to track the distribution of these creatures and provide a better understanding of their ecology. In January and February 2000, a research cruise (through the pack-ice zone of the eastern Ross and western Amundsen Seas) will enable scientists to survey and sample along six transects perpendicular to the continental shelf. Each of these transects will pass through five environmental sampling strata – continental shelf zone, antarctic slope front, pelagic zone, the ice-edge front, and the open water outside the pack ice. This plan will encompass all potential ecological zones except for the open water.

Antarctic pack ice seals (APIS): Ecological interactions with prey and the environment.

John L. Bengtson, Jeffrey L. Laake, and Peter L. Boveng, National Oceanic and Atmospheric Administration, National Marine Fisheries Service; Stanley S. Jacobs, Lamont-Doherty Earth Observatory; Joseph J. Torres, University of South Florida; Kendra Daly, University of Tennessee; Stephen Ackley, U.S. Army Cold Regions Research Laboratory; Langdon Quetin and Robin Ross, University of California, Santa Barbara.

During surveys along each transect we will gather data on the seals' environment (i.e., bathymetry, hydrography, sea-ice dynamics and characteristics), their trophic (nutritional) resources (i.e., phytoplankton and ice-algae stocks, and prey species such as fish, cephalopods and euphausiids), and on their numbers, distribution and diet. This collaborative project involves four different groups of researchers, each responsible for different aspects of the field program:

- Seals: Surveys by air and ship; capture and attach instruments to track behavior; collect diet samples to better understand their food habits. *(Bengtson, Boveng, and Laake)*
- Sea ice and hydrography: Measure near-surface temperature, salinity, and sea-floor bathymetry; record sea-ice and iceberg distribution and properties; collect ice cores; make CTD measurements from the ship and from ice floes. *(Jacobs and Ackley)*
- Fish and cephalopods: Assess species composition, distribution, and relative abundance, using hydroacoustic techniques and net tows; compare these data with distribution and abundance data for fish prey – such as krill – and for fish predators – such as seals. *(Torres and Daly)*
- Euphausiids and other zooplankton: Sample abundance and distribution of krill and other zooplankton, using hydroacoustic techniques, net tows and direct observations by divers; sample the demographics of krill at various depths within the study area; measure chlorophyll concentrations to evaluate the diet of krill. *(Quetin and Ross)*

A primary goal of this interdisciplinary research is to test a central hypothesis: Measurable physical and biological features in the Southern Ocean create an area of high biological activity by upper trophic level predators. We expect this physical/trophic approach to investigating an ecological web to develop insight into the interplay between pack-ice seals and the biological/physical features of antarctic marine ecosystems, and also to aid scientists in predicting seal population fluctuations attributable to environmental change. (BE-198-A, BE-198-B, BE-198-C and BE-198-D)

Antarctic pack ice seals (APIS): Distribution and abundance along the Oates and George V Coast.

John L. Bengtson, Jeffrey L. Laake, and Peter L. Boveng, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

The Oates and George V coasts offer one of the primary sea-ice habitats for seals during the austral summer. This component of the APIS program entails surveying the numbers and distribution of four seal species: Crabeater (*Lobodon carcinophagus*), leopard (*Hydrurga leptonyx*), Weddell (*Leptonychotes weddellii*), and Ross (*Ommatophoca rossii*) seals.

As some seals will be in the water during the line transect surveys, we will correct our estimates by attaching satellite-linked, time-depth recorders to crabeater seals and deriving estimates from published values for the other species. As part of the survey, we will also monitor sea-ice characteristics, such as ice type, floe size, and percentage of coverage. Our objective is to investigate the relationships among seal abundance, bathymetry, and sea-ice characteristics. We hope to produce new insights into the ecology of pack ice seals and to improve the precision of population estimates for these prominent (but still poorly-chronicled) members of the upper-trophic antarctic marine ecosystem.
(BE-198-E)

Antarctic pack ice seals: Nutritional physiology and body condition of seals.

Michael A. Castellini, University of Alaska, Fairbanks.

This component of the APIS program examines seal nutritional physiology – health, body condition and nutritional status – using a suite of biomarkers and morphometric indices. We will make comparisons within and between species, measuring: Blood and clinical markers, nutrition indices, lipid signatures and stable isotope signatures, as well an array of protein markers. This work complements other studies on the health status of Antarctic ice seals.
(BE-199-O)

Antarctic pack ice seals: Immunogenetic diversity of antarctic pack ice seals

Brent S. Stewart and Niles E, Lehman, Hubbs-Sea World Res Institute.

Like any species, pack-ice seals display genetic variability among individuals. This component of the APIS program examines two sets of genetic loci:

- the major histocompatibility complex, which is involved in immune system responses; and
- the microsatellite locus, which does not code directly for a gene product.

This dual approach will enable the team to assess how much immunologically-relevant genetic variation occurs against the background of overall genetic variation. This study complements others on the health status of Antarctic ice seals.
(BE-229-O)

Antarctic pack ice seals: Health, disease and pathology.

Pamela K. Yochem and Brent S. Stewart, Hubbs-Sea World Res Institute.

There has been very little clinical data developed on the health of animals residing in undisturbed populations, seals in Antarctica in particular. Thus baseline information on the incidence of disease organisms and pathology is critical. This component of the APIS program undertakes to evaluate the health, pathology, and exposure to disease of antarctic pack ice seals encountered during the cruise. These data should enable us to investigate population dynamics as a function of disease and pathology.
(BE-230-O)

An examination of genetic patterns and phylogeny of Antarctic pack ice seals: A coordinated multinational project.

Donald B Siniff , Curtis Strobeck, and Ian Stirling, University of Minnesota-Twin Cities

Antarctica represents an enormous tableau against which to examine genetic diversity, especially for the discrete species of seals. This component of the APIS program is investigating genetic relationships within and between all four species. Since the seal populations tend to be widely dispersed, studies of genetic diversity may indicate patterns of evolutionary strategies, as well as common and divergent traits.

We will employ microsatellite techniques to explore heterozygosity patterns within each species and to relate these patterns to what we know about their life histories. Mitochondrial DNA analysis should indicate the sequence of divergence among and between the four species, work that will be abetted through a collaboration with the University of Alberta, Canada.
(BE-309-O)

LONG-TERM ECOLOGICAL RESEARCH

Ecology has taken its place among science's vital, strategic disciplines, thanks to ever-greater awareness of how the web of life and Earth's other dynamic processes constitute a coherent system. As part of this evolution, NSF's Long-Term Ecological Research Program (LTER), begun in 1980, has grown into a network of 21 research sites established to acquire long-term data sets from Alaska to Puerto Rico to Antarctica. Such a geographical spread is necessary to collect information on a variety of ecosystem types; such as, grassland, desert, forest, tundra, lake, stream, river, agricultural and coastal systems. To enhance understanding of ecological phenomena, the program focuses on the role of cyclical/episodic events (ranging from years to decades to centuries) in the structure and function of these distinctive ecosystems.

The Antarctic Biology and Medicine Program supports two of these LTER project sites – to facilitate research on unique aspects of antarctic ecology – one in the Palmer Station area of the Antarctic Peninsula and the other in the McMurdo Dry Valleys.

The **Palmer Station/Antarctic Peninsula LTER** program is ideally sited to probe a fundamental issue: As the pack ice varies (seasonally and year-to-year), what happens to the antarctic marine community; that is, how do ecological processes influence organisms at different trophic levels? The Palmer Station LTER research program was initiated during the 1991-1992 season with the installation of an automatic meteorological station, annual research cruises in the austral summer, and a focused research program at the station facility. During the austral fall and spring seasons, process study research cruises develop data that can be compared to that collected from other coastal systems in the Antarctic Peninsula.

The **McMurdo Dry Valleys LTER** project is more wide-ranging – also due to its unique site – and stages interdisciplinary study of aquatic and terrestrial ecosystems in a cold desert region of Antarctica. The area is one of the most fascinating – and contrarian – spots on Earth. In fact, it is as unearthly as any; NASA scientists wondering what conditions on Mars might be like came here – an island of rock in a sea of ice, the largest ice-free area in Antarctica – where winds howl, what little water there is evaporates, and where the only creatures that can survive are microorganisms, mosses, lichens, and relatively few groups of invertebrates; higher forms of life are virtually non-existent. Thus LTER projects based here take advantage of perhaps the coldest and driest ecosystem on Earth, where life approaches its environmental limits; as such this may be seen as an "end-member" in the spectrum of environments included in the LTER Network.

Why is it necessary to conduct long-term ecological research in such a place? All ecosystems are dependent upon liquid water, and are shaped to varying degrees by climate and material transport; but nowhere is this more apparent than in the McMurdo Dry Valleys. In very few of Earth's environments do minor changes in solar radiation and temperature so dramatically affect the capabilities of organisms to grow and reproduce as happens in the dry valleys. Thus, this site may well be an important natural regional-scale laboratory for studying the biological effects of climate changes attributable to human activity. While the antarctic ice sheets respond to climate change on the order of thousands of years, the glaciers, streams and ice-covered lakes in the McMurdo Dry Valleys often respond almost immediately. Thus, it is there that the first effects of climate change in Antarctica should be observed.

The overall objectives of the McMurdo Dry Valleys LTER are to understand the influence of physical and biological constraints on the structure and function of dry valley ecosystems, and to understand the modifying effects of material transport on these ecosystems. Though driven by the same basic processes found in all ecosystems – such as microbial utilization and re-mineralization of nutrients – these dry valley ecosystems lack many con-

founding variables (biota levels of plants and higher animals) present in other ecosystem research.

McMurdo Dry Valleys: A cold desert ecosystem.

W. Berry Lyons, University of Alabama at Tuscaloosa.

The largest ice-free area in Antarctica can be found in the McMurdo Dry Valleys, located on the western coast of McMurdo Sound. In 1993, this region was selected as a study site for the National Science Foundation's Long-Term Ecological Research (LTER) program. Among the most extreme deserts in the world, the dry valleys are the coldest and driest of all LTER sites. Consequently, the biological systems are limited to microbial populations, microinvertebrates, mosses, and lichens. Yet complex trophic interactions and biogeochemical nutrient cycles develop in the lakes, streams, and soils of the Dry Valleys. In the austral summer, solar energy produces glacial meltwater which supplies vital water and nutrients that are a primary influence on the ecosystems. Such material transport and climatic influences shape all ecosystems, but nowhere is this more apparent than in the McMurdo Dry Valleys.

The overall objectives of the McMurdo Dry Valleys LTER project are to understand the influence of physical and biological constraints on the structure and function of dry valley ecosystems. These objectives will be pursued through a program of systematic environmental data collection, long-term experiments, and the development of explanatory models.

The McMurdo Dry Valleys LTER project focuses on the marine and terrestrial ecosystems in the dry valley landscape as contexts to study biological processes and to explore material transport and migration.

During the 1999-2000 field season, the following studies will be conducted in the McMurdo Dry Valleys as part of the LTER project:

- glacier mass balance, melt, and energy balance; Andrew Fountain, Portland State University
- chemistry of streams, lakes, and glaciers; W. Berry Lyons, University of Alabama
- flow, sediment transport, and productivity of streams; Diane McKnight, University of Colorado
- lake pelagic and benthic productivity and microbial food webs; John Priscu, Montana State University at Bozeman
- soil productivity; Diana Wall, Colorado State University and Ross A. Virginia, Dartmouth College
- paleoclimatology, paleoecology and meteorological data collection; Peter T. Doran, University of Illinois at Chicago
- ecological modeling; Daryl Moorhead, University of Toledo

(BM-042-F, BM-042-L, BM-042-M, BM-042-P, BM-042-W, BM-042-V, BM-042-D and BM-118-O)

Long-term ecological research on the antarctic marine ecosystem: An ice dominated environment.

Raymond Smith, University of California at Santa Barbara.

The Palmer Long-Term Ecological Research (LTER) project is focused on one major ecological issue:

> To what extent is the annual advance and retreat of sea ice a major physical determinant of spatial and temporal changes in the structure and function of the antarctic marine ecosystem?

Evidence shows that this dynamic variability of sea ice has an important (perhaps determinant) impact on all levels of the food web, from total annual primary production to breeding success in top predators. For example, variability in sea ice may affect prey and predators directly by controlling access to open water or preferred habitats; or indirectly, as changes in the sea ice cover affect other species that serve as food. We hypothesize that sea ice is a major factor regulating for

- the timing and magnitude of seasonal primary production;
- the dynamics of the microbial loop and particle sedimentation;

- krill abundance, distribution, and recruitment; and
- survivorship and reproductive success of top predators.

These factors probably differ for different key species, as the magnitude and timing of sea-ice changes can have very specific local impacts. What remains unclear are the ramifications for the whole antarctic ecosystem. As one of the basic examples: Greater sea-ice areal coverage promotes more available antarctic krill (a primary food), which enhances the survivorship and reproductive success of Adélie penguins.

Thus, the overall objectives of the Palmer LTER project are to:

- document not only the interannual variability of annual sea-ice and the corresponding physics, chemistry, optics, and primary production within the study area; but also the life-history parameters of secondary producers and top predators;
- quantify the processes that cause variation in physical forcing and the subsequent biological response among the representative trophic levels;
- construct models that link ecosystem processes to environmental variables and which simulate spatial/temporal ecosystem relationships; and then
- employ such models to predict and validate ice-ecosystem dynamics.

A key challenge for the Palmer LTER project is to characterize and understand the many cross-linkages that have developed in the antarctic ecosystem: Environmental phenomena vary, over time and across areas, having both physical and biological consequences; these changes in turn can develop other loops and linkages that influence each other. The participants for the 1998–1999 field season will be:

- William Fraser, Montana State University (BP-013-O);
- Maria Vernet, Scripps Institution of Oceanography (BP-016-O);
- Douglas Martinson, Columbia University (BP-021-O);
- Langdon Quetin, University of California at Santa Barbara (BP-028-O);
- Raymond Smith, University of California at Santa Barbara (BP-032-O); and
- David Karl, University of Hawaii (BP-046-O).

ENVIRONMENTAL MONITORING PROGRAM

Recognizing that scientific research and related logistic support can have effects on the antarctic environment, the Antarctic Treaty Consultative Parties adopted recommendations on environmental monitoring in Antarctica with two important goals: To detect any unforeseen effects and to verify the actual impact and scope of those effects that were anticipated.

