SCIENCE ON THE ICE: THE UNITED STATES ANTARCTIC PROGRAM

Fifth Edition

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The Royal Society Range frames Vince's Cross, erected for a fallen member of the Discovery Expedition 1901-04, on Hut Point Peninsula.

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Science on the Ice: The United States Antarctic Program
© 2010 *(formerly The Environments of McMurdo Sound)*
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Credit: C. Carpenter

AUTHORSHIP AND DESIGN

Office of Polar Programs
National Science Foundation
www.nsf.gov

Polar Geospatial Center
University of Minnesota
www.pgc.umn.edu

Credit: E. Mockbee

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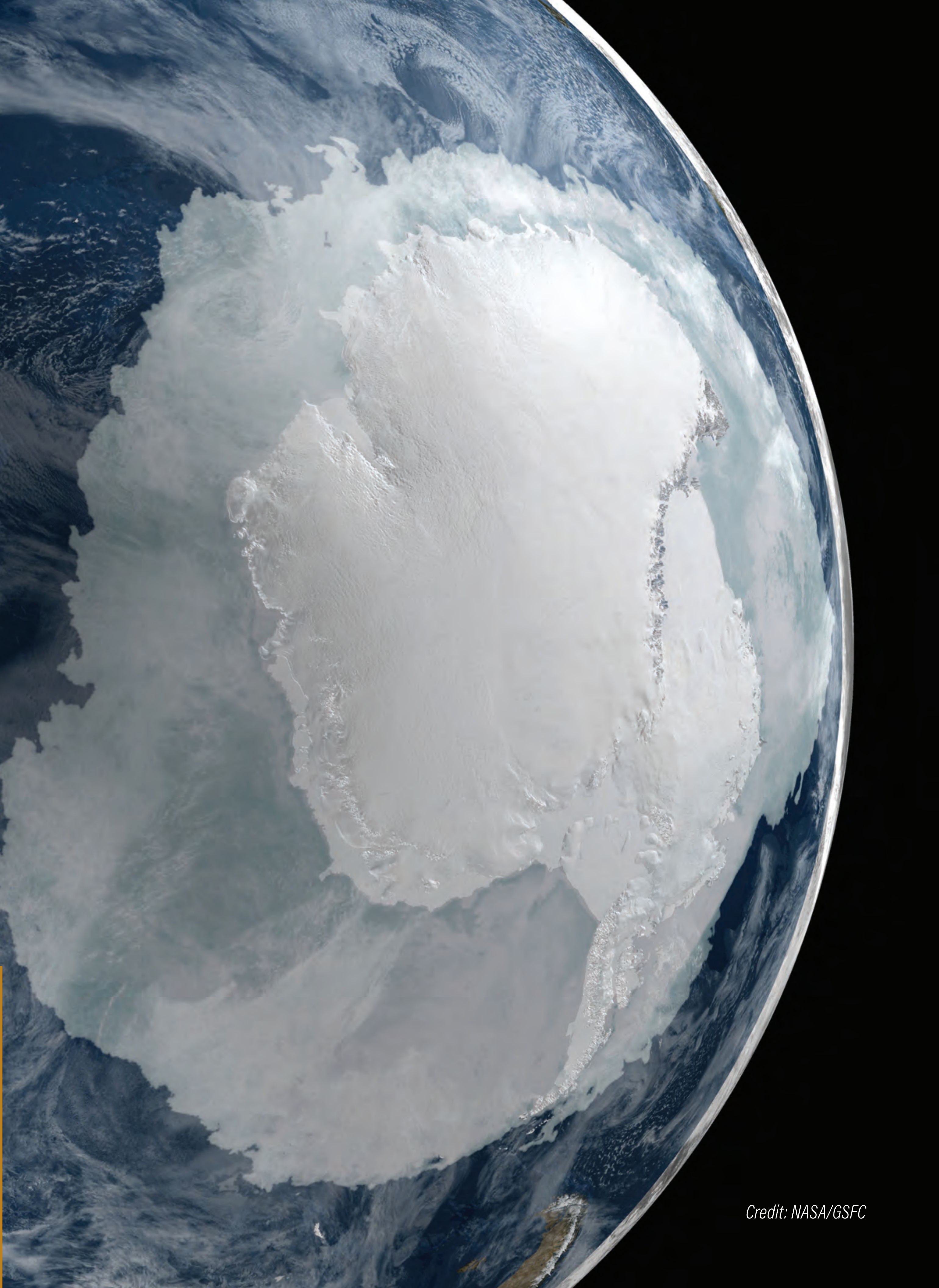
Emperor penguins *(Aptenodytes forsteri)* are the largest of all penguin species.



Credit: NASA/GSFC

Preface

Science on the Ice: The United States Antarctic Program (Fifth Edition) is a broad introduction to United States research and operations in Antarctica. The publication has grown organically since its first edition, titled *The Environments of McMurdo Sound*, to more comprehensively describe the extent of United States Antarctic Program (USAP) research and operations on the icy continent—on it, above it, below it, and around it. We will explore many realms of Antarctica including historical and contemporary United States presence and the logistical challenges involved, the commitment to preserving the continent, and the scientific endeavors and discoveries spanning fields from astrophysics to geology to zoology (and a lot in between). Two goals of this publication are to showcase groundbreaking science that can only be done in Antarctica and to build reader understanding for the support infrastructure that makes it all possible.

The National Science Foundation (NSF) is the operator and primary funding source for USAP research and its participants, from lifelong Antarctic academic researchers to graduate students to support staff that make USAP a highly successful research and operational enterprise. NSF is dedicated to its responsible, safe, environmentally conscious, and collaborative mission to advance Antarctic knowledge. We hope that is reflected in this publication.

Science on the Ice is written to those with no knowledge of USAP research, seeking to gain an understanding of U.S. science and support in this challenging environment, and to those who are experts in a field wishing to broaden their knowledge of other disciplines. Please acknowledge those who have dedicated their careers to advancing Antarctic research; their body of work is represented here. The National Science Foundation thanks everyone that supported this publication and you, the reader, for your interest in one of the most complex, remote, and critical regions on the planet.

USAP Research Vessel Icebreaker Nathaniel B. Palmer conducting science at Thwaites Glacier in the Amundsen Sea.

SECTION 1: INTRODUCTION

Credit: A. Mazur

1.1 Global Importance of Antarctica

Antarctica affects everyone. It has consequential and, in some instances, immediate impacts on our lives. Though the continent is thousands of miles away from the United States, Antarctica reaches globally through ocean and atmosphere, through discoveries about its wildlife and the Universe, and through its status as a continent of international cooperation, environmental protection, and peace.

Just as Antarctica's influence is experienced around the globe, its physical and biological systems are, in turn, influenced by human actions. Humankind's future is intertwined with that of Antarctica and yet fundamental knowledge gaps exist despite the remarkable pace of scientific discovery over the past decades. These gaps motivate urgent and complex research campaigns to better anticipate and prepare for the future.

Credit: National Oceanic and Atmospheric Administration

Figure 1.1-1: Flooding in coastal cities
Sea-level rise is causing flooding to occur without a storm through a 'sunny day' event during high tide in coastal cities.

Sea-level rise is one of the most pressing examples. The United Nations' Intergovernmental Panel on Climate Change projects, with high confidence, that Antarctica will continue losing ice at an accelerating rate over the coming decades and beyond. Along the U.S. coastline, sea level will rise 10 to 12 inches on average over the next 30 years alone, and damaging coastal flooding will, on average, be at least 10 times more prevalent than today. Understanding how much and how fast the Antarctic ice sheets will contribute to sea level as a result of greenhouse gas emissions is a pressing, international science priority. The uncertainty around how Antarctica responds to emissions is at the root of the broad spectrum of possible additional sea-level rise by the end of the century, and this motivates intensive research efforts on contemporary processes as well as finding records of past Antarctic responses.

The Antarctic region, including the Southern Ocean that surrounds it, is a one-of-a-kind biological laboratory to study life's capacity to adapt and evolve under harsh conditions of deep cold, months-long periods of continuous dark and light, and even the permanent absence of light. From such research springs insight into the possibilities and limits for life to adapt to extreme conditions, analogs for life beyond Earth, and potential for advances in medicine and biotechnology by revealing new compounds to fight cancer or antibiotic-resistant bacteria. Despite the isolation of Antarctica, recent changes from ocean warming, fishing, and tourism bring new risks to its delicate ecosystems. Science is underway that can inform policymaking on environmental protection and management.