The Protocol on Environmental Protection to the Antarctic Treaty also requires that environmental impacts be monitored. The U.S. Antarctic Program (USAP) is developing an Environmental Monitoring Program designed to detect and measure any impacts from science and operations at its research stations in Antarctica. Only with a sustained and coherent monitoring program can a reliable basis for sound environmental management decisions – and possible improvements – be established. Data obtained from the monitoring program will be used to document baseline conditions, verify operational impact, and monitor activities undertaken to recover from accidental impacts to the environment.

Spatial and temporal scales of human disturbance—McMurdo Station, Antarctica.

Mahlon Kennicutt, II, Texas A&M University.

Antarcica represents perhaps one of the most carefully-tended and strictly-monitored habitats on Earth. Aside from the obvious desire to protect the flora, fauna and the atmosphere of a relatively pristine environment per se, there is the value the extreme southern latitudes provide as a virtual baseline barometer of global pollution. The Antarctic Treaty's Protocol on Environmental Protection, supplemented by the policies and practices of the nations who work and do science there, have combined to focus scrutiny on any anthropogenic (exogenous) impacts that can be foreseen or detected.

This three year project will establish a system of observations that should enable the United States to be more aware of any such impacts – on both marine and terrestrial habitats – in and around McMurdo Station, locating them precisely and tracking them over time.

Using a combination of aerial photography and point-data sampling grids at various spatial scales, we will measure a series of attributes indicative of change within these two habitats. Our objectives are to determine:

- the spatial and temporal scales of change and its origin;
- how efficient this observational system is in documenting relevant changes in important habitat characteristics; and
- the usefulness of various approaches to reference or control locations.

We will use modern GIS techniques and geostatistical methods to organize these diverse datasets into a coherent, coordinated framework. The results should provide fundamental scientific information for developing a long-term strategy to document and minimize the impacts of future science and support operations on antarctic resources and values. (EO-318-O)

GEOLOGY & GEOPHYSICS PROGRAM

Antarctica is not only one of the world's seven continents, but also comprises most of one of its dozen major crustal plates, accounting for about nine 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. The ice sheets average some 3 kilometers deep – a virtual vault, 90 percent of the ice on Earth is here. And it is heavy, depressing the crust beneath it some 600 meters. These physical characteristics, while not static, are current. Yet thanks to the sciences of geology and geophysics, powered by modern instruments and informed by the paradigm of plate tectonics/continental drift, Antarctica is also a time machine.

Geologists have found evidence that there was once a forested supercontinent in the Southern Hemisphere, which they call Gondwanaland. Before the Earth's constantly shifting plate movement began to break it up 150 million years ago, Antarctica was a core piece of this assembly; its adjoining land has since become Africa, Madagascar, India, Australia and South America. The Antarctic Plate drifted south at little more than a centimeter each year, but geologic time eventually yields cataclysmic results: The journey moved it into ever colder, high-latitude climates, at a rate of about 4°C for each million years; eventually life conditions had changed dramatically, and Antarctica arrived at a near polar position. This astounding history of rock and life on Earth has left a stratigraphic and fossil record, locked in and beneath the ice, the sea, and in the bedrock below both.

As the ice sheets developed, they assumed what has become a key role in modulating global climate, through their interaction with oceanic and atmospheric circulation. As a bonus, the South Pole also presents a strategic point to monitor the Earth's current 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 focused on by the Geology and Geophysics program include:

- 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 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 continental margins.

All of these problems will be simplified as scientists improve their models of where, when, and how crustal plate movement wrought Antarctica and its surrounding ocean basins. The program funds investigation into the relationships between the geological evolution of the antarctic plate and the life and processes that can be deduced to accompany it: Paleocirculation of the world ocean, paleoclimate of the Earth, and the evolution of high-latitude biota. A current emphasis is the West Antarctic Ice Sheet Program (WAIS), research on the smaller of the continent's two ice sheets, conducted also under the aegis of the Glaciology program. Several important research support activities are also underway:

- Meteorites: In a partnership with NASA and the Smithsonian Institution, the program supports meteorite collection through ANSMET, the Antarctic Search for Meteorites, and chairs an interagency committee, responsible for curating and distributing samples of the antarctic meteorites.
- Mapping and geodesy: In partnership with the U.S. Geological Survey, the program

supports mapping and geodetic activities as an investment for future research in earth sciences. The U.S. Antarctic Resources Center (US-ARC) constitutes the USAP contribution to the Scientific Committee on Antarctic Research (SCAR) library system for earth sciences information; 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 a partnership with the Antarctic Marine Geology Research Facilty 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 CIROS drilling program, and the Cape Roberts Drilling Project. The facility fills requests for samples from researchers worldwide, and also accommodates visiting researchers working on site.

Air-ground study of tectonics at the boundary between the eastern Ross embayment and western Marie Byrd Land, Antarctica: Basement geology and structure.

Christine S. Siddoway, Colorado College.

The West Antarctice Ice Sheet (WAIS) is a complex, dynamic system. In Neogene time (between about 1.6 and 23.3 million years ago), movement and shifting of the Earth's crustal plates (tectonics) contributed to the formation of WAIS and associated ice streams of the region. A better understanding of what may have happened will contribute to a comprehensive model for the Cenozoic origins of the Ross Sea Rift, and should also help specify the extent of plume activity in Marie Byrd Land.

This project undertakes both geologic and geophysical investigations of these two regions. The goal is to determine the tectonic history of the region during the Cenozoic Era (the last 65 million years); specifically to learn whether Neogene structures that localized outlet glacier flow may have developed within the context of Cenozoic rifting on the eastern Ross embayment margin (on the one hand), or, rather, within the volcanic province in Marie Byrd Land; or perhaps due to a combination of both.

Faulting and volcanism, mountain uplift, and glacier down-cutting appear to be active now in western Marie Byrd Land, where generally east-to-west-flowing outlet glaciers incise much older (Paleozoic and Mesozoic) bedrock, and deglaciated summits indicate a previous north-south glacial flow direction.

Our study relies on Support Office for Aerogeophysical Research (SOAR) to collect data; this facility uses a high-precision differential global positioning system to support a laser altimeter, ice-penetrating radar, a towed proton magnetometer, and a Bell BGM-3 gravimeter.

SOAR should help us to glean glaciology data useful for studying driving stresses, glacial flow, and mass balance in the WAIS. The ground program, centered on the southern Ford Ranges, will map: Glaciated surfaces and deposits; small-scale brittle structures, to determine the regional kinematics; and datable volcanic rocks to establish the geochronology. We will also determine the relative significance of fault and joint sets, the timing relationships between them, and how they were probably formed; as well as exposure ages for erosion surfaces and moraines. To aid in the interpretation of potential field data and to aid paleomagnetic studies, we will sample magnetic properties and density as well as take ground-based gravity measurements and oriented samples.

By combining these airborne and ground investigations, we expect to gather the basic data to describe the geology and structure at the eastern boundary of the Ross embayment, in both outcrop and ice-covered areas. These data should help distinguish between Ross Sea Rift-related structural activity and tectonic uplift/faulting that may have occurred on the perimeter of the Marie Byrd Land dome and in the volcanic province. Ultimately, the aerogeophysical data and the outcrop geology should permit us to infer the geology that resides beneath the WAIS. (GF-088-0)

Global positioning system measurement of isostatic rebound and tectonic deformation in Marie Byrd Land, West Antarctica.

Bruce Luyendyk, University of California at Santa Barbara.

The Ross embayment and western Marie Byrd Land are part of the west antarctic rift system. Most scientists agree that this region is undergoing active deformation, but the rates and causes of deformation remain essentially unknown. Tectonic extension may be occurring in the Ross embayment as West and East Antarctica continue to separate. Crustal uplift could be occurring in western Marie Byrd Land due to isostatic rebound following the last glacial age.

If tectonic extension is occurring in the embayment – depending on its magnitude – it could greatly influence global plate circuit calculations. It could also constrain our understanding of the history of extension in the embayment and the consequent uplift history of the Transantarctic Mountains. Postglacial rebound in western Marie Byrd Land would depend on when and how the ice sheet was configured during the Last Glacial Maximum. The big question is whether the ice sheet collapsed in mid-Holocene time.

This study will install three continuous and autonomous global positioning system (GPS) stations on outcrops in western Marie Byrd Land, on baselines of around 100 kilometers. These stations will gather data over a 4-year period and operate in concert with GPS stations being installed in the Transantarctic Mountains in a separate project; the result will be a baseline array all across the Ross embayment. The array will also detect strain gradients in western Marie Byrd Land.

This system should determine crustal strain rates to an accuracy of 1 millimeter per year for horizontal, and 2 millimeters per year for vertical. The strain data from western Marie Byrd Land and the Transantarctic Mountains should enable us to construct both tectonic extension and glacial rebound models.

This joint project between Bruce Luyendyk of the University of California at Santa Barbara and a team at the Jet Propulsion Laboratory at the California Institute of Technology – Andrea Donnellan, Carol Raymond, and Erik Ivins – brings together experts in western Marie Byrd Land geology and tectonics, tectonic geodesy, and lithospheric deformation.
(GF-121-O)

Structure and sedimentology of the Beardmore Group, Antarctica: Latest Neoproterozoic to Early Paleozoic tectonic evolution of the east antarctic margin.

John W. Goodge, Southern Methodist University.

The Neoproterozoic to early Paleozoic transition (700 to 500 million years ago) marked a critical period in the history of the Earth: A supercontinent known as Rodinia coalesced, then fragmented, and subsequently amalgamated as a second supercontinent, known as Gondwanaland. During these events, major mountain-building, continental erosion, species diversification, sea-level fluctuations, and changes in seawater composition took place. Scientists have built detailed records of sea-level fluctuations, faunal distributions, and post-depositional tectonism out of continental margin sedimentary sequences.

The Beardmore Group in Antarctica is one of these sequences, undoubtedly a significant element in the evolution of the east antarctic craton (the main, relatively stable nucleus of the continent). Yet very little is known about its depositional or tectonic history.

Previous workers have suggested that the entire Beardmore Group is Neoproterozoic in origin, and that it records two distinct deformations, the well-known Ross orogeny and an earlier, cryptic, “Beardmore” orogeny. Field reconnaissance and geochronologic studies reveal portions of the Beardmore Group to be significantly younger than previously believed, which would support the view that Ross deformation was the exclusive formative event. These preliminary data reflect uncertainty in the geologic relations of these rocks; we believe the Neoproterozoic tectonic history for the region must be revised.

To improve understanding of the Beardmore Group's depositional history and its role in orogenic events shaping the outer margin of Gondwanaland, we will conduct:

- detailed field study of the stratigraphy, sedimentology, and structure;
- provenance (source) study of graywackes to constrain the depositional setting of the turbidites;
- determination of carbonate isotopic compositions for comparison with the global carbon-isotopic refinement of depositional age(s) through uranium-lead dating of detrital and igneous zircons; and
- thermochronology to constrain the deformation ages with argon-isotopes.

During the 1999 – 2000 austral summer, we will continue to test a recently proposed model for Beardmore Group deposition and deformation; namely that Ross activity caused the latest Neoproterozoic/Early Paleozoic(?) rift-margin sedimentation and structural inversion. These explorations should help to resolve long-standing uncertainties in the geologic history of Antarctica, and improve our understanding of global paleogeographic and plate-tectonic events during the formation of the supercontinent at the close of the Proterozoic. (GO-014-O)

Antarctic mapping and geodesy.

Jerry L. Mullins and Richard E. Witmer, U.S. Geological Survey.

Geodetic surveying, aerial photography, remote sensing (principally using several varieties of satellite imagery), and mapping are all activities necessary for the successful operation of a multifaceted scientific and exploration effort in Antarctica. The U.S. Geological Survey provides these support activities to the U.S. Antarctic Research Program.

Year-round data acquisition, cataloging, and data dissemination activities will continue in the U.S. Antarctic Resource Center for geospatial information. Field surveys will be conducted in support of specific research projects, and as part of a continuing program to collect the ground-control data necessary to transform existing geodetic data to an earth-centered system suitable for future satellite mapping programs.

LandSat data will be collected as part of satellite image mapping activities; this will permit continued publication of additional 1:50,000 scale topographic maps in the McMurdo Dry Valleys region. Such topographic maps provide a uniform base map on which to portray scientific information (from geology, glaciology, biology and other studies) such that it is spatially accurate. These, as well as the satellite image maps, are used by scientists to plan and execute future research work. Spatially-referenced, digital cartographic data will be produced in tandem with the published maps. (GO-052-M, GO-052-P and GO-052-S)

Response of the East Antarctic Ice Sheet to Middle Miocene global change.

David R Marchant, Boston University.

As evidence of global climate change continues to accumulate, scientists concentrate on models that might indicate what impacts such change could have. For example what could happen to the East Antarctic Ice Sheet?

One of the largest known global climate shifts occurred in Middle Miocene time (between about 15.6 and 12.5 million years ago). As the isotopic composition of oxygen in the oceans shifted, dramatic global cooling and reorganization of ocean circulation patterns can be seen. This dramatic and irreversible shift set the stage for modern oceanic and atmospheric circulation, and for the bipolar ice ages that have dominated climate records for the last 12.5 million years. How did Antarctica respond to this great climate shift? Could growth of the antarctic ice sheet have initiated this shift? If so, how might future fluctuations in the volume of ice on East Antarctica influence atmospheric and oceanic circulation?

Recently there was an unexpected breakthrough in antarctic geology, discovery of Miocene-age volcanic ashes interbedded with surficial sediments in southern Victoria Land. These terrestrial deposits provide unambiguous data from which to generate

precise climatic and glaciological reconstructions of how the global climate changed and the ice sheet evolved. This site appears to be the only place in Antarctica where pristine, Miocene-age, unconsolidated deposits are preserved at the ground surface. These data are further permitting scientists to address key questions, such as:

- What contributing factors in Antarctica led to the abrupt global cooling about 14 million years ago?
- Does the middle Miocene shift in the isotopic composition of the oceans signify a major expansion of east antarctic ice?
- Or rather, does this isotopic shift instead reflect a change in ocean temperature or circulation?
- And a related question – When did cold, hyperarid, polar-desert conditions (signifying the development of the polar East Antarctic Ice Sheet) first evolve in Antarctica?

In analyzing these deposits, we expect to obtain precise chronological control, based on 50 laser-fusion isotopic analyses of in-situ volcanic ashes and 20 cosmogenic, exposure-age analyses of ancient deposits. We also expect to develop a coeval record of the Miocene paleoclimate, based on textural changes in alpine drifts, the areal distribution of ice-marginal lakes, the abundance of dated, patterned ground and ventifact pavements, and the geochemistry of buried soils and volcanic-ash deposits. (GO-054-O)

The ferrar magmatic mush column system, Dry Valleys, Antarctica.