Credit: R. Robbins

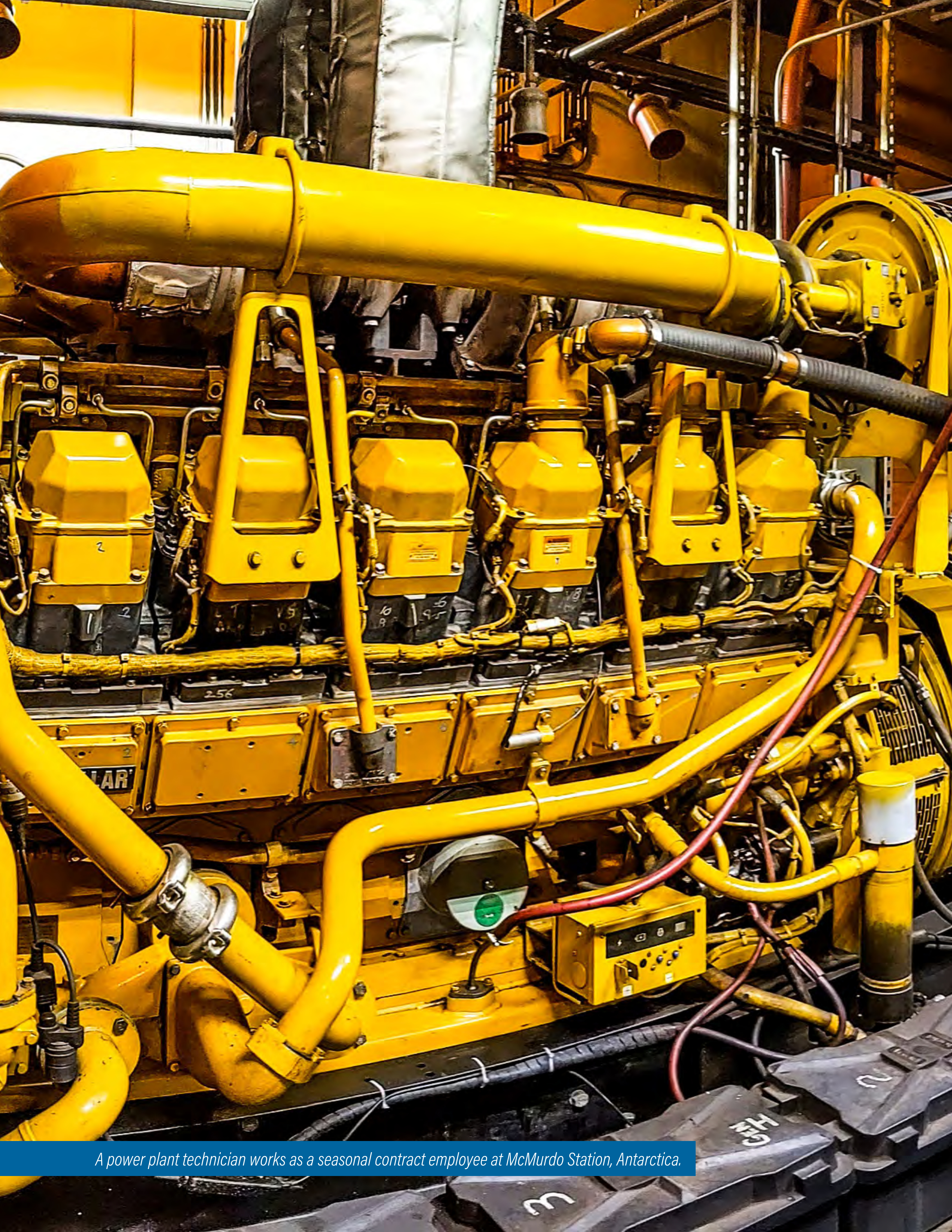
Figure 1.1-2: **Antarctic toothfish**
The Antarctic toothfish has evolved to withstand sub-freezing water temperatures by producing antifreeze glycoproteins to keep its blood from freezing in its veins.

There is perhaps no deeper question than the origin and fundamental physics of the Universe. Antarctica's clear, dry, and cold skies combined with the long winter night offer unparalleled opportunities to conduct large-scale astronomy and astrophysics research into these profound topics. In addition, Antarctica offers a platform over a wide range of latitudes, including the geomagnetic south pole, across which to study the solar wind—the fluctuating stream of particles and radiation from the sun. Occasional energetic bursts in the solar wind threaten essential Earthly technologies such as power grids, electronic equipment, satellites, and GPS navigation systems. Science in Antarctica provides insight to advance forecasting of these events.

The essential science conducted in Antarctica is fundamentally possible because of the unique international governance structure of the Antarctic Treaty, which the United States and 11 other nations created in 1959 to protect Antarctica as a place of peace, international scientific cooperation, and environmental preservation. Now with 29 consultative parties and six decades of unity and productive activity, the treaty remains a unique example of global cooperation. Continued U.S. leadership in the treaty and the science that it underpins is crucial to navigate the interconnected future of Antarctica, Earth, and its inhabitants.

Credit: D. Hampton

Figure 1.1-3: **The South Pole Telescope and BICEP Array**



A power plant technician works as a seasonal contract employee at McMurdo Station, Antarctica.