Bruce D. Marsh, Johns Hopkins University.

Earth's basic structure was formed by processes involving the crystallization of magma (molten rock). Operating on billion-year time scales, these processes have produced a wide diversity of rock types. In turn, these different elements comprise the continents and the ocean basins – the basic surface features of Earth. Yet many of the details of these physical and chemical processes remain obscure.

Present day volcanism exemplifies this overall process of differentiation – so many different varieties of lava erupt – yet scientists have not been able to relate this diversity to the prolonged and detailed deep-Earth processes that undoubtedly generate it. Solidified bodies of magma (plutons) that were once deeply buried and are now exposed through erosion also furnish evidence, but most often how these plutons relate to the magmatic-volcanic system is not clear.

This research is pointed at this fundamental problem: We will examine magma crystallization processes by studies of sills from the Ferrar Group in Antarctica. These studies should expose the relationship of plutonism to volcanism and may provide some important insights on planetary magmatism. The Ferrar magmatic system of the McMurdo Dry Valleys, Antarctica (Ferrar-DV) exemplifies the emerging global paradigm. Magmatic sheets or sills occur in stacks, connected below to a deep-seated magmatic source and above to a volcanic center.

The world's major magmatic systems reveal this pattern, as they tend to occur at ocean ridges (e.g., Kilauea, Mt. Etna, Stillwater, and Rum, among many others). Only the Ferrar-DV, however, clearly reveals the critical physical and chemical connections between the deep, mush-dominated system and the near-surface, pre-eruptive sill system.

This project seeks to ascertain the full physical and chemical nature of the Ferrar-DV magmatic system, by:

- fully delineating its vertical and horizontal extent and explaining how it was established;
- explaining the mechanics of formation of the Dais layered intrusion;
- producing a map of Ferrar rocks throughout the Dry Valleys; and
- producing a 3-D model of the opx tongue and feeder system.

The central science goal is to elucidate a rarely seen transition between plutonic and volcanic systems, one which may have implications fundamental to planetary magmatism. (GO-056-O)

Antarctic search for meteorites.

Ralph Harvey, Case Western Reserve University.

Since 1976, ANSMET (the Antarctic Search for Meteorites program) has recovered more than 9,000 meteorite specimens from locations along the Transantarctic Mountains. Antarctica is the world's premier meteorite hunting ground for two reasons:

- Although meteorites fall all over the globe at random, 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.
- Along the margins of the sheet, ice flow is sometimes blocked by mountains, nunataks, and other obstructions; this exposes slow-moving or stagnant ice to the fierce katabatic winds which can diminish the ice and expose what is known as 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 millenia, the concentration of meteorites unveiled can be spectacular.

It is important to continue recovering antarctic meteorites because they are the only currently available source of new, non-microscopic extraterrestrial material. As such, they provide essential "ground truth" (existence proof) about the composition of asteroids, planets, and other bodies of our solar system. This connection brings The National Aeronautics and Space Administration (NASA) into ANSMET as a collaborator; their robotics development project will aid the search in the Allen Hills region

During the 1999-2000 field season, ANSMET will visit the Walcott Névé region (just north of the headwaters of the Beardmore Glacier, and just south of the Law Glacier). This has been a prolific source of meteorites for ANSMET field parties. Our primary target will be an area informally called "Foggy Bottom" at the south end of the Walcott Névé, where 5 previous seasons of work have recovered over 3,400 meteorites.

Other targets this season are the Goodwin Nunataks icefields (near Foggy Bottom) and the MacAlpine Hills icefield. Another significant effort will involve reconnaissance of icefields further north, in the Miller and Geologist ranges surrounding the headwaters of the Nimrod Glacier.

After the main party returns to McMurdo in early January, a two-person ANSMET field party will visit the Elephant Moraine icefield northwest of the Allan Hills. In addition to trying to re-establish several key survey points to specify meteorite find locations across the region, ANSMET personnel will participate in a robotics experiment in meteorite collection. The National Aeronautics and Space Administration and investigator Dimi Apostolopoulos will stage a number of experiments here that could yield data useful for future collection efforts elsewhere in the solar system.
(GO-058-O and GO-059-O)

A test for Tertiary-age deep fluvial incision and strongly melting valley-glaciers in the McMurdo Dry Valleys using ground-penetrating radar: A pilot project.

Michael Prentice, University of New Hampshire.

The study of geology, as with most sciences, is closely linked to technological advancements in measurement and exploration. This research deploys ground-penetrating radar (GPR) – a technique not previously used on antarctic sediments – to study two types of large morphologic features in the McMurdo Dry Valleys in order to address controversy in the geology of Antarctica.

- First, spurlike aprons. Situated below tributary valleys that project into trunk valleys, spurlike aprons have been interpreted to be remnants of bedrock fluvial spurs; as such, they provide a record of preglacial fluvial incision of trunk-valley floors to sea level. If this interpretation is correct, it follows that a major sector of the Transantarctic Mountains landscape is largely fluvial and not glacial in origin. A corollary to this thesis requires the antarctic ice/climate system

to have been quite stable throughout the Tertiary ice ages, that is, restricted to its current high-polar state.

We believe the bedrock/spur interpretation to be unsupported and – considering form and structure analyses – unlikely. We will conduct a GPR survey of the best example (below Denton Glacier in eastern Wright Valley) in search of relevant data.

- Second, large moraines. Using form and structure analyses, we postulate that large moraines are stratified. If so, these features reflect deposition from valley glaciers that possessed strong melting margins. Deposition of this type implies that at least the regional antarctic ice/climate system was in a subpolar state – that is, was warmer, wetter, and more dynamic than the high-polar state.

We will use GPR to study three moraines whose internal composition is unknown, and which might provide evidence on the issue. Two such moraines are in central McKelvey Valley, possibly associated with glaciolacustrine sediment; the other is in central Wright Valley, and associated with glaciomarine sediment.

In addition, we will examine a few distinctive drift patches that crop out asymmetrically on trunk-valley walls, using conventional surficial geologic techniques. These patches appear to be traceable into high alpine valleys and thus may have been deposited from expanded alpine glaciers that merged with trunk-valley glaciers. If true, these patches record the synchronous advance of alpine and trunk-valley glaciers, which would imply that the coeval climate was significantly wetter and warmer than it would have been in the high-polar state. (GO-063-O)

Late Cretaceous and Cenozoic reconstructions of the southwest Pacific.

Steven C Cande, Scripps Institution of Oceanography.

Crustal plate motion is never as predictable as earth scientists would like – witness the devastation wrought by unpredicted earthquakes. In Antarctica, there is controversy regarding a possible missing plate boundary, as well as tectonic uncertainties in the motion between East and West Antarctica; in particular, questions about the relative drift between major hotspot groups. The plates of the Southwest Pacific region are rotational, so that earthquakes are relatively rare. Still, the models that describe the motion of the Pacific, Antarctic, and Australian plates – and the continental fragments of New Zealand, West Antarctica, Iselin Bank, East Antarctica, and Australia – could be improved. This is the object of this research.

Previous work has documented mid-Tertiary seafloor spreading in a NNW-striking direction, producing magnetic anomalies between East and West Antarctica. This would explain the approximate 150 km-opening of the Adare Trough, north of the Ross Sea. The hypothesized motion, however, is insufficient to resolve the apparent discrepancy between the actual plate motions and those that would follow from the assumption that the hotspots were fixed.

The motion between East and West Antarctica indicates a very small rotation. Thus, scientists would like to develop models of finite plate rotation in this area to a high degree of accuracy, particularly for older times. This goal is now attainable, based on the analysis and interpretation of data that should result from this project, in conjunction with other data sets compiled by Japanese and Italian scientists on recent cruises in the region.

Our new marine geophysical data will be collected on selected transits of the *Nathaniel B. Palmer*. We hope to:

- improve the rotation model for mid-Tertiary extension between East and West Antarctica by directly considering the plate boundary between the Pacific and Australia plates in the calculation of Australia-West Antarctica motion;
- improve the reconstructions for Late Cretaceous and Early Tertiary times by including new constraints on several boundaries not previously used in the reconstructions;
- address the issue of the fixed position of global hotspots through the implications of new rotation models; and,
- re-examine the geophysical data from the western Ross Sea embayment in light of a model for substantial mid-Cenozoic extension.

(GO-071-O)

Vertebrate paleontology of the Triassic to Jurassic sedimentary sequences in southern Victoria Land and the Beardmore Glacier area, Antarctica.

William R Hammer, Augustana College.

Vertebrates of several different ages spanning the Triassic to Jurassic (roughly from 250 to 150 million years ago) have been discovered in recent years in Antarctica. These fossils provide paleontologists a unique opportunity to study the evolution of high latitude faunas, which in turn contribute to our understanding of high latitude climates during the Mesozoic.

This project undertakes antarctic field work in the Transantarctic Mountains, to search for and collect new terrestrial vertebrates of Triassic and Jurassic age. During the austral summer of 1999-2000, with the support of helicopters operating from McMurdo Station, we plan to explore exposures of the Feather and Lashly Formations in southern Victoria Land. These field efforts will concentrate on finding exposures equivalent to the Hanson Formation – where the only Jurassic dinosaur fauna from Antarctica was found – as well as searching for new Middle to Upper Triassic fossil vertebrates. We will also construct interpretations of the taphonomic/depositional settings for each of these localities.

During the project's second year, we will prepare and study the vertebrate finds, including investigations of the evolutionary significance of the member taxa of these high latitude Mesozoic faunas.

(GO-074-O)

Dry valleys seismograph project.

Kent Anderson, U.S. Geological Survey.

One recurrent issue in seismography is "noise" – that is background phenomena that can interfere with clear and precise readings. The Dry Valleys Seismograph 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 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 Newell 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 Hatheton they pass via 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, the Australian station.

GO-078-A

Mount Erebus volcano observatory: Gas emissions and seismic studies.

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

Mount Erebus on Ross Island is Antarctica's most active volcano; also the only one with a persistent convecting lake of molten silica and alkali-rich photolitic magma in its summit crater. This makes Erebus one of the few volcanoes on Earth with nearly continuous, small explosive activity and internal earthquake (seismic) activity. As such, it provides the ideal natural laboratory to study these phenomena: How gas is given off by magma, and the seismic activity that results from a convecting magma conduit.

This project entails a combination of seismic studies and gas emission rate measurements, designed to elucidate the nature and dynamics of the magmatic plumbing system, as well as eruptions and degassing from the lava lake.

The gas studies will provide some of the first data available on carbon dioxide degassing from a highly alkalic magma system. They should also help to evaluate how much lead from Mount Erebus (relative to lead released by marine aerosols) gets into the snow on the East Antarctic Ice Sheet, and thus shed light on hypotheses about the anthropogenic origins of lead. Further goals of the gas studies are to:

- examine the role of Erebus as a source of gas and aerosols to the antarctic environment;
- understand the role of volcanism as a source of carbon dioxide emissions to the atmosphere, especially for a highly alkalic magma;
- understand the evolution of the main volatile substances (water vapor, carbon dioxide, total sulfur, fluorine and chlorine) in the Erebus magmatic system, as well as their role in the eruptive behavior of Erebus; and
- correlate the nature of the gas emissions with the observed seismic activity.

The seismic studies of the volcano will:

- add a permanent broadband seismic station to the array and update the present data acquisition system;
- deploy a temporary network of broadband stations to augment the results of a previous pilot study; and
- expand development of current software to allow automatic and precise timing of earthquake occurrences and thus allow precise locations to be determined.

The resultant data should enhance the collection of earthquakes that we are using in a computer model of the interior of the volcano, as well as provide a tool scientists can use for volcano surveillance, eruption monitoring, and for detecting subtle changes in the internal behavior of volcanoes. The broadband data will support a detailed study of the explosion mechanism, especially the very-long-period signals they emit. It should also help us detect temporal and spatial variability in earthquake mechanisms, which in turn might provide more insights into how variations in gas emissions may be implicated. (GO-081-O)

Global positioning system measurements of crustal motion in Antarctica.

Barclay Kamb, California Institute of Technology, and Carol Raymond, Jet Propulsion Laboratory.

Geodesy is the mathematically-grounded science of using measurements to map the positions and shapes of the Earth's surface features. The satellite-based global positioning system (GPS) has revolutionized the techniques and enhanced the accuracy of geodetic work. This project has established a geodetic network in the Transantarctic Mountains of Antarctica to measure both vertical and horizontal crustal velocities:

- The vertical crustal velocities measured by GPS reflect the viscoelastic response of the solid Earth to antarctic deglaciation. That data will enable us to evaluate discrepancies between models that describe when antarctic deglaciation probably occurred: Either in Late Pleistocene-Early Holocene (about 10,000 years ago) or later, in Late Holocene time. These data will also constrain the length of

time over which the antarctic ice sheet disintegrated, and should provide a reconstruction of its changes. If antarcitc deglaciation occurred in the mid-Holocene, we would expect a specific pattern of uplift, near the Transantarctic Mountains. This new, high-precision GPS geodetic system should be able to pin that event within a time span of 4 years.

- Horizontal deformation induced by rebound can also be measured; these data help constrain models of present-day changes in antarctic ice mass by monitoring how the lithosphere is deformed by ongoing glacial loading and unloading. We predict that horizontal component (the lithospheric response to ongoing ice-mass changes) to be an order of magnitude smaller than the vertical (the viscoelastic response to late Pleistocene-Holocene deglaciation). Conversely, that predicted rebound signal should be much larger than the associated tectonic uplift rates. Our baseline measurements will cross known fault lines in the Transantarctic Mountains, and may capture co-seismic motion, in the event of an aseismic slip or an earthquake.

This autonomous GPS station (AGS) network sends daily data reports to McMurdo Station, and has been designed as a permanent installation that will continue to monitor motion in the region. Advanced processing techniques – such as orbit modeling, troposphere correction, ionosphere correction, and extraction of annual and seasonal solid Earth and ocean tidal signals – have been developed to refine the accuracy of these crustal velocity measurements, especially for the vertical component. (GO-082-O)

GPS measurements of rock and ice motions in South Victoria Land

Ian M. Whillans, Terry J. Wilson, and Clyde C. Goad, Ohio State University.

Southern Victoria Land and its environs appear to contain invaluable evidence about the tectonics of Antarctica and how the ice sheet may have changed. Leading models differ on one vital question: Is the continent rebounding due to reduced ice load from East and/or West Antarctica, or is the current tectonic motion better explained by Terror Rift or uplift of the Transantarctic Mountains? This project uses Global Positioning System (GPS) measurements of this region to probe for data relevant to this controversy.

We will also measure ice motion, hoping to develop data that would test models for ice flow in the Allan Hills meteorite-concentration region, and help determine whether small glaciers in the McMurdo Dry Valleys are thickening or thinning. This aspect of the work requires setting monuments into rock and ice, and establishing their current position with GPS receivers; any motion will be detected as the data set is compounded in subsequent years.

Our field activities involve close cooperation with the U.S. Geological Survey. (GO-084-O)

Logistics support for global seismic station at the South Pole.

Rhett Butler, Incorporated Research Institution for Seismology.

Seismology, perhaps as much as any other science, is a global enterprise: The waves resulting from the Earth's interior motion can only be interpreted through simultaneous measurements at strategic points all over the planet. To help establish the facilities required to accomplish this crucial scientific mission, IRIS (the Incorporated Research Institution for Seismology) was created in 1985.

IRIS is a consortium of institutions that run research programs in seismology. Fifty-seven universities are currently members, including nearly all U.S. universities that run seismological research programs. IRIS has developed a 10-year plan to implement the global seismographic network (GSN). In addition to portable stations, the GSN will comprise about 100 broadband, digital, wide-dynamic-range stations, designed to broadcast such that any site on Earth will have real-time access to the complete global data set.

We will install, maintain, and operate IRIS seismic equipment at Amundsen-Scott South Pole Station and at Palmer Station, Antarctica.

Such capability is essential for seismic studies of Antarctica. The resultant state-of-the-art, broadband, digital seismic capability continues the National Science Foundation effort to improve seismic instrumentation globally, and will provide a crucial link in the GSN. (GO-090-O and GO-091-O)

Paleohistory of the Larsen Ice Shelf: Evidence from the marine record.

Eugene W. Domack and Patrick D. Reynolds, Hamilton College.

Over the last 10 years, scientists have observed a dramatic decay and disintegration of floating ice shelves along the northern end of the Antarctic Peninsula. Meteorological records and satellite observations attribute this catastrophic decay to regional warming, measured at nearly 3°C during the last 50 years. (The links between this warming and the global change attributable to the greenhouse effect, however, are not fully understood.) Such a retreat of floating ice shelves is unprecedented in historic records, but scientists do not know enough about the longer context, and thus are interested in the natural variability of ice shelf systems over the last few thousand years.

The Larsen Ice Shelf provides an excellent point of reference for such studies: Located in the northwestern Weddell Sea along the eastern side of the Antarctic Peninsula, the shelf (according to satellite images taken over the past five years) is undergoing a rapid, catastrophic retreat that is unprecedented in historic time, leaving vast areas of the seafloor uncovered and in an open marine setting.

This project of marine geologic research will collect a series of short sediment cores (within the Larsen Inlet and in areas that were previously covered by the Larsen Ice Shelf). By applying established sediment and fossil criteria to the cores, we hope to discover and demonstrate whether the Larsen Ice Shelf has experienced periods of retreat and subsequent advance (similar to that of the last half century) within the Holocene (the last 10,000 years).

Previous work throughout the Antarctic (in areas of the Ross Sea, Antarctic Peninsula, and Prydz Bay) has used ice shelf depositional models to discern the timing of ice shelf retreat/advance. This research should build on that data and enhance understanding of the dynamics of ice shelf systems and their role in climate oscillations – past and future. (GO-096-O)

Acquisition and operation of broadband seismograph equipment at chilean bases in the Antarctic Peninsula region.

Douglas Wiens and Gideon P. Smith, Washington University.

The present-day tectonics and seismological structure of the Antarctic Peninsula and Scotia Plate region are among the most poorly understood of any location in the world. This region offers a unique and complex geodynamic setting, as illustrated by recent changes in the pattern of volcanism and other tectonic activity. We constitute the U.S. component of an international effort – using a large-scale deployment of broadband seismographs – to study the seismotectonics and seismic structure of these regions.

During 1997 and 1998, a network of 11 broadband seismographs in the Antarctic Peninsula region and southernmost Chilean Patagonia were installed and have since been maintained. Data return from this project has been excellent, producing some interesting initial results. We need to extend these observations, however, because there have been few larger magnitude regional earthquakes and thus internal strain can be presumed to be increasing, a longer time frame should elicit data on more revealing events.

However, instruments from this project are borrowed from the IRIS-PASSCAL instrument pool and must be returned to PASSCAL in April 1999. This project undertakes the transformation of these three temporary seismometers into semi-permanent stations, and the continued seismological investigation of the region for 4 years. Washington University equipment will also be used to operate a fourth station, in Chilean Patagonia.

Continued operation of these stations should enhance understanding of the seismicity of the South Shetland Trench, an unusual subduction zone where young lithosphere is subducting very slowly. The continuing collaboration between Washington University and the Universidad de Chile will contribute important seismological data to the IRIS data center, as well as to other international seismological collaborators.

Such mutual exchanges with other national antarctic seismology research programs will accumulate data from a variety of other proprietary broadband stations in the region. These data will support seismic studies of the upper mantle velocity structure of several complicated tectonic regions in the area, including the South Shetland subduction zone, the Bransfield backarc rift, and diffuse plate boundaries in the areas around Patagonia, the Drake Passage, and along the South Scotia Ridge. Such studies should provide important constraints on the crustal structure beneath the stations; in turn improved structural models will help to pinpoint better locations for future instruments. (GO-097-O)

Antarctic network of unattended broadband integrated seismometers (ANUBIS).

Sridhar Anandakrishnan, Pennsylvania State University.

Despite much attention in recent years, the structure and dynamics of the antarctic crust and the composition and geometry of the mantle are still poorly understood. Seismology remains the primary method for studying these structures, as well as processes in the Earth's deeper asthenosphere, but Antarctica lags far behind in the effort to improve global seismic imaging and tomography. On this huge continent, there are only eight broadband seismic observatories. Except for the installation at South Pole, those stations are along the margins of the continent and none are in West Antarctica. By contrast, there are 200 permanent stations worldwide in the Federation of Digital Seismograph Networks (FDSN), and some 1,000 more, in national networks not yet integrated into the FDSN.

This project is developing a passive seismic network for the antarctic interior. We will develop and deploy 11 long-term broadband seismic stations on the continent itself. Because 98 percent of the continent is ice covered, these stations will be installed at the surface of the ice sheet. The body-wave data thus recorded from regional and teleseismic earthquakes can be analyzed at each station for local crustal thickness, lamination, Poisson's ratio (a measure of crustal composition), crust and mantle anisotropy (a measure of current and former stress regimes), and identification of rift zones and crustal block boundaries. In addition, the data from all stations (including the existing peripheral ones) can be used for seismic tomographic analysis to detail lateral variations in these properties.

Six of the stations will be installed at existing automatic geophysical observatory sites (in East Antarctica), which will provide heat and power for the data loggers. The remaining five stations will be established in West Antarctica, and will be powered and heated by wind turbines during the austral winter. (GO-180-O)

UNAVCO's global positioning system receiver.

Bjorn Johns, University NAVSTAR Consortium.

UNAVCO, a consortium of 100 international universities and laboratories, joined to promote the use of global positioning system (GPS) for geosciences research. As part of this activity, UNAVCO manages a satellite facility at McMurdo Station and provides equipment and logistical assistance to earth scientists making use of the (GPS) for research in crustal dynamics, earthquake, volcano, and global change research. In addition to supporting researchers in the U.S. Antarctic Program, UNAVCO also supports operations at McMurdo Station and Taylor Valley. The UNAVCO facility in Boulder, Colorado, offers a complete support program for university-based investigators including

- preseason planning,
- GPS equipment,
- training,
- field support and technical consultation, and
- data processing and archiving.

UNAVCO also represents the academic research community, acting as a central clearinghouse for information on the scientific applications of GPS. As a part of its service to investigators, UNAVCO works to improve GPS surveying accuracy by testing GPS equipment and techniques.

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 in investigations of 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. (GO-295-O)

The young marginal basin as a key to understanding the rift-drift transition and andean orogenesis: OBS refraction profiling for crustal structure in Bransfield Strait.

James A. Austin, Gail L. Christeson, Ian W. Dalziel, and Yosio Nakamura, University of Texas, Austin.

Bransfield Strait (in the northern Antarctic Peninsula) is one of a small number of modern basins that may be critical for understanding ancient mountain-building processes. The Strait is an actively-extending marginal basin in the far southeast Pacific, situated in an inactive volcanic arc between the Antarctic Peninsula and the South Shetland Islands. Widespread crustal extension, accompanied by volcanism along the Strait's axis, may be associated with slow underthrusting of oceanic crust at the South Shetland Trench. Some 140 million years ago (during the Jurassic-Early Cretaceous), similar "back-arc" extension is known to have occurred along the entire Pacific margin of the supercontinent known as Gondwanaland. This area has become western South America and West Antarctica.

Then, some 100 million years ago, mid-Cretaceous deformation of these basins initiated the uplift that produced the Andes. Thus, scientists believe that elucidating the deep structure and evolution of Bransfield rift could provide a model of crustal precursor activity that will more fully describe the early evolution of this globally important mountain chain.

Years of international earth sciences research in Bransfield Strait have produced consensus on important aspects of its geologic environment. It is a young (probably ~4 million years old) rift in preexisting Antarctic Peninsula crust; continued stretching of this crust results in complex fault patterns and associated volcanism. The volcanism, high heat flow, and mapped crustal trends are all consistent with the basin's continuing evolution as a rift.

It is also agreed the volcanism is recent and continues to occur along a "neovolcanic" zone centralized along the basin's axis. Multichannel seismic data collected aboard *Maurice Ewing* in 1991 illustrate the following basin-wide characteristics of Bransfield Strait:

- widespread extension and faulting,
- the rise of crustal diapirs or domes associated with flower-shaped normal-fault structures, and
- a complicated system of fault-bounded segments across strike.

The geophysical evidence also suggests northeast-to-southwest propagation of the rift, with initial crustal inflation/doming followed by deflation/subsidence, volcanism, and extension along normal faults.

Although Bransfield Strait exhibits geophysical and geologic evidence for exten-

sion and volcanism, continental crust fragmentation in this "back-arc" basin is still underway, and has yet to generate ocean crust. Instead, the Bransfield rift lies near the critical area that marks the transition from intracontinental rifting to seafloor-spreading. Because the basin is asymmetric and appears to manifest shallow intracrustal detachment faulting, it is near the edge of the spectrum of models to explain how continents break up. As such, the region is an excellent "natural lab" for studying the diverse processes that form continental margins.

Thus some significant questions arise: What stage of evolution is the Bransfield rift experiencing? Does it provide a basis for constructing models of Andean mountain-building? The answers are to be found by defining Bransfield rift's deep crustal structure. This research work will begin this task by collecting and analyzing high-quality, high-density ocean bottom seismometer (OBS) profiles both along and across the Strait's strike. The scientific objectives are to:

- develop a detailed seismic velocity model for this rift;
- calibrate velocity structure and crustal thickness changes associated with presumed northeast-to-southwest rift propagation, as deduced from the multichannel seismic interpretations;
- document the degree to which deep velocity structure corresponds to along- and across-strike crustal segmentation; and
- assess structural relationships between the South Shetland Islands "arc" and Bransfield rift.

The OBS data we expect to collect will also be integrated with other geophysical explorations of the region (such as both Ewing profiles). This piece of the puzzle will complement ongoing deep seismic analysis of Antarctic Peninsula crust to the southwest, as well as additional OBS monitoring for deep earthquakes. Ultimately, the complex plate tectonic evolution of this region may be clarified. (GO-306-O)

Glacial history of the Amundsen Sea shelf.

Thomas Kellogg, Davida Kellogg, and David Belknap, University of Maine.

The West Antarctic Ice Sheet (WAIS) is the last marine-based ice sheet in the world, and may be inherently unstable. The limited marine geological and geophysical data available from the Amundsen Sea suggest that grounded ice or an ice shelf occupied the inner Amundsen Sea embayment until perhaps 1,000 to 2,000 years ago, and this ice may have retreated rapidly since then. Organized inquiry has been formalized with the WAIS science plan. Their Priority Goal H2 asks:

> "What is the deglaciation history in the eastern Ross, the Bellingshausen and Amundsen Seas?"

This project responds to the last of these targets by undertaking a study of the marine geology and geophysics of the Amundsen Sea continental shelf from 100° W to 130° W.

Unlike other embayments in West Antarctica, major ice streams draining into the Amundsen Sea from the interior of the WAIS lack buttressing ice shelves. Analysis of the distal portions of these ice streams (Pine Island and Thwaites Glaciers) indicate glacial mass is either in balance or may be dissipating. Because both ice streams have beds that slope downward toward the center of the ice sheet, grounding-line recession resulting from either continued thinning or sea-level rise could trigger irreversible grounding-line retreat, leading to ice-sheet disintegration. If this ice sheet were to melt, the rise of sea level around the globe would follow.

This project will examine bathymetric data of the Amundsen Sea continental shelf to determine the positions of former ice-steam channels, and to help select optimal sites from which to obtain sediment cores. Single-channel seismic reflection studies will also help identify sites for coring, and will locate and identify morphologic features indicative of former grounded ice (e.g., moraines, scours, flutes, striations, till wedges and deltas). The coring will be concentrated along former ice flow-lines. Core samples will

be analyzed in the laboratory for sedimentology, to look for basal tills (indicating former grounded ice and its former extent), and for calcareous and siliceous microfossils. The chronology of grounding-line and ice-shelf retreat from a presumed position during the Last Glacial Maximum near the shelf break will be established, using accelerator mass spectrometry (AMS) carbon-14 dates of acid-insoluble particulate organic carbon.

This project shares ship time in the Amundsen Sea with a project in physical oceanography. Our marine geologic data and collected samples – together with the findings of other investigators – should provide another important step toward a comprehensive interpretation of the history of the WAIS. (GO-307-O)

Support Office for Aerogeophysical Research (SOAR).

Donald D. Blankenship, University of Texas at Austin.

The Support Office for Aerogeophysical Research (SOAR) was established to facilitate aerogeophysical research over continental Antarctica, by abetting research efforts to understand the dynamic behavior of the ice sheet and the nature of the underlying lithosphere. SOAR uses high-precision laser altimetry to develop data on gravity, magnetics, and navigation. SOAR also provides information essential to selecting sites for ice coring in West Antarcta, as well as locations for over-snow seismic transects.