SECTION 2: SCIENCE SUPPORT

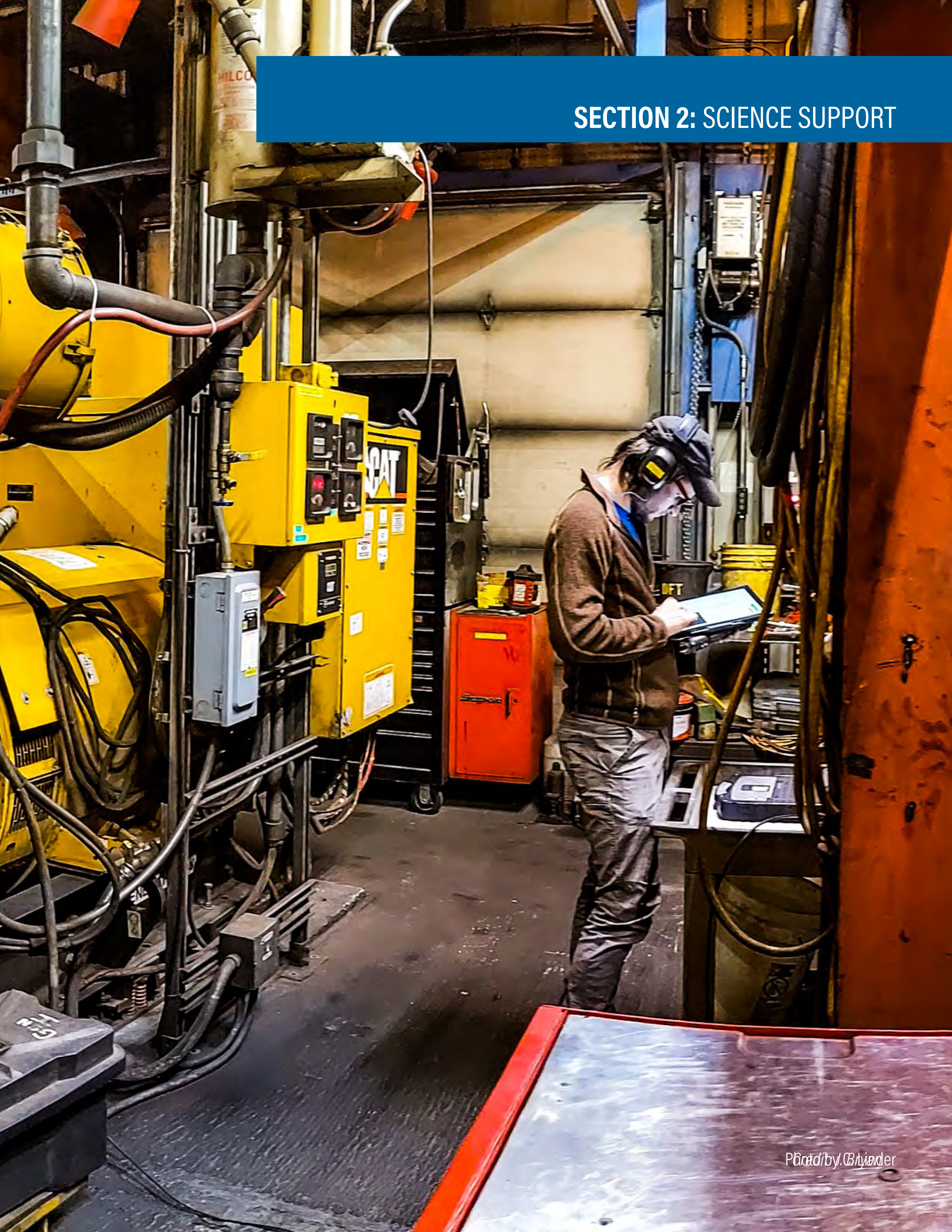


Photo by C. Lynder

2.1 History of the United States Antarctic Program

A NEW CONTINENT

The U.S. scientific presence in Antarctica began in 1830 when James Eights became the first U.S. scientist on the continent. Although by trade a physician, Eights is credited with being the first to describe the fossils and geology of the Antarctic peninsula region. In 1841, Charles Wilkes led a U.S. expedition to map part of the Antarctic coast and, in doing so, demonstrated that Antarctica was a continent.

INTERNATIONAL GEOPHYSICAL YEAR

American interest in the Antarctic continent did not pick up in earnest until after World War II, when several well-resourced private and national expeditions were conducted. In 1956–57 the U.S. Navy, in conjunction with research teams from the National Science Foundation (NSF), established bases in Antarctica in preparation for the International Geophysical Year (IGY, 1957–58).

Since 1956, Americans have been continuously conducting research in the Antarctic to better understand the continent and its interactions with the rest of the planet. For 43 years (1955–98) the U.S. Navy, through the Naval Antarctic Support Unit, conducted Operation Deep-Freeze in support of U.S. activities in Antarctica.

Credit: Cdr. J. Waldron

Figure 2.1-1: U.S. Navy R4D Aircraft (1956)

The United States was a leader in IGY, which was crucial for establishing Antarctica as a continent for peace and science. During IGY, 12 nations established 60 Antarctic research stations. The U.S. Antarctic Research Program (USARP, later changed to U.S. Antarctic Program [USAP]) was established in 1959, immediately after IGY. The international coordination resulting from IGY led to the development of the Antarctic Treaty. In 1959, the United States was one of the 12 original signatory nations to the Antarctic Treaty. It is currently a consultative party with voting rights to make decisions about Antarctica, and the number of consultative parties has grown to 29 nations.

EVOLVING LOGISTICS SUPPORT

Since the late 1960s, NSF has increasingly relied on private contractors to provide research and logistical support for operations in the Antarctic as the original IGY-era program evolved into USAP.

Gradually, Antarctic support by the U.S. Navy was replaced by private contractors, Department of Defense (DOD) support via the Joint Task Force—Support Forces Antarctica, and partnerships across other government providers. Currently, NSF manages all U.S. scientific research and related logistics in Antarctica, as well as on two research vessels that operate around the continent.

Antarctic policy and USAP objectives were set forth in President Ronald Reagan's directive of Feb. 5, 1982. These objectives center on the conduct of a balanced program of scientific research and include cooperative activities with Antarctic programs of other governments. In 1994, Presidential Decision Directive 26 (U.S. Policy on Arctic and Antarctic Regions) reinforced U.S. policy for Antarctica and articulated the four fundamental objectives that remain in effect: (1) protecting the relatively unspoiled environment of Antarctica and its associated ecosystems; (2) preserving and pursuing unique opportunities for scientific research to understand Antarctica and global physical and environmental systems;(3) maintaining Antarctica as an area of international cooperation reserved exclusively for peaceful purposes; and (4) assuring the conservation and sustainable management of the living resources in the oceans surrounding Antarctica.

2.2 USAP Facilities

PERMANENT STATIONS

The USAP operates three permanent, year-round research stations in Antarctica (Fig. 2.2-1):

- McMurdo Station on Ross Island at the southern end of the Ross Sea.
- Palmer Station on Anvers Island off the Antarctic Peninsula.
- Amundsen-Scott South Pole Station high on the East Antarctic Ice Sheet.

These stations are diverse in their location and size, but all require significant skilled resources to ensure they run smoothly in support of the science mission. Each year the USAP employees hundreds of staff including chefs, firefighters, medical staff, weather observers and forecasters, mountaineers, equipment operators, laboratory technicians, fuel specialists, air traffic controllers, mechanics, cargo handlers, IT experts and much more.

Credit: B. Herried

Figure 2.2-1: USAP Permanent Stations

IT AND COMMUNICATIONS

The importance of reliable communications to and from Antarctica would be difficult to overstate; communications infrastructure enables everything from the transfer of science data to morale-boosting phone calls home. USAP IT&C serves the program through a federal government network at 12 operating locations across four continents and including the two research vessels. This supports the NSF-funded science research and the mission operations of federal partners such as National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), the Department of Defense (DOD) and the United States Geological Survey (USGS).

The bandwidth to support these broad IT&C needs is provided by satellite. McMurdo and Palmer stations utilize conventional geosynchronous fixed satellite services. USAP research vessels utilize mobile satellite service, depending on the ocean region and coverage, and they use Iridium mobile satellite service as a global backup. Seasonal deep-field communications also utilize Iridium mobile satellite service. At McMurdo, NSF is teamed with NOAA Joint Polar Satellite System (or JPSS) to provide satellite communications. The recent completion of a new, larger antenna and Earth station on Ross Island provides the opportunity to increase station bandwidth.

Looking into the future, NSF is assessing emergent commercial low-Earth orbit satellite communications constellation providers to explore geographic coverage, bandwidth rates, service availability, and ground terminal availability for Antarctic coverage.

FUTURE PLANS

NSF's Antarctic Infrastructure Recapitalization (AIR) program is a strategic approach that will meet critical science needs while engaging the community and stakeholders broadly in an ongoing renewal program that will keep the United States at the forefront of Antarctic research. AIR will assure safety, enhance efficiency and sustainability, increase resilience, and fulfill NSF's mandate of continued leadership on the continent.

The AIR program is a portfolio of investments that improve general-purpose USAP infrastructure including facilities, utilities, equipment, and fleet equipment that are used across the program. This critical infrastructure supports all fields of science. The AIR program also includes technical support for needs assessments, cost-benefit analyses, and design efforts to define transformative solutions to Antarctica's unique challenges as an integral part of renewal. Life-cycle costs for investment alternatives will be developed and considered as well.

MCMURDO STATION

USAP FACILITIES: PERMANENT STATIONS

HUB OF CONTINENTAL RESEARCH IN ANTARCTICA

McMurdo Station (77° 50.89' S, 166° 40.11' E) was established on December 18, 1955, for USAP. It is situated on bare volcanic rock at the southern tip of Hut Point Peninsula on Ross Island (Fig. 2.2-2), the southernmost solid ground accessible by ship. Since the IGY of 1957–58, McMurdo Station has staged logistics and science for USAP, hosting more than 1,000 participants during the austral summer. It serves as both the United States' largest base and central hub for research on the continent and onward to the Amundsen-Scott South Pole Station.

The location of McMurdo Station is ideal because of its proximity to open water and stable sea ice. Nearby the station, situated on the McMurdo Ice Shelf, are the station's two airfields critical to its role as a hub for work further afield. Williams Field has two skiways and supports skied aircraft, and Phoenix Airfield has a compacted snow runway to support heavy wheeled aircraft year-round. Also, the station is within a helicopter's ride from the McMurdo Dry Valleys and scientifically important locations on Ross Island, such as Mount Erebus, Cape Crozier, and Cape Royds. When the nearby McMurdo Sound sea ice is frozen, many sites around Erebus Bay are accessible by snowmobile and other light vehicles.