This type of interdisciplinary yet focused research and support represents a unique part of the U.S. Antarctic Program, and could revolutionize how earth science and glaciology research is conducted in Antarctica. (GS-098-O)

THE CAPE ROBERTS PROJECT

This joint venture brings together the national antarctic programs and scientists from Australia, Germany, Italy, New Zealand, the United Kingdom and the United States of America. The aim is to recover and analyze cores from the sedimentary strata beneath the sea floor off Cape Roberts, in the southwest corner of the Ross Sea, Antarctica. Geologically the strata to be drilled are located just within a major rift – the West Antarctic Rift System – and have also been close to the South Pole for the last 130 million years. They are over 1,500 meters (m) thick, and were laid down between 30 and more than 100 million years ago.

Normally, strata from that long ago (Mid-Cretaceous to Paleogene) are deeply buried, but strata from the sea floor off Cape Roberts record old glacial and rifting events at or near the surface. Operations are designed to recover a complete core representing the target 1,500 m of strata; drilling for cores at three separate locations will accomplish this, with the depth of individual excavations up to 700 m below the sea floor. Curators cut the aggregate core into 1 m lengths, describe them in geological detail, and then photograph them. Samples are then distributed to researchers for a wide range of analyses – from extracting specific target fossils to determining more precise age and composition data for the sample.

The cores should help scientists answer two important questions:

- Before the glaciations of the last 36 million years, were there ice sheets on Antarctica that may have caused fluctuations in world-wide sea levels?
- How and when did the rifting of the Antarctic continent contribute to the formation of the Transantarctic Mountains and the Ross Sea?

Developing scientific models to answer these questions should provide more general insight into the etiology of changes in global sea level, as well as the origins of mountains and basins.

Cretaceous-Paleogene foraminifera of the Victoria Land Basin (Cape Roberts Project).

Peter-Noel Webb, Ohio State University.

Fossils recovered from Cape Roberts Project (CRP) cores contribute to scientists' ability to reconstruct the ancient prehistory of the region. Foraminifera are marine protozoa with calcareous shells, one of the basic species found in the region. The drill may provide cores that aggregate to about 1,500 meters in depth, which indicate ages from 30 to about 100 million years (Late Cretaceous/Paleogene). This interval of geological time has yet to be documented by in situ stratigraphic sections in either the Ross Sea or East Antarctica.

The final disintegration of Gondwanaland occurred during this time frame, as New Zealand and Australia moved north, away from Antarctica. Foraminifera from the CRP drill holes should contribute to an understanding of the paleogeography and paleoceanography of a number of significant structures: The highlands and Pacific margin of East Antarctica (the location of the proto-Transantarctic Mountains), the west antarctic rift system basins and the highlands of West Antarctica. This will help scientists reconstruct the history of the marine margin of East Antarctica (the region near the drill holes), and decide among current, contending hypotheses: Was it located in a Cretaceous cul-de-sac; or did it occupy (at times) a position on a major oceanic circulation pathway between the southwest Indian, southwest Pacific, and southwest Atlantic Oceans?

By developing a comprehensive accounting of foraminifera – presence, abundance, preservation, species dominance and diversity, stratigraphic distribution, levels of endemism or cosmopolitanism in faunas, and completeness or fragmentation of population structures – we hope to provide data that can be used to address a variety of geological problems:

- We will date disconformities and acoustic reflectors, which we expect to encounter in the drill hole, as they extend across the rift system basins.
- We will use benthic foraminiferal bathymetric indicators to deduce major basin subsidence/uplift trends resulting from compaction and/or rift margin faulting.
- We hope to document phases of transgression and regression, based on more subtle cyclicity in the stratigraphic distribution of benthic species. These, in turn, may indicate a relationship between sea level oscillation and terrestrial glacial events.

(GL-049-A and GL-049-B)

Diatom biostratigraphy and paleoenvironmental history of Cape Roberts Project cores.

David Harwood, University of Nebraska at Lincoln.

Diatoms are unicellular algae well represented in the fossil record because of their silicified cell walls that persist as skeletons after death. Analyses of these and other siliceous microfossils in Cape Roberts Project (CRP) cores are fundamental to an integrated biostratigraphy for the late Cretaceous/Paleogene age (30 million to 100 million years ago), a time period not well documented in the southern high latitudes. Diatoms, for example, can provide evidence of environmental changes in water depth, primary productivity, and the presence or absence of sea ice. CRP cores will provide an excellent opportunity to study diatom evolution, including adaptations made in response to strong polar seasonality.

CRP studies also provide a useful point of contrast and comparison for similar studies based in the Arctic. Data on Paleogene siliceous microfossils found in Arctic strata (for example, Ocean Drilling Program Leg 151) can be assimilated with our results to develop a wider perspective on Paleogene high-latitude phytoplankton evolution.

This project begins with field-based paleontologic analysis of siliceous microfossils retrieved from Cape Roberts cores. Core sections are then ferried to the Crary Science and Engineering Center (CSEC) at McMurdo Station for further, immediate analysis. As drilling operations continue and siting decisions must be made, this age-and-paleoenvironmental data is quickly available and can be a valuable part of such decision-making.

Each season, a preliminary biostratigraphic/paleoenvironmental report based on siliceous microfossils is produced, and becomes incorporated into the CRP Initial Reports volume, along with preliminary results from other microfossil groups, as well as lithostratigraphic, magnetostratigraphic, and other analyses.
(GL-051-O)

Downhole logging for the Cape Roberts Project.

Richard Jarrard, University of Utah.

Through continuous-core and downhole logging at the Cape Roberts Project (CRP) scientific drill holes, this project produces geophysical well logs that reveal variations in mineralogy and porosity through time. Geophysical logging is essential to producing the basic stratigraphic framework on which all of the other scientific work depends. This is accomplished by integrating our detailed one-dimensional records for each hole with available high-resolution seismic data; the result is a fine-grained, two-dimensional interpretation of the core's stratigraphy. This spatial/temporal framework then becomes the context for scientists from several disciplines to locate their own data in space and time, facilitating studies of climate, tectonics, and sea-level change and helping to pinpoint the onset of antarctic glaciation.
(GL-055-O)

Calcareous nanofossil biostratigraphy and paleoenvironmental history of the Cape Roberts Project cores.

James J. Pospichal and Sherwood W. Wise, Florida State University; and David Watkins, University of Nebraska.

Calcareous nanofossils are an important element in the Cape Roberts Project (CRP), since their biostratigraphic record spans the entire time interval revealed in the CRP cores.

Recent work from other ocean drilling sites around Antarctica on this species has allowed scientists to produce a refined zonation model for the Southern Ocean. Hemipelagic and pelagic sediments recovered by the CRP can immediately be placed within this high-resolution biostratigraphic framework. By combining these results with data from other fossil groups, with magnetostratigraphic data, and with other age-dating methods, geological investigators will have a powerful, built-in control for dating their results.

This project supports the drilling program by providing rapid age-and-paleoenvironmental information; as with other allied work, sedimentary cores will be studied at the Crary Science and Engineering Center (CSEC) at McMurdo Station for the target species – in this case calcareous nanofossils – and a biostratigraphic record of the core published in the Initial Reports volume.

These nanofossils also provide an excellent paleoenvironmental gauge of surface-water temperature and productivity. Through statistical analysis, a census of their population in an area can tell scientists a lot about the general climate. When combined with data from other fossil groups and sedimentological studies, they provide a lens to assess climatic change in the distant past. (GL-057-O)

Initial sedimentological characterization of the Late Cretaceous-Early Cenozoic drill cores from Cape Roberts, Antarctica.

Lawrence Krissek, Ohio State University; and Ross Powell, Northern Illinois University.

The Cape Roberts Project (CRP) aims to provide new data about the development of the west antarctic rift system, the subsidence history of the Ross Sea, and ice-sheet fluctuations on Antarctica through a critical time interval for which not enough is known. Previous work has, however, successfully documented the development of the region and its environmental history. But CPR can now draw upon newly compiled geophysical databases, and hopes to produce a sharper and more fine-grained spatial and temporal record.

While other researchers examine the sedimentary cores for fossilized fauna and other elements, this project is solid geology – initial description and sedimentological characterization of the successive layers, defining and constructing facies sequences, and interpreting environments through time when specific depositions were made. The sediments are also subjected to petrologic, petrogenetic, and initial clay mineralogical analysis.

The stratigraphic sections so described then become points of reference for modeling observed marine and geophysical events. The results also go into the Ocean Drilling Program-style Initial Report for each drilling season. Combined with information provided by other specialists (such as biostratigraphy, magnetostratigraphy, geophysical logs, and geochemical interpretations), these yield an initial interpretation of the region's history, and provide a foundation for any regional or global ramifications that may flow from that history. (GL-070-O)

Paleomagnetic and mineral magnetic characterization of drill cores from the Cape Roberts Project.

Kenneth Verosub, University of California at Davis; and Gary Wilson, Ohio State University.

Over time, the magnetic polarity of the Earth is dynamic, and periodically reverses altogether. This change in turn affects magnetized and other particles in the earth; over long, ancient time frames (paleo) the study of these changes – paleomagnetic stratigraphy – combined with the appropriate mineral magnetic studies, can produce an age record of the region.

The integrated science plan for the Cape Roberts Project (CRP) entails delivering the cores to McMurdo Station, where all of the initial scientific characterization of the cores will be done, including magnetostratigraphy, biostratigraphy, petrography, mineralogy, and sedimentology. A primary output of this initial work is the age of the strata in the cores, because a temporal framework is fundamental to the his-

tory of climatic and tectonic events. The on-site magnetic studies of this project will:

- undertake logging of the whole-core magnetic susceptibility, which will help correlate the several overlapping cores to be recovered during the CRP;
- determine a magnetostratigraphic framework for dating the cores;
- undertake mineral-magnetic and environmental-magnetic studies to assess the reliability of the paleomagnetic signal;
- determine if environmental magnetic properties yield information concerning changes in the tectonic, sedimentologic, diagenetic, or climatic influences on the sedimentary record at Cape Roberts; and
- undertake detailed environmental and mineral magnetic studies to evaluate how well the sediments actually record the geomagnetic field.

Ultimately, the CRP records provide the potential to obtain rare, high southern latitude constraints on geomagnetic field behavior. Paleomagnetic studies should also provide important data concerning crustal movements and rift development in the Ross Sea sector.
(GL-075-O)

Stress field history, Cape Roberts, Antarctica.

Terry Wilson, Ohio State University.

The Cape Roberts Project (CRP) is providing the opportunity to develop the first age-calibrated stress-field history within the west antarctic rift system of Antarctica. The drill site, (not coincidentally) located along the margin between the uplifted Transantarctic Mountains and the rifted crust of the Victoria Land basin, is expected to yield information on the paleostress history of the Mesozoic and Cenozoic rift-basin fill material through analysis of the core, and from downhole logging of natural fractures and faults.

To establish the stress state contemporaneous with any particular stratigraphic level, researchers in this project will examine the cores for coring-induced stress fractures; and also the borehole (with a downhole televiewer and dipmeter) for any wellbore breakouts and fractures that may have been reactivated by contemporaneous geologic and tectonic events.

The stress data should produce answers to a number of questions relevant to the paleo- and neo-tectonic evolution of the Antarctic Plate. A number of seminal, outstanding issues may be resolved; such as:

- the cause of the anomalous aseismicity of the continent,
- the geometry of stresses along the lithospheric boundary between the Transantarctic Mountains and the west antarctic rift system, and
- the evolution of the antarctic intraplate stress field and its relation to rifting episodes associated with the breakup of Gondwanaland.

Current stress data obtained from this research will be added to the global stress database, helping to fill out the sketchy global stress evaluations associated with the Antarctic Plate.
(GL-079-O)

Initial palynological characterization of Cape Roberts drill cores.

Rosemary Askin, Ohio State University; and John Wrenn, Louisiana State University.

Palynomorphs – both marine (dinocysts) and nonmarine (spores, pollen) types – have proven invaluable for constructing the biostratigraphic and paleoenvironmental record in Antarctica. They record extensive and diverse geologic information, and are preserved in a wide variety of lithofacies formed in various paleoenvironments.

This collaborative project with New Zealand palynologists will provide initial palynological characterization of the Cape Roberts Project (CRP) drill cores. Our analyses provide constraining data for an integrated biostratigraphic and paleoenvironmental framework, based on all microfossil groups present. Such a framework should be of use to all future geologic, geophysical, and paleontologic studies conducted on the cores and in the drilling area.
(GL-080-O)

GLACIOLOGY PROGRAM

Ice is the defining characteristic of Antarctica, indisputably. The entire continent (with a few exceptional areas such as the McMurdo Dry Valleys and some lakes and mountains) is covered by a "sheet" of ice that has been laid down over eons, if the term sheet can be used to describe a dynamic mass several thousand meters (m) thick, larger than most countries, rising over 2,000 m above sea level (peaking in an ice dome in the east nearly twice that high), and heavy enough to depress the bedrock beneath it some 600 m. Actually there are two sheets: The East Antarctic Ice Sheet is much the larger, covering the bedrock core of the continent. The smaller West Antarctic Ice Sheet overlays a group of islands and waters.

The Glaciology Program is concerned with the history and dynamics of the antarctic ice sheet; this includes research on near-surface snow and firn, floating glacier ice (ice shelves), glaciers, ice streams and continental and marine ice sheets. These species of ice facilitate studies on ice dynamics, paleoenvironments (deduced from ice cores), numerical modeling, glacial geology, and remote sensing. Some current program objectives include:

- correlating antarctic climatic fluctuations (from ice core analysis) with data from arctic and lower-latitude ice cores;
- integrating the ice record with the terrestrial and marine records;
- investigating the physics of fast glacier flow with emphasis on processes at glacier beds;
- investigating ice-shelf stability; and
- identifying and quantifying the relationship between ice dynamics and climate change.

These topics come together in the multidisciplinary West Antarctic Ice Sheet program (WAIS), a major initiative of the Office of Polar Programs. The WAIS program – by developing an understanding of its history, current state, internal dynamics and its coupling to the current global climate – is hoping to perfect models to predict the ice sheet's future behavior. The Antarctic Glaciology Program also supports much of the land-based glacial geology undertaken by the U.S. Antarctic Program, especially more geologically recent events during the last 3 million years (between the Pliocene and Recent epochs).

Initial examination of the 500,000-year climate record at Mt. Moulton, West Antarctica

Nelia W. Dunbar and William C. McIntosh, New Mexico Institute of Mining & Technology.