The station covers nearly 1.5 square miles and includes over 100 structures, including the Albert P. Crary Science and Engineering Center (Fig. 2.2-3) as the primary laboratory and research facility. Many additional facilities exist in McMurdo to fully support scientific research in a remote location: a powerplant, full waste management facilities (including for the handling of hazardous waste), over 13 million gallons of fuel storage, lodging, offices and more. Recent investments have been made in a new IT&C facility. Over the next several years, construction will proceed on a new lodging building and Vehicle Equipment and Operations Center.

Credit: P. Rejcek

Figure 2.2-2: McMurdo Station on Ross Island

Credit: R. Piuk

Figure 2.2-3: Crary Lab

The Albert P. Crary Science and Engineering Center, dedicated in 1991, is a three-phased science facility (above) that includes laboratories, field staging, meeting space, and a full aquarium (below), able to take in water from the sea to support marine research.

Credit: M. Hoffman

DID YOU KNOW?

Phoenix Runway (NZFX)

Phoenix runway was commissioned in November 2016 after extensive design and construction in close coordination with the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory. No other airfield in the world uses deep compacted snow to land heavy wheeled airplanes. The 11,000-foot long and 250-foot wide surface requires year-round maintenance with a 160,000-pound heavy roller to maintain the high level of bearing strength needed to land aircraft.

PALMER STATION

USAP FACILITIES: PERMANENT STATIONS

Credit: M. Goerke

Figure 2.2-4: Palmer Station on Anvers Island, Antarctic Peninsula

HUB OF PENINSULA RESEARCH IN ANTARCTICA

Palmer Station (64° 46.45' S, 64° 3.2' W) is a year-round research station located on Anvers Island off the west coast of the Antarctic Peninsula. Palmer Station is the only U.S. Antarctic station north of the Antarctic Circle and is the only one accessed routinely during the austral winter. Palmer Station logistics and personnel movements are supported by the ARSV *Laurence M. Gould (LMG)* from Punta Arenas, Chile. The vessel's course follows the Strait of Magellan past Cape Horn, then directly south across the Drake Passage and on to Anvers Island. The entire journey usually takes four days; however, sea ice and storms can make the journey longer and rougher.

Palmer Station is named for Nathaniel Brown Palmer, who in 1820 became the first American to record sighting Antarctica. The original station was built in 1965 on Amsler Island. From 1967 to 1970, the U.S. Navy constructed the current larger and more permanent station on Anvers Island. Today, two main buildings and several smaller structures make up Palmer Station and provide year-round housing and research facilities for scientists and support personnel (Fig. 2.2-4). In 2022 a new $42M concrete pylon pier was completed as the first step in modernizing the research station. It now allows for a range of vessels to dock at the Station—including the USAPs' largest research vessel the RVIB *Nathaniel B. Palmer (NBP)*.

Palmer Station has a large and extensively equipped laboratory with seawater aquaria. The station is also in an ideal location to conduct biological studies of birds, seals, and marine ecosystems. The majority of the science research conducted at the station is biological, but there are also investigations of climate, aeronomy and geospace science, marine geology, and glaciology.

Marine research from Palmer Station is primarily supported by the *LMG*, Zodiacs (small inflatable boats), and Rigid Hull Inflatable Boats (RHIB). The two primary Palmer Station RHIBs (Fig. 2.2-5), which began service in the 2017-2018 season, were custom built for NSF with specifications derived from research community input. Each vessel is outfitted with twin diesel inboard/outboard drives, heated cabins, mechanical winches and A-frames, and are equipped with hull-mounted echosounders. The RHIBs now extend the Palmer boating more than 20 nautical miles from station. The RHIBs also support divers and have been fitted with a unique suite of water sampling equipment to unlock new research opportunities near Anvers Island.

Figure 2.2-5: Divers enter water from an RHIB

Credit: M. Amsler

AMUNDSEN-SCOTT SOUTH POLE STATION

USAP FACILITIES: PERMANENT STATIONS

TO THE BOTTOM OF THE EARTH

More than a century ago, on Dec. 14, 1911, Norwegian explorer Roald Amundsen was the first person to reach the South Pole, the southernmost point on Earth. Robert Falcon Scott, Amundsen's British rival for that honor, arrived at the South Pole with his party roughly a month later. Scott and his party, who died returning from the pole, were the last people to stand there for 45 years.

No human visited the South Pole again until November 1956, when construction began on the original Amundsen-Scott South Pole Station to carry out scientific observations during the IGY of 1957–1958. This station, now referred to as the "Old Pole," was built by an 18-man U.S. Navy crew. This group was the first to overwinter at the South Pole.

Wind-blown ice crystals and snow eventually bury all structures built on the high Antarctic plateau. The original South Pole Station, designed to be used for only a few years, was buried beneath 45 feet of snow before it was abandoned in 1975 because of concerns about the structural integrity of the facility. During the austral summer of 2010–11, the NSF imploded the majority of "Old Pole" station after an accident occurred involving heavy equipment falling through the unstable ice above its location.

DID YOU KNOW?

South Pole Rodwell

How do you make water for 150 people at the top of an ice sheet?

A Rodwell, a subsurface water well made by melting the firn to create a reservoir of meltwater that can be pumped to the station for use. South Pole Station had its first experimental water well in the 1970s that operated for approximately 13 months. Water is currently supplied to the station from the third water well, Rodwell 3, that came online in 2013. Since that time, Rodwell 3 has supplied over 6.1 million gallons of water to the station.

EVOLUTION IN SUPPORT OF SCIENCE

South Pole Station was relocated and rebuilt in 1975 under a geodesic dome 164 feet wide and 50 feet high that housed living quarters and offices. Since that time, instruments were brought to the South Pole for numerous and complex projects in astronomy and astrophysics for monitoring the Earth's seismic activities and the upper and lower atmosphere.

In 1992, design of a new elevated station that could accommodate the need for an increasing station population was initiated and construction began in 1999 at a site adjacent to the dome. The National Science Foundation officially dedicated the new facility on Jan. 12, 2008, making it the third successive U.S. station on the South Pole since 1957. Two years later, the dome station was disassembled when cracks were discovered along the aluminum base ring beams of the foundation. Sections of the dome are now on display in the U.S. Navy Seabee Museum in Port Hueneme, Calif.

Credit: M. Lucibella

Figure 2.2-6: South Pole Station

SOUTH POLE TODAY

The current Amundsen-Scott South Pole Station (90° S, 0° E) and the area around it (Fig. 2.2-7) provide a support system for complex astrophysics telescopes, seismic instruments, a massive in-ice detector for elusive subatomic particles called neutrinos, an atmospheric observatory, and large-scale scientific experiments.

The low temperatures (often reaching near −100° F in austral winter) and near zero humidity of the polar air, combined with an altitude of more than 9,000 feet, causes the air to be far more transparent on some radio frequencies than is typical elsewhere, and the months of darkness permit sensitive equipment to run constantly. The favorable atmospheric conditions and the unique location of the Amundsen-Scott South Pole Station on the high Antarctic plateau enable astronomers and astrophysicists to better study and understand outer space. The location of the South Pole Station also allows it to serve as a logistics hub, providing access to East Antarctica.

Austral summer operations begin November of each year and during that time an enormous effort begins to resupply the Station by air and land, bringing fuel (up to 450,000 gallons per season), personnel, and all cargo needed to keep the station and science operating for a year until the next resupply is possible. The short summer operating mode lasts until early February, at which point the eight-month long winter season begins.

Credit: A. Dixon

Figure 2.2-7: **South Pole Station Aerial View**
Completed in 2008, the elevated station at the South Pole houses researchers, staff, and scientific experiments. The new station was constructed using a modular design that can be raised to prevent burial in drifting snow. The building's rounded corners and edges also help reduce snowdrifts.

Snow drifting remains a significant annual challenge for infrastructure both at and below the surface. Each summer, two to three heavy equipment operators work full-time to bulldoze, load, and transport snow away from the station to ensure facility access.

The station has a maximum capacity of 150 personnel in the summer and the winter population is 45. During the summer period, on average 45 percent to 50 percent of the population is operations staff working to keep the complicated facility running; the remaining space allocated annually to science and infrastructure recapitalization needs.