Geologists crave opportunities to examine the vertical face of any significant structure, since moving down through the horizontal layers exposes clues to the history of the region. One such opportunity presents itself at Mt. Moulton in West Antarctica, where a summit crater presents 600 meters of exposed ice, in which can be seen intercalated layers of tephra, the solid material (especially ash) that is ejected into the air during a volcanic eruption.

Using the Argon-40/Argon-39 technique, scientists provisionally believe the tephra layers range in age from 15,000 to 480,000 years; they appear to have originated in a nearby volcano, Mt. Berlin. In this 2-year project, we will revisit the Mt. Moulton blue ice site for detailed sampling of the ice section and associated tephra layers, which will be subjected to geochemical analysis to further refine the dates. Examination of the ice should help to determine climatic variations in West Antarctica over the last 500,000 years.

Our data should supplement that to be gleaned from the proposed west antarctic deep ice core, though ours could potentially yield a much longer climatic record. (10-151-0)

Ice dynamics, the flow law, and vertical strain at Siple Dome.

William Harrison, University of Alaska, Fairbanks.

Iceflow near a divide such as Siple Dome is unique because it is predominantly vertical. As ice is deformed vertically, the vertical strain rate dominates, and must be known in order to calibrate dynamic models of iceflow.

This 3-year project – a collaboration between the Universities of Alaska, Washington and UC-San Diego – will measure the vertical strain rate (as a function of depth) at two sites on Siple Dome, Antarctica. We hope to develop a better analysis of the ice core than was possible from recent coring sites in central Greenland.

We plan to use two relatively new, high-resolution systems for measuring the core in hot-water drilled holes. These data, coupled with a determination of the flow-law, will be used to interpret the shapes of radar internal layering as indicators of the accumulation patterns and dynamic history of Siple Dome over the past 10,000 years; an improved model should emerge. This model will then provide a context in which to interpret the ice core drilled at Siple Dome: Both the thicknesses of the annual layers (as indicative of annual accumulation rates) and the borehole temperatures. (IO-164-O)

West Antarctic Ice Sheet surface melting: Recognition controls and significance.

Richard Alley, Pennsylvania State University.

Glaciologists work to discover the history of dynamic processes, such as ice melting and climate. For example, surface melting on polar ice sheets can be said to occur when the temperature increases above some threshold. With data on these parameters, scientists try to link observed patterns to detectable changes in the macro glacial terrain, in hopes of developing models that may predict the future of antarctic ice.

This project focuses on the critical Ross Ice Shelf and Siple Dome regions of West Antarctica. There are currently in use several different procedures to measure melting:

- space-based microwave sensors record the occurrence of liquid water or refrozen ice layers in the near surface;
- Automatic Weather Stations (AWS) record the high temperatures that are linked to development of liquid water; and
- snow-pit and ice-core studies show layers where re-freezing of sufficient liquid water has caused a visibly distinct layer to form.

Each approach is different, and they are presently not well calibrated to one another. We hope to determine how the different measures of melting may be correlated, using a combination of techniques: Snow-pit, ice-core, AWS, remotely sensed data, and experiments on melt generation. By looking at a variety of records of past surface melting events in Antarctica, we hope to develop a context that will pinpoint especially high temperatures. With all of this data, we hope to develop a model for a seasonally resolved paleothermometry, based on a joint approach to measuring ice melt, as well as complementary paleothermometers such as borehole temperature, and isotopes. (IO-168-O)

Stress transmission at ice-stream shear margins.

Ian M. Whillans and Cornelis J. van der Veen, Ohio State University.

Shear margins are areas of particular interest to glaciologists, providing evidence of how the slow accumulation of forces over time can create cataclysmic features. Three such ice stream shear margins are the object of this 3-year project aimed at elucidating the transmission of stress. From measurements of the strain rate, we hope to deduce the net force per unit of ice-stream length transmitted between ridge ice and ice-stream ice. We hope to:

- determine how much of the motion of the ice streams is controlled from the inter-stream ridges;
- correlate the magnitude of this lateral drag with the driving stress on the ice stream, and with ice stream width; and
- determine whether lateral drag support can be associated with the margin moving laterally.

For field work, we will use ski-equipped Twin Otters to install two remote camps that will each be occupied for about 6 days. The Support Office for Aerogeophysical Research in Antarctica (SOAR) facility will conduct aerial surveys to determine the ice thickness on the inter-stream ridges, as well as the ice thickness and surface slope on the ice streams. The field measurements will be complemented by repeat images of Ice Stream E adjacent to the field site [taken by the french SPOT satellite], to allow velocities in the ice-stream side of the margin to be determined. Comparing these velocities to those obtained from the strain-grid surveys will provide an estimate of the amount of softening of the ice in the margins.
(IO-169-O)

West Antarctic glaciology.

V. Robert Bindschadler, National Aeronautic and Space Administration.

The West Antarctic Ice Sheet (WAIS) shows patterns of iceflow that are not fully understood. One so-called surge hypothesis has been put forth to explain the basis of these patterns; to test it, two critical questions must be answered:

- Are ice streams B, D, and E currently surging?
- What has been the buttressing effect of an enlarging Crary Ice Rise on the flow of ice stream B?

This 3-year project is addressing these questions by collecting data from the air, from space and from the surface. Many of the studies of change in West Antarctica have been based on interpolations and calculations with large uncertainties. We hope to take advantage of global positioning system data to minimize field logistic requirements and develop sharper data. Specifically, we plan to obtain direct measures of (expected) thinning in the upper portion of ice stream D; as well as repeated satellite image measurements at the heads of ice streams B, D, and E. If these reveal inland migration of the onset area, sustained surging may be verified and the hypothesis strengthened.

We will also take new measurements of the thickness, surface elevation, and velocity of the ice, in order to compare the buttressing impact (of Crary Ice Rise) on ice stream B's flow with data collected during the 1950s, 1970s, and 1980s. This part of the study should yield a time series of change in the WAIS over the last half century.
(IO-173-O)

High-resolution chronology of millennial-scale lake-level fluctuations in the Dry Valleys (Antarctica) from uranium-thorium and radiocarbon dating.

Brenda L. Hall, University of Maine.

Virtually all research science enhances the wisdom and experience of the investigator, but some programs are actually designed around that concept, and targeted at specific groups of scientists. The Professional Opportunities for Women in Research and Engineering (POWRE) program affords new research and educational enhancement opportunities for women scientists.

After a program of study and apprenticeship designed around specific scientific skills, the principal investigator (PI) will undertake a study of the fluctuations (on a millennial scale) of lake levels in the Dry Valleys of Antarctica, looking for basic causes of climate change. The primary activity will be testing the reservoir effect in order to ensure that the chronology of lake-level fluctuations is accurate. With this data in hand, she will make a comparison study of millennial-scale fluctuations in other lakes around the world.

The project was specifically designed to increase the educational and research skills of the principal investigator. She will learn the following new information/skills:

- thermal ionization mass spectrometry (TIMS) uranium/thorium (U/TH) dating with Dr. G. Henderson at Lamont-Doherty Earth Observatory (LDEO) and Oxford University;

- millennial-scale climate change with Drs. W. Broecker and G. Bond, LDEO, and with Drs. D. Oppo and L. Keigwin, Woods Hole Oceanographic Institution;
- antarctic limnology with Dr. C. Hendy, University of Waikato; and
- regional climate modeling with Dr. K. Maasch, University of Maine.

In gathering data from the Dry Valleys, the PI will use TIMS, U/TH and accelerator mass spectrometric (AMS) radiocarbon dating of lacustrine carbonates. Her knowledge of limnology will help not only to assess the lake reservoir effect, but provides a foundation to inquire into the causes of large-scale changes in lake level. Likewise, regional climate modeling will allow her to gain insight into the energy balance and wind patterns of the Dry Valleys region during the last Glacial Maximum.
(IO-196-O)

SOAR laser: Calibration and first measurement for ice-sheet change detection.

Ian Whillans, Ohio State University.

The Support Office for Aerogeophysical Research in Antarctica (SOAR) facility provides equipment and analysis for a number of Antarctic projects and researchers. Thus, its data are ramified through numerous studies, and must be verifiably valid. This 3-year project will evaluate some of SOAR's capability; especially the use of its laser, to generate precise and accurate measurements of the elevation of the antarctic ice sheet, and to track ongoing changes.

Tests will be made in two modes: While the aircraft is parked, as well as during flights over ground-surveyed sites near the aircraft base camp. Once the laser and other equipment has been validated and calibrated, we will begin a limited program to measure changes over time in the surface elevation of glaciologically interesting sites. The goal is to run a "test case" to demonstrate SOAR's ability to accurately and precisely determine – and track change in – surface elevation. Thus "vetted," SOAR will become an asset to all investigators involved in precisely mapping and detecting change in the antarctic ice sheet.
(IS-166-O)

SIPLE DOME ICE CORING

Snow flakes form in the atmosphere and trap samples of the cloud water, atmospheric gases and dust through which they fall. When it lands in the accumulation zone of an ice sheet, the snow is compressed, re-crystallized, and builds up in ice layers which can be as thick as several kilometers. Thus discrete ice strata can be traced to snow that fell over 100,000 years ago. Analyzing this ice for such traces permits scientists to estimate climate properties such as the temperature, the snow accumulation rate, circulation patterns of the general ocean and atmosphere, and the concentrations of greenhouse gases when the snow fell – in short, a reconstruction of the paleoclimate. Such a model of the ancient weather improves our ability to predict how these phenomena may interact in the future; ultimately, we may be able to control the climate society will experience. We can almost certainly better predict how human activities will influence the climate.

The NSF has established the West Antarctic Ice Sheet (WAIS) initiative to investigate the influence of the West Antarctic Ice Sheet on climate and sea level change. The WAIS-CORES effort will recover and interpret an ice core from Siple Dome, Antarctica, and eventually plans to obtain a second core from a more inland site. These locations were selected to provide climate records that will extend back 80,000 to 100,000 years; cores from two sites will permit scientists to separate local and regional influences on the climate record they extract from the cores. The current season will wrap up these activities and complete scientific evaluation of the cores.

Recovery and science coordination of an ice core at Siple Dome, Antarctica.

Kendrick Taylor, Desert Research Institute.

Siple Dome, located between ice streams C and D, is well situated to investigate coastal climate conditions and the dynamics of the Siple Coast ice streams, which drain the West Antarctic Ice Sheet (WAIS). Ice accumulates 7 to 11 centimeters each year. By recovering an ice core to 1,000 meters, we expect to be able to distinguish annual layers back for at least 6,000 years. Beyond that, data will still be indicative (on a slightly coarser time frame) extending to at least 80,000 years ago.

This project provides the background for the Siple Dome drilling program, part of the WAIS program, an effort to understand the current behavior of the WAIS, and to decipher the climate it has been subjected to back through time. We also provide the working context for individual scientists to do research on the ice core, as well as establish an office to coordinate the various science activities of the organizations involved in the project, including the National Science Foundation (NSF), the Polar Ice Coring Office (PICO), Antarctic Support Associates (ASA), and the National Ice Core Laboratory (NICL). (II-152-O)

High precision borehole temperature measurements at Siple Dome, Antarctica, for paleoclimate reconstruction and ice dynamics studies.

Edwin D. Waddington and Gary D. Clow, University of Washington.

One of the procedures involved in ice coring is high-precision borehole temperature profiling. By constructing continuous temperature logs, scientists can develop data vital to paleoclimate reconstruction and ice dynamics studies. This project will work in the 1 kilometer (km) deep fluid-filled Siple Dome borehole and in several 160 meter-deep holes along a 20 km north-south transect across Siple Dome. The borehole temperature data will be used to:

- establish the conductive heat flux across the basal interface of the ice sheet;
- reconstruct the surface temperature history at Siple Dome, using geophysical inverse methods, known as borehole paleothermometry;
- constrain how thick the ice sheet was during the late Wisconsin, the magnitude of the Wisconsin/Holocene deglacial warming, and the background geothermal heat flux;

- determine calibration constants for the oxygen-isotope paleothermometer at Siple Dome in the past; and
- establish the spatial variability of surface temperature over the last century on the 20 km scale near the main drill site.

We expect the results to provide information needed to assess the short-term stability of the West Antarctic Ice Sheet; also improved estimates of the pore close-off ages in the past, which should in turn provide an improved age-scale for the Siple Dome ice core. Ultimately, this work should enhance our understanding of the magnitude of past temperature changes at this significant southern hemisphere site. (II-171-O)

INTERNATIONAL TRANS ANTARCTIC SCIENTIFIC EXPEDITION

From its original formulation in 1990, the International Trans Antarctic Scientific Expedition (ITASE) has coordinated the efforts of scientists from several nations to collect and interpret a continent-wide array of environmental parameters. This cooperative endeavor is geared to produce an improved description and understanding of environmental change in Antarctica over the last ~200 years. These original ITASE scientific objectives have been adopted as key science initiatives by both the International Geosphere-Biosphere Program (IGBP) and the Scientific Committee on Antarctic Research (SCAR).

In 1996 an NSF workshop was held to develop a Science and Implementation Plan for the United States contribution to ITASE (called "US ITASE"). Because of the long-standing U.S. research effort in West Antarctica, U.S. ITASE chose to focus its activities there. At the U.S. ITASE workshop, participants developed a multi-disciplinary research plan that integrates different approaches to environmental research: Meteorology, remote sensing, ice coring and surface glaciology, and geophysics. They established a plan with four phases:

- In Phase 1 meteorological modeling and remote sensing was used to plan sampling strategies in support of U.S. ITASE's major objectives
- Phase 2 initiates ground-based sampling over four study areas (corridors). Notwithstanding the broad spatial sampling of West Antarctica proposed, the logistic requirements for this sampling will be modest and highly efficient.
- Phase 3 will continue ground-based sampling at a limited number of key sites where monitoring is required.
- Phase 4 entails data interpretation and modeling.

The United States component of ITASE (which has established a wide range of general scientific objectives) is trying to refine answers to the following questions:

- At what rate is the mass balance changing over West Antarctica?
- How do the major oceanic and atmospheric circulation systems (e.g., ENSO) influence the moisture flux over West Antarctica?
- How and why does climate (e.g., temperature, accumulation rate, atmospheric circulation) vary over West Antarctica on seasonal, interannual, decadal and centennial scales?
- What is the frequency, magnitude and effect (local to global) of any extreme climate events recorded in West Antarctica?
- What is the impact of anthropogenic activity (e.g., ozone depletion, pollutants) on the climate and atmospheric chemistry of West Antarctica?
- How much has biogeochemical cycling of sulfur, nitrogen and carbon, as recorded in West Antarctica, varied over the last ~200 years?

Radar studies of internal stratigraphy and bedrock topography along the U.S. ITASE traverse.

Robert W. Jacobel, Saint Olaf College.

The U.S. component of the International Trans-Antarctic Scientific Expedition (U.S. ITASE) conducts radar studies to determine the internal stratigraphy and bedrock topography of the terrain along the traverses. To help in the selection of core sites as the traverse proceeds, the radar provides information on ice thickness and internal layer structure that is immediately available to those working in the field. These data can also be used to site deeper millennial scale cores (planned at less frequent intervals along the traverse) and to provide a context for selecting the location of the deep inland core (planned for the future). In addition to mapping the traverse route, radar is used to examine a grid surrounding each of the core locations, to better characterize the accumulation and bedrock topography in each area.

This radar system works as a complement to that operated by the Cold Regions Research and Engineering Laboratory (CRREL). Theirs is a high-frequency radar, most suited to the shallower portion of the record down to approximately 60 meters (m); it can detect

near-surface crevasses. Our radar system is most sensitive at depths below 60 m, able to depict deep bedrock and internal geological layers deep into the ice.
(IU-133-O)

Science management for U.S. ITASE.

Paul A. Mayewski and Mark S. Twickler, University of New Hampshire.

Coordinating the effort developed for the United States component of the International Trans-Antarctic Scientific Expedition (U.S. ITASE) is the Science Management Office (SMO). The broad aim of U.S. ITASE is to develop an understanding of the last 200 years of west antarctic climate and environmental change. ITASE is a multidisciplinary program that integrates remote sensing, meteorology, ice coring, surface glaciology and geophysics. To marshal this effort, SMO runs a series of annual workshops to coordinate the science projects that will be involved in ITASE. They also establish and operate the logistics base that supports ground-based sampling in West Antarctica.
(IU-153-A)

U.S. ITASE glaciochemistry

Paul A. Mayewski and Loren D. Meeker, University of New Hampshire.

Among the research targets for scientists in the U.S. component of the International Trans-Antarctic Scientific Expedition (U.S. ITASE) are the impact of anthropogenic activity on the climate and atmospheric chemistry of West Antarctica, as well as the variations in biogeochemical cycling of sulfur and nitrogen compounds over the last 200 years.

This 5-year project is conducting glaciochemical analyses of the major anions and cations to be found in shallow and intermediate depth ice cores collected on the U.S. ITASE traverses. The ionic composition of polar ice cores provides one of the basic stratigraphic tools for relative dating. Also, these data can be used to document changes in chemical-species source emissions, which in turn facilitate mapping and characterization of the major atmospheric circulation systems affecting the West Antarctic Ice Sheet.
(IU-153-B)

Snow and firn microstructure and transport properties: U. S. ITASE.

Mary R. Albert and Robert E. Davis, U.S. Army Cold Regions Research and Engineering Laboratory.

Not all valuable data are buried deep within the ice. The microstructure and bulk properties of snow and firn near and at the surface control the air/snow/firn transport processes; i.e., how heat, vapor, and chemical species in air are incorporated into snow and polar firn. Since many of the snow and firn properties also affect the interaction of radiation in different parts of the electromagnetic spectrum, field measurements provide a valuable ground truth "check" for complementary efforts using remote sensing to map the spatial variations of snow, firn and ice properties.

This project does the field and lab work to characterize snow and firn properties along the U.S. International Trans-Antarctic Scientific Expedition (U.S. ITASE) traverses in West Antarctica. Our objectives are to obtain field measurements of near-surface [down to 2 meters(m)] snow and firn properties: Surface roughness, permeability, density, grain size, surface-to-volume ratio, and tortuosity. In the laboratory, firn cores from as deep as 20 m will be analyzed for these properties and for their microstructure. Ultimately, we will develop a transport model to elucidate the nature of the air/snow/firn exchange and firnification process at the various sites along the U.S. ITASE traverse.
(IU-155-O)

Hydrogen peroxide, formaldehyde, and sub-annual snow accumulation in West Antarctica: Participation in west antarctic traverse.

Roger C. Bales, University of Arizona.

Atmospheric photochemistry leaves valuable traces in snow, firn and ice, and it has been verified that the efficiency of atmosphere-to-

snow transfer and the preservation of these components is strongly related to the rate and timing of snow accumulation. Thus the firn, as well as the atmosphere, provides the context for data.

This project will collect samples along the U.S. International Trans-Antarctic Scientific Expedition (U.S. ITASE) traverses. The wide-ranging extent of these traverses will train the scientific lens upon a variety of locations covering much of the West Antarctic region and reflecting a range of different depositional environments.

Measurements of the concentration of seasonally dependent species (such as hydrogen peroxide, nitric acid, formaldehyde and stable isotopes of oxygen) will be made on these samples and fed into a recently developed, physically based, atmosphere-to-snow transfer model in order to elucidate the photochemistry that led to the depositons.
(IU-158-O)

Mass balance and accumulation rate along U.S. ITASE routes.

Gordon S. Hamilton and Ian M. Whillans, Ohio State University.

One of the basic ways to deduce past climate variations is to track the accumulation of ice, which gives a measure of the balance of mass on the continent. Ice cores from the traverse routes of the U.S. International Trans- Antarctic Scientific Expedition (U.S. ITASE) program should provide a broad history of how West Antarctica has changed in this fundamental way.

This 5-year project is tracking the rate of ice sheet thickening/thinning along the traverses by looking at flow lines, ice divides and elevation contours. We will measure the vertical velocities of markers buried in subsurface ice, using the Global Positioning System (GPS) and surveying techniques to determine the precise location of these markers. As these markers move up and down, they provide a measure of the change in ice sheet thickness, when adjusted for the thickness of snow accumulation directly above them.

That can be accomplished through a series of recording instruments that provide continuous records of firn densification and snow surface elevation change. These altimeters measure the snow surface elevation transient changes, and provide the data necessary to deduce long-term change rates of ice thickness. The ice motion at drill sites, upglacier topography and upglacier gradients in accumulation rate will be measured and used to calculate iceflow-induced accumulation rate variations, which ultimately will refine the ice core records.
(IU-178-O)

High resolution radar profiling of the snow and ice stratigraphy beneath the ITASE traverses, West Antarctic Ice Sheet.

Steven A. Arcone, U.S. Army Cold Regions Research and Engineering Laboratory.

The U.S. component of the International Trans-Antarctic Scientific Expedition (U.S. ITASE) uses high-resolution radar profiling of the snow and ice stratigraphy beneath the traverse routes in West Antarctica. This project provides a complement to project IU-133-O [where levels below 60 meters (m) are the focus], concentrating on the shallower levels of the Earth. Excavating the traverses can be a hazardous undertaking, made much safer, however by the advanced crevasse detection capability of this system.

A coherent, short-pulse radar with a 400 MHz antenna will be the primary tool. The system allows real-time monitoring in a horizontally scrolled display, and provides exceptional vertical resolution – to an order of tens of centimeters – to a depth of 50 to 70 m. Analysis relies on simple data compression (stacking), which reveals subtle deformational features as well as long distance trends. Isochronal continuity will be interpreted from reflection horizons between core sites.
(IU-311-O)

OCEAN AND CLIMATE SYSTEMS

Though it borders the world's major oceans, the Southern Ocean system is like no other in the world, with four times more water than the Gulf Stream, 400 times more than the Mississippi River. It is a sea where average temperatures don't reach 2°C in summer, where even the water itself is so distinctive that it can be identified thousands of miles away in currents that originated here. These Antarctic Bottom Waters provide the major source of cooling for the world's oceans. In fact, if the earth is a heat engine, Antarctica should be viewed as its circulatory cooling component.

The climate in Antarctica is also unique, linked as it is to the extreme conditions of the land and sea below the troposphere (the inner region of the atmosphere, up to between 11 and 16 kilometers). This ocean/atmosphere environment defines and constrains the marine biosphere, and in turn has a dynamic relationship with the global ocean and with weather all over the planet. Few major energy exchanges on Earth can be calculated without factoring in these essential antarctic phenomena. As such, they are both an indicator and a component of climate change.

The Ocean and Climate Systems program sponsors research that will improve understanding of the high-latitude oceanic environment, including the global exchange of heat, salt, water, and trace elements; there is also an emphasis on sea-ice dynamics, as well as the dynamic behavior and atmospheric chemistry of the troposphere. Major program elements include:

- Physical oceanography: The dynamics and kinematics of the polar oceans; the interaction of such forces as wind, solar radiation, and heat exchange; water-mass production and modification processes; ocean dynamics at the pack-ice edge; and the effect of polynyas on ventilation.
- Chemical oceanography: The chemical composition of sea water and its global differentiation, reactions among chemical elements and compounds in the ocean, fluxes of material within ocean basins and at their boundaries, and the use of chemical tracers to oceanic processes across a range of temporal and spatial scales.
- Sea-ice dynamics: The material characteristics of sea-ice, from the individual crystal level to the large-scale patterns of freezing, deformation, and melting.
- Meteorology: Atmospheric circulation systems and dynamics, including the energy budget; atmospheric chemistry; transport of atmospheric contaminants to the antarctic; and the role of large and mesoscale systems in the global exchange of heat, momentum, and trace constituents.

Monitoring Antarctic Bottom Water.

Martin Visbeck, Lamont-Doherty Earth Observatory

The Antarctic Bottom Water is the coldest (and therefor the densest) natural water to be found on Earth, created as ice shelves melt into seawater and sink to the bottom. It occurs in the nether regions of the Southern Ocean, separated from the world's great oceans to the north by the Polar Front – water that provides a virtual barrier to the heat transfer from those more temperate and less stormy waters.

The global importance of Antarctic Bottom Water is linked to its subsequent long journey across the ocean floor to the Northern Hemishphere. The patterns and strengths of this current are crucial to the heat balance of the global ecosystem, for this process provides crucial oxygen to those seas, as well as reducing their temperature to nearly 2°C.

This project monitors the outflow of Antarctic Bottom Water from the Weddell Sea into the Scotia Sea, as it begins its journey northward. (OO-124-O)

Longwave radiation processes on the antarctic plateau.

Stephen G. Warren and Thomas C. Grenfell, University of Washington.

Long-wave radiation [also called infrared (IR) or thermal radiation] is an important component in the energy balance of the

atmosphere. On the antarctic continent radiation processes dominate the surface energy budget. In summer the balance is made up of four terms – primary solar energy in two forms (incoming and reflected short-wave radiation), and both emitted and reflected long-wave radiation. In austral winter after the sun sets, the short-wave terms fall to zero. The emitted long-wave radiation varies with temperature; thus the radiation balance at the surface determines the surface temperature.

This project entails an experimental study of long-wave radiation processes near the surface at South Pole station. We are developing instrumentation capable of high resolution measurements of the IR fluxes at the snow surface – a so-called Fourier Transform Interferometer – that will be deployed in late 1999 and operated through the following austral winter. Supporting observations will also be made of the temperature and moisture profiles in the lower atmosphere, and of ice crystals in the atmospheric boundary layer.

The research also includes several experiments concerning the emission characteristics of snow, of ice crystals in the atmosphere, and of greenhouse gases near the surface. Determining the concurrent environmental conditions (such as cloud-base altitude, temperature and humidity-structure), and the sizes and concentrations of ice crystals, will contribute to the newly developing climatology of cloud properties, and should substantially improve how radiation processes are represented in general circulation models. (OO-201-O)

Antarctic Meteorological Research Center: 1996-2000.

Charles R. Stearns and John T. Young, University of Wisconsin at Madison.

The Antarctic Meteorological Research Center (AMRC) is one of three research centers in the Science and Engineering Technology Center at McMurdo Station. It is a major center for meteorological research, and an ongoing experiment to improve operational synoptic (simultaneous atmospheric conditions/weather over a broad area) forecasting.

AMRC relies primarily on the Man-Computer Interactive Data Access System (McIDAS), a versatile computer-based system for organizing, manipulating, and integrating antarctic environmental data. It captures the flow of meteorological information from polar-orbiting satellites, automatic weather stations (AWS), operational station synoptic observations, and research project reports. McIDAS also receives weather forecasts and other environmental data products from outside Antarctica, and acts as a repository for existing archived databases.

Developed at the University of Wisconsin in the mid-1970s, McIDAS receives meteorological data from various sources: Standard synoptic observations, radiosonde profiles, satellite-based visible and infrared imagery, atmospheric profiles inverted from multispectral scanning sensors, and nonstandard data such as thematic ozone mapping spectrometer (TOMS) data, synthetic aperture radar (SAR) sea-ice information, and the AWS network observations. The system automatically registers, calibrates, and locates (by geographical coordinates) the input information, providing work station access to the combined database. Features available to the work station operator include: Sectorization, false color, enhancements, brightness stretching, overlays, looping, and differencing – all specifically keyed to synoptic meteorological research and weather forecasting. Because the look angles from geostationary satellites are so low, McIDAS relies primarily on data streams from the polar orbiters (AVHRR/HRPT and DMSP).

To fully use the power of McIDAS to produce meteorological data in the service of forecasting and research, data links to facilitate communications have been established with a number of scientific weather facilities world-wide; for example:

- Australian Bureau of Meteorology (ABOM)
- University of Wisconsin Space Science and Engineering Center (SSEC)
- Fleet Numerical Oceanography Center (FNOC) in Monterey, California
- European Center for Medium Range Weather Forecasts (ECMRWF) in Reading, U.K.

(OO-202-O)

Atmospheric oxygen variability in relation to annual-to-decadal variations in terrestrial and marine ecosystems.

Ralph F. Keeling, Scripps Institution of Oceanography.

Oxygen is the most abundant element on the Earth. Airborne, it comprises about a fifth of the atmosphere. But much of the Earth's oxygen exists in water, rocks and minerals, and of course in flora and fauna who recycle it directly and as carbon dioxide through the processes of photosynthesis and respiration.

Thus scientists are interested in measuring the concentration of molecular oxygen and carbon dioxide in air samples. This project is part of sample collections being made at a series of baseline sites around the world. The data should help to improve estimates of the processes whereby oxygen is cycled throughout the global ecosystem, specifically:

- net exchange rates of carbon dioxide with biota on land and in the oceans,
- photosynthesis rates, and
- atmospheric mixing rates.