The modern elevated station is one of about 47 structures at the site. Significant storage remains outdoors year-round, on berms that require a significant annual labor investment to ensure they remain above the snow level. Additionally, some critical infrastructure, including the power plant, vehicle maintenance facility and fuel storage, are in arches that are now below grade due to annual accumulation. Elevating the main station, as well as multiple science facilities in the area, will be major undertakings at the South Pole in the upcoming years. Last, and adding to the challenges of operating infrastructure in this location, the glacier, and therefore the station complex, is moving 30 feet per year, which creates many engineering challenges.

Credit: D. Stross

Figure 2.2-8: **Ceremonial Pole**
The Ceremonial South Pole is set aside for photo opportunities at the South Pole, but it is not marking the true geographic south pole (90° S). The Ceremonial South Pole remains in the same location relative to the station. The pole is surrounded by flags of the original signatories to the Antarctic Treaty.

Each year, South Pole Station and the ceremonial pole move 30 feet towards the Weddell Sea away from the geographic South Pole. As a result, annually on Jan. 1, a custom South Pole marker is replaced precisely at 90° S. This marker is designed by winter-over staff at South Pole Station.

NEAR-FIELD CAMPS

The United States annually supports more than 50 field sites from its primary Antarctic bases during the austral summer months. Typically, these "near field" sites are reached by traverse (tractor trains), helicopter or small fixed-wing aircraft.

Field camps can be single or multi-season efforts. The infrastructure at these sites can range from tents to longer-lasting modular structures. The staffing will vary with the size and type of operation – from a small camp of researchers working on their own for a few weeks to a larger camp that is doing ice drilling or supporting flight operations. These larger camps will have camp managers, weather observers, mechanics, medics, cooks, and others essential to support the activities.

Near to McMurdo, the USAP operates five semipermanent field camps within the Taylor Valley in the McMurdo Dry Valleys. In this region of significant scientific interest, these sites have laboratory facilities and are sized for six to 16 people for use in the austral summer. Access to the McMurdo Dry Valleys and these camps is usually by helicopter, although early in the austral summer vehicles may approach the coast from the sea ice. To preserve the sensitive environments of the McMurdo Dry Valleys, vehicles are only allowed on lake ice and within Facility Zones at Marble Point (helicopter refueling facility) and New Harbor Camp.

Additionally, the annual sea ice cover of McMurdo Sound creates a temporarily stable working platform and near-field camps can be constructed on the ice for oceanographic or biologic studies to include diving or sending autonomous vehicles under the ice. Access to these sites is typically over the ice with snow mobiles and other tracked vehicles. In these cases, the dynamic nature of the sea ice necessitates regular assessment by field safety specialists monitoring the overall "health" of the sea ice, surveying for new cracks and providing safe routes to operating locations.

Figure 2.2-9: F6 Camp

Credit: P. Rejcek

Figure 2.2-10: Bull Pass Camp

Credit: P. Rejcek

Figure 2.2-11: Big Razorback Seal Camp on sea ice

Credit: M. Lucibella

Figure 2.2-12: Lake Fryxell Field Camp

Credit: P. Rejcek

DEEP-FIELD CAMPS

To answer the most compelling science questions of our time, researchers increasingly need to access remote parts of the Antarctic that cannot easily be directly supported from the three USAP permanent stations. Therefore, USAP operates several deep-field satellite camps each season that are typically hundreds of miles from a main station. These camps vary in size from tent camps supporting a few individuals (Fig. 2.2-13) to those supporting a population of 50 or more participants at the camp (Fig. 2.2-15) with possibly more at nearby satellite camps.

Planning for operations at and from these facilities can be years in the making to ensure safety and proper logistical support. Although none of the deep-field camps operate in the Antarctic winter, some may close and reopen in subsequent summer seasons over the life of one or more science projects or for ongoing logistical purposes. The remoteness of these sites makes establishing and supporting them difficult. Multiple modes of transportation are used to supply them including LC-130 or small fixed-wing flights, overland traverses, and airborne fuel drops (Fig. 2.2-14). The harsh Antarctic weather can be challenging for the annual installation and removal of these sites and for researchers and camp staff living at the primitive facilities.

For safety, all field camps are required to do a daily "check-in" to report on the health and welfare of the camp. In case of injury or emergency, McMurdo annually trains teams (as a collateral duty) to respond to any number of incidents that may occur in the field.

Credit: R. Murray

Figure 2.2-13: Tent camps
Some science must be conducted from very specific locations. Small fixed-wing aircraft or snowmobiles are the primary means of transportation to satellite camps, here made up of a series of tents.

Credit: F. Banks

Figure 2.2-14: Aircraft support
A U.S. Air Force C-17 resupply plane drops scientific equipment, field gear, fuel, and rations to a remote research site in East Antarctica. The location of the site is one of the most isolated in Antarctica.

Credit: M. Lucibella

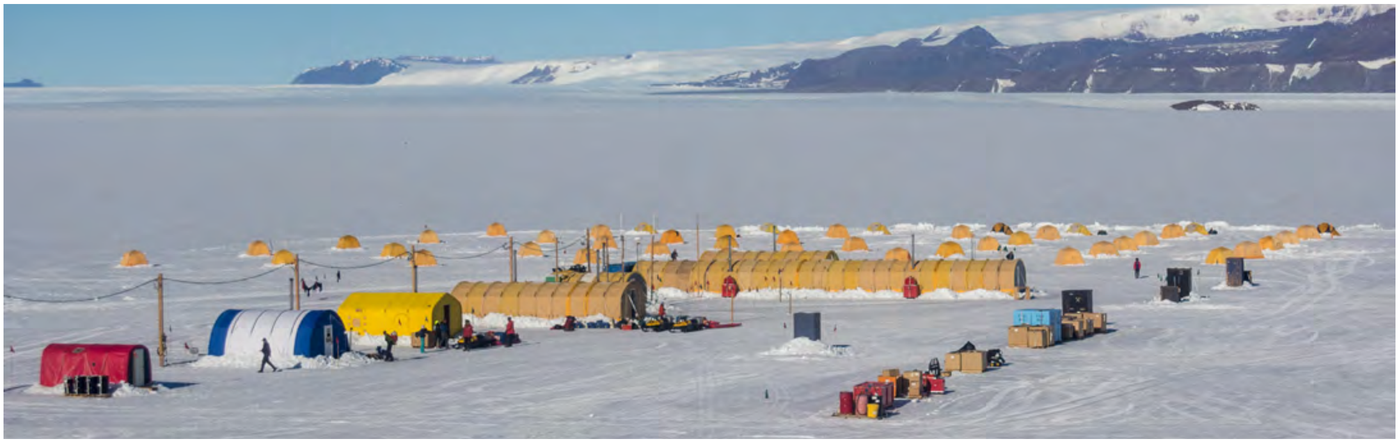


Figure 2.2-15: Deep-field camps
Large deep-field camps, although remote, can support many science groups from a central location. These camps can include groomed skiways, fuel storage, communications, and "tent cities," and serve as a hub for other research sites nearby via helicopters, fixed-wing aircraft, or snowmobiles. Deep-field camps may remain in the same location for several seasons.

2.3 USAP Logistics

AIRCRAFT OPERATIONS

TRANSPORTATION TO AND ACROSS THE CONTINENT

USAP has developed a logistics system larger than any other National Antarctic Program that can support scientific research in the McMurdo Sound area as well as deep-field locations in East and West Antarctica. Most USAP participants are transported from Christchurch, New Zealand, to the continent via U.S. Air Force C-17 (Fig. 2.3-1), New York Air National Guard 109th Airlift Wing Hercules LC-130 (Fig. 2.3-2), or aircraft from partner national programs (e.g., Italian C-130, Australian A-319). There are roughly 50-60 intercontinental flights per year.

On continent, fixed-wing aircraft service Amundsen-Scott South Pole Station and distant research sites. The fixed-wing fleet is currently made up of de Havilland Twin Otter (Fig. 2.3-3) and a Basler DC-3 aircraft under contract to the NSF. The Twin Otters (3–4 aircraft annually) fly up to 900 hours per season and the Basler (1–2 aircraft annually) fly up to 500 hours. Ski-equipped LC-130 aircraft provide the heavy lifting needed to move scientists, equipment, and fuel to the deep field. There are typically 4-6 airframes on continent each season flying some 150 missions.

Multiple helicopters (Figs. 2.3-4) under contract to the NSF, transport researchers to various field camps and research sites in the McMurdo Sound area during the austral summer and serve a critical role in case of regional emergency response.

For these operations, the aircraft rely on two unique airfield facilities on the ice shelf near McMurdo Station and a helicopter pad at McMurdo Station as well as a helicopter refueling site in the McMurdo Dry Valleys. These aviation facilities require extensive annual setup and take-down (approximately 2.5 months), an interagency agreement with the FAA for annual navigational aid flight checks, Airfield Rescue Firefighting (ARFF) staff and equipment and more.

Additionally, a robust aircraft operation requires 24-hour air traffic control, weather forecasting, weather observing and aides to air navigation—all services provided to the USAP through an interagency agreement with the U.S. Navy's Naval Information Warfare Center Atlantic (NIWC). NIWC, employs some 85 personnel to manage and operate an air traffic system that geographically covers the equivalent footprint of the continental United States and Mexico combined (4 million square miles). On average annually, NIWC supports 2,400 fixed wing missions and more than 11,000 rotary wing missions, while generating 8,500 total forecasts covering USAP air, ground, and maritime assets.

Figure 2.3-1: U.S. Air Force C-17

Credit: R. deLucia

Figure 2.3-2: LC-130 Hercules

Credit: B. Bezalel

Figure 2.3-3: de Havilland Twin Otter

Credit: S. Knuth

Figure 2.3-4: A-Star Helicopter

Credit: B. Minnear

SOUTH POLE TRAVERSE (SPoT)

USAP LOGISTICS

Until 2008, all supplies to Amundsen-Scott South Pole Station were delivered on LC-130 aircraft. To reduce the cost and increase the efficiency and reliability of transporting fuel and materials to South Pole Station, USAP established an overland traverse route from McMurdo Station to the pole. The traverse route is approximately 1,030 miles long and took several years of route-finding to prove and to mitigate areas with crevassing. This route is traveled by the South Pole Traverse (SPoT), a tractor train (Fig. 2.3-5) that hauls supplies and fuel using specialized sleds. SPoT tractors ascend more than 9,300 feet along the route to Amundsen-Scott South Pole Station. The average time for a round trip from McMurdo to Pole back to McMurdo is 52 days.

On average, the traverse delivers 300,000 gallons of fuel each season and has the capacity to deliver up to 540,000 pounds (or 23,000 cubic feet) of cargo in addition to the fuel. Each round trip of the traverse takes between eight and 10 personnel, equating to some 17,700 person hours to complete the typical three round-trip traverses in a season, not including the additional two months of effort for preparation and putting away each season.

DID YOU KNOW?

McMurdo Shear Zone

Thirty miles from McMurdo, the SPoT route crosses a heavily crevassed corridor about 3 miles long. Explosives are used along the crevasse bridges to expose voids posing a risk to tractor travel, and the resulting open crevasses are filled with snow mined from nearby areas along the route. The first crossing of the Shear Zone was accomplished through the mitigation of 32 individual crevasses, some nearly 30 feet wide. The same method is used as new crevasses open up along the route and need to be mitigated. Due to the dynamic nature of this section of ice, the route through the McMurdo Shear Zone is assessed (using ground penetrating radar, or GPR) and mitigated annually to ensure the safety of personnel traversing through this region.

Based on fuel delivery alone, each north-south trip of the traverse saves approximately 33 LC-130 flights and has a lower carbon footprint relative to the use of aircraft. An early innovation for SPoT was the development of a fuel transport system that consists of four polyethylene sheets attached to a spreader bar (Fig. 2.3-6). Each sheet carries two 3,000-gallon fuel bladders. More recently, special sleds were developed for the transportation of cargo that did not displace the quantity of fuel delivered.

Figure 2.3-5: SPoT Traverse en route to the South Pole
The lead vehicle on the first SPoT of the austral summer carries ground-penetrating radar for crevasse detection. *Credit: M. Lucibella*

Credit: G. Nerf

Figure 2.3-6: Fuel and cargo
SPoT arrival at South Pole Station with its special fuel bladders on polyethylene sheets to help it glide over the snow surface.

VESSEL OPERATIONS

USAP LOGISTICS

Polar research requires specialized logistics and infrastructure, including icebreakers and ice-strengthened vessels that can support research and operations in the ice-covered waters of the Antarctic continental margin and Southern Ocean.

ICEBREAKING, FUEL, AND RESUPPLY VESSELS

A critical resource is the U.S. Coast Guard icebreaker (USCGC) *Polar Star* (Fig. 2.3-7) that annually breaks a channel through the sea ice of Antarctica's McMurdo Sound to allow a cargo ship and a tanker to resupply NSF's McMurdo and Amundsen-Scott South Pole stations. This mission is part of Operation Deep Freeze, the U.S. military's logistical support for the civilian Antarctic program. Without the channel broken by the USCGC *Polar Star*, the nation's only heavy icebreaker, the Military Sealift Command-contracted tanker (every other year) and cargo vessel (annually) would not be able to transit to the McMurdo ice pier.

The USCGC *Polar Star* was commissioned in 1976. The vessel can break through up to 21 feet of ice by backing and ramming and can steam continuously through 6 feet of ice at 3 knots. The USCGC *Polar Star* is 399 feet long with a draft of 31 feet and a crew of 142. Given the age of the icebreaker, the U.S. Coast Guard (USCG) is currently executing a multi-year service life extension program (SLEP) for the ship. The SLEP essentially refurbishes/replaces/upgrades all of the main components of the ship over a five-year period in between executing Operation Deep Freeze. Concurrently, the USCG is developing the next-generation icebreaker, the Polar Security Cutter, to maintain the U.S. presence in the Antarctic.

Every other year, an ice-strengthened tanker uploads fuel (typically in the Northern Hemisphere) and travels across the world to McMurdo Station where it offloads about 8 million gallons of fuel. This fuel is used at McMurdo and South Pole stations, in the field, and to fuel equipment and aircraft for the following two years.

Annual visits by an ice-strengthened container ship deliver between 10 million and 12 million pounds of cargo to McMurdo Station from the USAP staging location in Port Hueneme, Calif. These items are for use at the station and for distribution to Amundsen-Scott South Pole Station and other inland sites. The ship also takes between 9 million and 10 million pounds of retrograde cargo to the United States, including USAP waste for recycling or proper disposal, and scientific samples collected during the Antarctic field season by science groups.

Ship operations occur annually in January-February. It is several weeks of work, on a 24x7 schedule, to offload these vessels and requires cargo handlers, supply personnel, heavy equipment operators, waste handlers, and fuels operators, among many others, to make this evolution run safely and smoothly.

Since the early 1970s, the vessels visiting McMurdo Station have used an ice pier built in Winter Quarters Bay for cargo and fuel operations. In the last decade, the ice pier failed during use, or was unable to be constructed due to environmental variability, several times. During these years, contingency planning was needed to resupply the operation at considerable cost and risk to the program. To mitigate this risk, the USAP is working with the U.S. Army Corps of Engineers on a more permanent pier solution—a barge pier. The new infrastructure, approved by the National Science Board in 2022, will be installed in Winter Quarters Bay after vessel operations in February 2025.

RESEARCH VESSELS

Two research vessels are operated by the USAP: the research vessel icebreaker (RVIB) *Nathaniel B. Palmer (NBP)* and the Antarctic research supply vessel (ARSV) *Laurence M. Gould (LMG)*. These vessels facilitate a broad range of marine research in ice-covered seas and have allowed U.S. researchers to investigate high-priority research topics, including the rates and processes controlling the extent of sea and glacial ice, the role of the polar oceans in the global climate system, the influence of the Southern Ocean on the global carbon cycle, and the influence of climatic change on polar marine ecosystems. In addition, the USAP research vessels host education and outreach efforts that train the next generation of polar scientists and enable educators and outreach specialists to make polar research more accessible to the general public.