An important part of the measurement program entails developing absolute standards for oxygen-in-air, to ensure stable long-term calibration. We also are conducting surveys of the oxidative oxygen/carbon ratios of both terrestrial- and marine-based organic carbon, hoping to improve the quantitative basis for linking the oxygen and carbon dioxide geochemical cycles.

These results are needed to enhance our understanding of the processes that regulate the buildup of carbon dioxide in the atmosphere. They should also contribute to our understanding of the change processes – especially climate change – that regulate ecological functions on land and in the sea.
(00-204-0)

Chlorine- and bromine-containing trace gases in the antarctic.

Reinhold A. Rasmussen and M.A.K. Khalil, Oregon Graduate Institute of Science and Technology.

Airborne trace constituents in atmospheric gases come from both biogenic and anthropogenic sources. Scientists monitor them closely, as they have been implicated in depletion of the ozone layer over Antarctica as well as other alterations of the Earth's climate.

This study will investigate the seasonal trend of trace gas concentrations by collecting a year-long suite of air samples at Palmer Station. Samples will subsequently be analyzed at the Oregon Graduate Center for a number of trace components, especially chlorine- and bromine-containing species.

This work should contribute to a better understanding of the buildup of trace constituents, particularly those of high-latitude marine origin.
(00-254-0)

South Pole monitoring for climate change: Amundsen-South Pole Station.

David Hofman, Climate Monitoring and Diagnostics Laboratory, National Oceanographic and Atmospheric Administration, Palmer Station.
(00-257-0)

James T. Peters, Environmental Research Laboratories, National Oceanic and Atmospheric Administration.
(00-264-0)

The National Oceanic and Atmospheric Administration (NOAA) has been engaged in studies to determine and assess the long-term buildup of global pollutants in the atmosphere. The NOAA Climate Monitoring and Diagnostic Laboratory team will continue long-term measurements of trace atmospheric constituents that influence climate and the ozone layer.

These measurements will be enable time-series analyses of multiyear data records. Phenomena of particular interest are:

- seasonal and temporal variations in greenhouse gases,
- stratospheric ozone depletion,
- transantarctic transport and deposition,
- the interplay of the trace gases and aerosols with solar and terrestrial radiation fluxes on the polar plateau, and
- the development of polar stratospheric clouds over Antarctica.

Four scientists will work from the Amundsen-Scott South Pole Station observatory during the austral summer, and two NOAA personnel will stay over the winter (working from the Atmospheric Research Observatory) to measure carbon dioxide, methane, carbon monoxide, aerosols, chlorofluorocarbons, and other trace constituents. Concurrent measurements will be made of water vapor, surface and stratospheric ozone, wind, pressure, air and snow temperatures and atmospheric moisture. Other personnel at Palmer Station also will collect carbon dioxide samples in support of this project.

These measurements will allow us to determine the rates at which concentrations of these atmospheric constituents change, and will suggest likely sources, sinks, and budgets. Our work also includes collaborating with climate modelers and diagnosticians to determine how the rates of change of these parameters affect climate.

Drake Passage expendable bathythermograph program.

Ray Peterson, University of California.

The Antarctic Circumpolar Current (ACC) is a powerful force that drives waters in the Southern Ocean; four times as fast as the Gulf Stream, for example. Wherever the distance between Antarctica and other continents is narrowed – so-called chokepoints such as The Drake Passage off the tip of South America and the sea regions between Antarctica and the Cape of Good Hope and Tasmania, respectively – the current is even stronger. Scientists deploy bottom pressure gauges and similar instruments to determine the fluctuations in the transport of the ACC, and to relate it to those in the subtropical and subpolar gyres and to the wind field over the southern oceans.

Specifically since 1996, scientists in this research project have collected data to characterize the water mass variability in the Drake Passage, to describe temperature and circulation variability in the Southern Ocean, and to define the role of the Southern Ocean in the global climate system. This season, using a high-density expendable bathythermograph (XBT), we will make expendable current/temperature/depth (XCTD) observations to measure the seasonal and year-to-year temperature fluctuations in the upper ocean within the Drake Passage.

To clearly describe inter-annual and seasonal changes in upper-ocean temperature, we need closely-spaced, underway XBT and XCTD measurements to be made on every *Laurence M. Gould* cruise throughout the year. As the ship crosses the Drake Passage, approximately 60 XBT profiles and 12 XCTD profiles (measuring salinity) are made, beginning and ending at the 200 meter bathymetric contour on either side of the passage. XBT casts are spaced approximately 1 hour apart, although sampling is more frequent across the Subantarctic, Polar, and ACC fronts, as the water temperature changes more rapidly in these regions. (00-260-0)

Katabatic winds in eastern Antarctica and their interaction with sea ice.

Gerd Wendler, University of Alaska, Fairbanks.

Katabatic winds are driven by the flow of cold dense air down a mountain or glacier slope, especially in regions subject to radiational cooling of the Earth's surface. These winds can drive the sea ice offshore and are responsible for extremely high heat fluxes from the ocean to the atmosphere. They are also implicated in the formation of polynyas – areas of open ocean within sea ice. This project continues an international collaboration (France, Australia and the United States)

to study katabatic winds along the coast of Antarctica.

A number of weather stations collect data: One newly installed station 15 kilometers inland is sited at a point where atmospheric wind models predict extremely high average wind speeds; two other strings of existing automatic weather stations will continue to collect data; one that runs from France's Dumont d'Urville station inland to Dome C, at an altitude of some 3,200 meters; the other string runs along the coast, including stations at Cape Denison and Port Martin, an area where the highest average surface wind speeds on Earth have been recorded – a monthly average of 27.8 meters per second.

Project scientists hope to produce a numerical model of the structure of the region's atmosphere, which will incorporate a more detailed terrain map as well as a new mesoscale model developed by French scientists. Another goal is to analyze the formation, persistence and size of offshore polynyas as a function of wind speed; data from satellite-based active microwave imagery (synthetic aperture radar) will be combined with the observed meteorological data in that analysis. A final application of this work is to enlarge the body of information being collected by Australian and Japanese station networks (to the west of these stations) in hopes of assessing the influence of cyclonic storm systems on the drainage flow along the coast.
(00-263-0)

Circumpolar deep water and the West Antarctic Ice Sheet.

Stanley S. Jacobs and Martin Visbeck, Lamont-Doherty Earth Observatory, Columbia University.

Circumpolar Deep Water (CDW) is a relatively warm water mass (+1.0°C or warmer) found on the outer edge of the continental shelf; normally it is confined by an oceanic front that provides a barrier to the colder and saltier waters of the shelf. In the Amundsen Sea, for example, the deeper parts of the continental shelf are filled with nearly undiluted CDW. The temperature gradient causes this CDW to mix upward and deliver significant amounts of heat both to the base of floating glacier tongues and to the ice shelf. As a consequence, the melt rate beneath the Pine Island Glacier averages ten meters (m) of ice per year, and some specific local areas lose twenty m. By comparison, typical melt rates beneath the Ross Ice Shelf cost it only twenty to forty centimeters of ice per year.

This project focuses on the dynamics of CDW on the Amundsen Sea shelf, specifically in the regions of the Pine Island and Thwaites Glaciers, and the Getz Ice Shelf. Both the Pine Island and Thwaites Glaciers move very fast, and have a major influence on the regional ice mass balance of West Antarctica.

Specifically, we hope to:

- delineate the frontal structure of the continental shelf sufficiently to measure the major routes of CDW inflow, meltwater outflow, and the westward evolution of CDW influence;
- use that data set to validate a three-dimensional model (currently under construction) of sub-ice ocean circulation; and
- refine the estimates of in situ melting on the mass balance of the West Antarctic Ice Sheet.

This research should help to elucidate antarctic glaciology by assessing the combined effect of global change on the antarctic environment. The observational program will be carried out from the research ship *Nathaniel B. Palmer* in February and March, 2000.
(00-274-0)

Operation of an aerosol sampling system at Palmer Station.

Gail dePlannque and Colin G. Sanderson, Environmental Measurements Laboratory, U.S. Department of Energy.

The Environmental Measurements Laboratory [(EML); a unit of the U.S. Department of Energy based in New York City] installed an array of instruments at Palmer Station in 1990: A high-volume

aerosol sampler, a gamma-ray spectrometer, and a link to the National Oceanic and Atmospheric Administration's ARGOS satellite system. Sampling data from Antarctica contributes to EML's Remote Atmospheric Measurements Program, part of its worldwide surface-air sampling program.
(00-275-0)

Particulate organic carbon production and export in the Indian sector of the Southern Ocean: A United States-China collaborative research project.

Cynthia Pilskaln, University of Maine at Orono.

The Polar Front Zone, where the cold, dense waters of the antarctic meet the warmer waters of the northern oceans, is subject to major currents and water displacements beneath the sea. Each austral spring, phytoplankton bloom in this region. Scientists believe the blooms are driven by nutrient transport brought to the surface, as intermediate and deep water masses are ventilated. Each year, the theory goes, such blooms are the primary source of particulate organic carbon (POC) and biogenic silica flux to the ocean bottom. But the theory remains to be tested, as no data exist on the amount of particulate organic matter that is sinking through the water column. Without such quantitative measurements in this region, the hypothesized relationships between biomass production and the currents must remain undefined.

As part of a collaboration between the University of Maine and the Chinese Antarctic Research Expedition (CINARE), we will study the biological production and export flux of biogenic matter in response to ventilation of intermediate and deep water masses within the Polar Front Zone. The shipboard work will be done aboard the Chinese antarctic resupply vessel, working off Prydz Bay in the Indian Ocean sector.

The initial phase of our work consists of setting out a time-series sediment-trap mooring at approximately 64S 73E. The biweekly-to-monthly trap samples will be analyzed for their organic constituents and, in conjunction with primary productivity observations, will provide the basic data from which export values can be derived. Data gathered in this effort will be enhanced by the historical dataset that CINARE has obtained in this area over the past decade.

Our work will be carried out in collaboration with the State Oceanic Administration (SOA) of the People's Republic of China and the Chinese Antarctic Research Expedition. In addition to providing time on the antarctic resupply vessel, the SOA will sponsor the primary productivity experiments on board ship and will provide the supporting hydrographic measurements. The collaborating American scientists will provide the hardware for the moored sediment trap and will bring their expertise in making these observations to standards developed for the Joint Global Ocean Flux Study. All samples and data will be shared between the U.S. and Chinese investigators, and the data analysis will be carried out jointly.
(00-278-0)

Antarctic automatic weather station program: 1998-2001.

Charles Stearns, University of Wisconsin at Madison.

A network of nearly 50 automatic weather stations (AWS) has been established on the antarctic continent and several surrounding islands. These facilities were built to measure surface wind, pressure, temperature and humidity; further, some of them also track other atmospheric variables, such as snow accumulation and incident solar radiation.

Their data are transmitted via satellite to a number of ground stations, and put to several uses: Operational weather forecasting, accumulation of climatological records, general research purposes, and specific support of the U.S. Antarctic Program. The AWS network has grown from a small-scale program in 1980 into a significant data retrieval system that is now extremely reliable, and has proven indispensable for both forecasting and research purposes. This project maintains and augments the AWS, as necessary.
(00-283-M and 00-283-P)

Shipboard acoustic doppler current profiling on *Nathaniel B. Palmer* and *Lawrence M. Gould*.

Teresa K. Chereskin, Scripps Institution of Oceanography.

Currents in the Southern Ocean have a profound influence on the world's oceans – and therefor upon global temperature and the planet's ecosystem – yet some remote regions receive little scientific attention. Using doppler (sound wave transmission and reflection) technology, this project is exploring upper ocean current velocities and will try to generate a quality-controlled data set in one such sparsely sampled and remote region – a region which nonetheless appears to play a significant role in global ocean circulation. We will develop and maintain a shipboard acoustic Doppler current profiler (ADCP) program on board the *Nathaniel B. Palmer* and the *Laurence M. Gould*, two research ships operated by the United States Antarctic Program.

This work is part of a long-term science goal to characterize the temporal and spatial velocity structure in the Southern Ocean. This will entail measuring the seasonal and annual changes in upper ocean currents within the Drake Passage, combining this information with similar temperature observations, and exploring how the heat exchange varies and how it drives upper ocean currents.
(OO-315-O)

The influence of hydrothermal discharge on coastal ocean dissolved iron concentrations at Deception Island, Antarctica.

Anne Sturz, University of San Diego.

Iron plays a crucial role, along with some other trace elements, in fueling biological production. Over large parts of the Southern Ocean inorganic nutrients are under-utilized because (scientists believe) some trace element is insufficient, most probably iron. Yet some shallow regions, within the Bransfield Strait for example, show productivity 50 to 60 times as great as that in the open ocean, where iron is presumed to be abundantly available.

One direct way of probing this problem is to examine specific sources of iron. There is a drowned and breached volcanic crater at Deception Island, Antarctica; might the hydrothermal discharge from this underwater feature provide sufficient dissolved iron to support the regional primary productivity in the ocean?

This study will trace the discharge volume, its iron concentration, and the flushing rate of the crater during a cruise of *Laurence M. Gould* in November 1999. Since the scientific mission on that cruise is devoted to the study of how pelagic and benthic communities respond to the seasonal variations in the sea ice cover, it will provide a valuable context for the iron study.
(OO-319-O)

Record of atmospheric photochemistry in firn at South Pole.

Roger Bales and Joseph R. McConnell, University of Arizona.

Scientists are eager to develop models that will expand their knowledge of current, active dynamic processes into the past. One such process vital to the Earth is photochemistry, how the sun's radiant energy affects conversion of oxygen in the atmosphere. By measuring and interpreting the hydrogen peroxide, formaldehyde, and nitric acid concentrations in the snow and firn at South Pole station, we hope to develop a credible history of the oxidation capacity of the atmosphere over the last two centuries. We also hope to evaluate methods that will confirm statistically significant changes in the concentration of these species over that time.

South Pole station is ideal for this work: The extreme cold makes the chemistry relatively simple; the NOAA Climate Modeling and Diagnostics Laboratory provides a context of high quality meteorological and chemical data; and the station is staffed continuously so that samples can be taken year-round.

We will sample air and near-surface snow throughout the year; during the summer, we will sample and analyze snow pits and firn cores, and will model the air/snow chemistry to try to explain the observed concentrations in the firn. Also in summer, we will sample two snow pits around the perimeter of the snow stake field intensively (for accumulation observations), a process that will establish markers to maintain time control for stratigraphic and chemical horizons.

During earlier work at South Pole and in central Greenland, we have developed and tested physically-based models of air snow exchange of hydrogen peroxide. This project extends that work.
(00-324-0)

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