The *NBP* (Fig. 2.3-10) was purpose-built for the NSF in 1992 by Edison-Chouest Offshore Inc. in Galliano, La, and is capable of breaking 3 feet of ice at a speed of 3 knots. The *NBP* was designed with light icebreaking capabilities for the scientific use of USAP researchers. The *NBP* navigates around the entire Antarctic continent, enabling scientists to conduct research in a wide range of environments. At 308 feet long, the *NBP* can accommodate 45 scientists and technicians, a crew of 22 people, and is capable of 75-day missions. The *NBP* can operate safely year-round in Antarctic waters, which are often stormy or covered with sea ice.

The *LMG* (Fig. 2.3-9) was named in honor of Laurence McKinley Gould, the polar explorer who was second-in-command on Admiral Richard E. Byrd's first Antarctic expedition of 1929–30. During this expedition, Byrd established the base camp at Little America from which his team explored the continent, including flights over the South Pole. Like the *NBP*, the *LMG* was purpose-built for the NSF in 1997 by Edison-Chouest Offshore. The *LMG* is 250 feet in length and is ice-strengthened, though not an icebreaker. Although the *LMG* is a multidisciplinary research platform, the primary use of the vessel is for biological and oceanographic research. In addition, the *LMG* is the primary resupply vessel for Palmer Station and also serves as the primary transport for USAP participants from Punta Arenas, Chile, to and from Palmer Station. The *LMG* can accommodate 26 researchers for science missions up to 65 days long, or up to 37 personnel through the use of berthing vans when transiting just to Palmer Station.

The Office of Polar Programs is currently in the design stages for the next generation Antarctic Research Vessel (ARV) (Fig. 2.3-8). While the project is dependent on approvals from the NSF Director, and the National Science Board, and appropriations from Congress, the ARV will ensure uninterrupted science operations in the Southern Ocean and the Antarctic for decades to come. The ARV project will produce a modern, world-class, icebreaking research vessel coupled with modern scientific tools and enhanced capabilities compared to those of the *NBP*, which is rapidly approaching the end of its service life. The new research vessel will support the National Science Foundation's science mission goals by increasing access to ice-protected, hard-to-reach study sites, allowing for longer mission durations, and delivering more scientists and equipment to the Antarctic theater. ARV construction is due to begin in 2026 and be fully operational by 2031.

Credit: B. Bezalel

Figure 2.3-7: **USCGC *Polar Star* and fuel tanker docked at McMurdo Station**

Credit: NSF, illustrated by Glosten Associates Inc.

Figure 2.3-8: **ARV rendering**

Credit: C. Hush

Figure 2.3-9: **ARSV *Laurence M. Gould***

The ice-strengthened ARSV *Laurence M. Gould (LMG)* is smaller than the *NBP* and is not capable of breaking ice. Nevertheless, the *LMG* is a highly capable science vessel that supports a majority of USAP research in the Antarctic Peninsula. The *LMG* was designed to not only conduct research, but also to transport personnel, fuel, and supplies to Palmer Station.

Figure 2.3-10: **RVIB *Nathaniel B. Palmer***

The RVIB *Nathaniel B. Palmer (NBP)* is a scientific icebreaker suited for expeditions within sea ice and in the open ocean. The long endurance of the *NBP* enables USAP researchers to conduct experiments around the entire Antarctic continent and in the Southern Ocean. The *NBP* has a flexible configuration to accommodate a wide range of science activities.

Credit: D. Munroe

The NASA IceBridge mission collects geophysical data over Marie Byrd Land.

SECTION 3: USAP RESEARCH

Credit: M. Studinger

3.1 USAP Research

Antarctica is the highest, coldest, windiest, and driest continent on Earth and is a focal point for scientific discovery. Scientific research in the Antarctic and the Southern Ocean has always been, and remains, a challenging endeavor. Scientific research, along with the needed operational support, is the principal activity of the USAP.

Research supported by the NSF Office of Polar Programs aims to expand fundamental knowledge of the Antarctic region, elicit the connection and impact of Antarctica to the rest of the Earth, and leverage Antarctica as a unique research platform. USAP research has advanced fundamental understanding of Earth and the Universe through investments across numerous research disciplines. Among the many scientific advances are:

- Identification of a microbial ecosystem native to Subglacial Lake Whillans beneath 2,600 feet of ice in the West Antarctic Ice Sheet may provide an analog to life on other planets.
- High-energy neutrinos captured as they passed through detectors of the IceCube Neutrino Observatory, which is buried under thousands of feet of ice at the South Pole, have detected neutrinos that likely originated outside the solar system.
- Ice cores recovered on the Antarctic continent contain archives of how atmospheric composition has changed over millennia. They have demonstrated the interconnectivity of regional and global environmental change, and provide clues to future climate dynamics.
- Geologic research has demonstrated that Antarctica and North America were once linked as part of the Neoproterozoic supercontinent Rodinia, which existed approximately 1 billion years ago.
- Research on marine ecosystems is documenting the southern migration of Antarctic krill populations, and its commercial fishery, from their previous highest concentrations in the Scotia Sea towards the south in the western Antarctic Peninsula.
- Precision measurements of cosmic microwave background radiation have probed the physics of the Universe at its inception and have led to advances in understanding the makeup and evolution of the Universe, and, in doing so, have provided new insights into fundamental physics.
- The Antarctic Circumpolar Current circulating around Antarctica is the largest, longest, and strongest in the world's ocean. It is now warming and accelerating. Deep water derived from this current penetrates and interacts with the ice-sheet margins, enhancing melt of ice shelves, increasing glacier flow to the ocean, and accelerating sea-level rise.
- Studies of fish and seals in Antarctica are giving clues to how animals have evolved to survive in freezing conditions. Such findings provide insights into strategies for cold survival, food preservation, and for medical sciences.

Figure 3.1-1: Navigating icy waters

Credit: M. Lucibella

A marine technician (standing) steers a small inflatable Zodiac boat through icy waters toward Spring Point along the Antarctic Peninsula with the research vessel ARSV ***Laurence M. Gould*** in the background.

Figure 3.1-2: **Science in the field**

Credit: B. Glazer

A USAP helicopter delivers supplies and equipment to a camp in the northern McMurdo Dry Valleys.

Credit: J. Capps

Figure 3.1-3: **Ribbons of light**

At Windless Bight, on the Ross Ice Shelf, the austral darkness provides spectacular views of auroras and the Milky Way.

Credit: A. Toh

Figure 3.1-4: **A Weddell seal visits as USAP diver in McMurdo Sound**

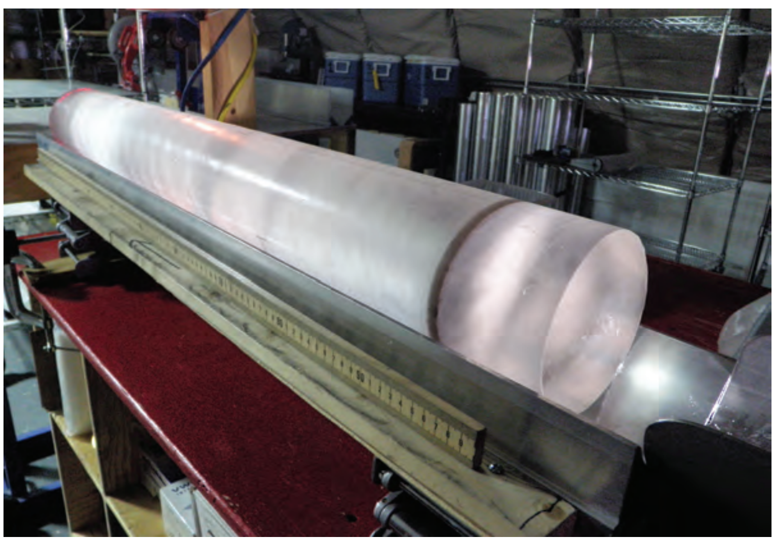
Credit: C. Krueger

Figure 3.1-5: **A time lapse of a balloon launch at South Pole Station**

PAST CLIMATE AND ATMOSPHERIC CHANGE

Ice core research in Antarctica relies on access to remote deep-field sites in the East and West Antarctic ice sheets. Ice cores (Fig. 3.2-1) provide the most direct and detailed way to investigate past climate and atmospheric conditions. They are collected by coring into the ice sheet using specialized drills. Ice sheets form from the accumulation of yearly snowfall. With each additional layer, the weight on the lower layers increases and the snow gradually becomes denser with depth. This compacted snow turns into firn, which eventually turns to ice. The air within this ice is sealed into bubbles, and, once sealed, the trapped air no longer circulates with the atmosphere. In this way, bubbles record atmospheric compositions at the time the ice formed. By drilling into the ice, often a mile or more deep (Fig 3.2-2), the scientific community can extract and then carefully transport ice cores for lab analyses to decipher the record.

Ice cores have provided an important resource for understanding environmental change in the past and future. Many kinds of analyses are performed on these cores, including visual layer counting; tests for electrical conductivity and physical properties; and measurements of gases, particles, radionuclides, and various molecular species. Ice core records can be used to reconstruct temperature, greenhouse gas concentration, atmospheric circulation strength, precipitation, ocean volume, ocean temperature, atmospheric dust, volcanic eruptions, solar variability, marine biological productivity, sea ice and desert extent, and forest fires. Clues about past climate change gained from Antarctic ice cores have provided researchers with key insights into past environmental change that are essential to constrain global climate models of the past and the future.



Credit: H. Roop

Figure 3.2-1: Ice cores
The dark band in this ice core from West Antarctic Ice Sheet Divide (WAIS Divide) ice core drill site is a layer of volcanic ash that settled on the ice sheet approximately 21,000 years ago.

Credit: M. Lucibella

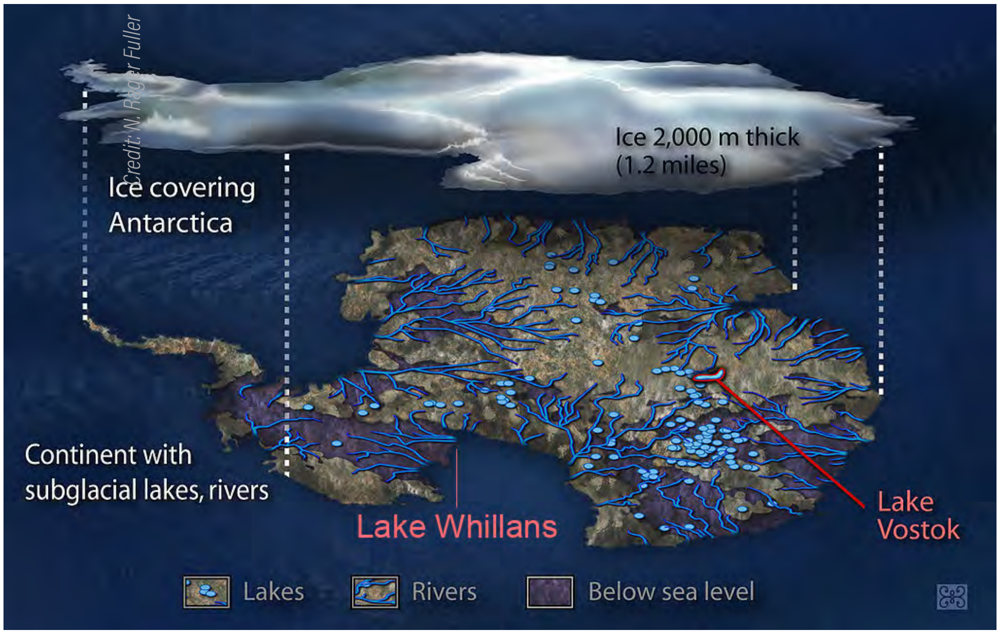
Figure 3.2-2: Drilling deep
A view of the inside the South Pole Ice Core (SPICECORE) project drilling building, with the drill rig visible in the center. The project collected ice samples as deep as 5,744 feet below the surface.

Sealed inside each ancient ice sample, or ice core, are numerous tiny air bubbles, which contain samples of the atmosphere from the past before the ice was buried. Climate scientists analyze these trapped bubbles to learn what the Earth's atmosphere was like thousands of years ago.

SUBGLACIAL LAKES

Over the last few decades, airborne radio-echo sounding and satellite imaging have been used to identify approximately 675 lakes beneath the Antarctic Ice Sheet. These lakes can be overlain by several miles of ice and sometimes have an interconnected hydrology that allows water to flow from lake to lake and out to the open ocean (Fig. 3.2-3). Some lakes fill and then drain over just a few years, and the ice surface above them can rise and fall by more than 10 feet. The irregular topography beneath the Antarctic ice sheets provides essential nucleation basins for lake formation.

Lake formation is likely linked to heat-flow variations that control melt rates at the bottom of the ice sheet and thus the distribution of subglacial water. Water in subglacial lakes below the ice sheet remains in liquid form as geothermal heating balances the heat loss to the ice surface and vertical pressure causes the melting point of water to be below 32° F. The largest known subglacial lake is Lake Vostok in East Antarctica, which is 160 miles long, 30 miles wide, and an average of 1,400 feet deep, all beneath more than 2 miles of ice. A smaller, 100-foot-deep subglacial lake persists only a few miles from the South Pole.



Credit: Z. Deretsky

Figure 3.2-3: Subglacial lakes
Almost 700 subglacial lakes are known to exist under the Antarctic Ice Sheet. Some have been isolated for millions of years. Others are interconnected and drain and refill over just a few years.

Although not confirmed, it is thought that some subglacial lakes may have been isolated from the atmosphere for up to 25 million to 35 million years. Subglacial lakes are hard to explore and only three have been sampled—Subglacial Lake Vostok in East Antarctica and Subglacial Lake Whillans and Subglacial Lake Mercer at the southeastern edge of the Ross Ice Shelf. Subglacial Lake Whillans is 2,600 feet beneath the surface of the ice sheet. It covers an estimated area of 20 square miles with an average depth of approximately 6 feet. To prevent contamination during the drilling and sampling of subglacial lakes Whillans and Mercer, researchers used ultraviolet radiation, water filtration and hydrogen peroxide to sterilize the machinery and the water used to bore through the overlying glacial ice.

Research at Subglacial Lake Whillans has demonstrated that subglacial lakes may provide unique refuges for life on Earth. Genetic analyses indicate that some of the lake's microbes are related to marine species that derive energy by oxidizing iron and sulfur compounds from minerals in sediments and microbially derived organic matter. This research has provided insight into organisms living in the unique environment of subglacial lakes and may provide an analog for early life forms found on Earth and elsewhere in the solar system. Sampling strategies used to sample Subglacial Lake Whillans provided a unique testbed for determining feasibility, strategy, and instrumentation for future missions to Mars and to Jupiter's moon Europa.

ICE SHEET VULNERABILITY

THE DEEP FIELD: THE CRYOSPHERE

An ice sheet is a mass of glacier ice that covers an area greater than 19,000 square miles. Ice sheets are bigger than ice shelves or alpine glaciers. The surface of an ice sheet is cold, but the sheet can be warmer at its base as a result of geothermal heating. Warmer temperatures can result in melting at the base of an ice sheet, which can allow it to flow more rapidly to the sea as an ice stream.

The East (EAIS) and West Antarctic (WAIS) ice sheets cover about 98 percent of the Antarctic continent. Together, they are the largest single mass of ice on Earth, covering an area of almost 5.4 million square miles and contain 6.4 million cubic miles of ice. The East and West Antarctic ice sheets hold approximately 61 percent of all fresh water on the Earth, an amount equivalent to about 190 feet of sea-level rise. The EAIS is grounded on the Antarctic continent, whereas the West Antarctic Ice Sheet is grounded as deep as 8,000 feet below sea level.

A recent focus of deep-field research has been on the stability of the WAIS. The WAIS is bounded by the Ross Ice Shelf, Ronne Ice Shelf, and outlet glaciers that drain into the Amundsen Sea, such as Thwaites (Fig. 3.2-4) and Pine Island glaciers. The weight of the WAIS has caused the underlying rock to sink by between 0.31 and 0.62 miles. As a result, the WAIS is a marine-based ice sheet whose bed lies below sea level with the bedrock sloping inland.

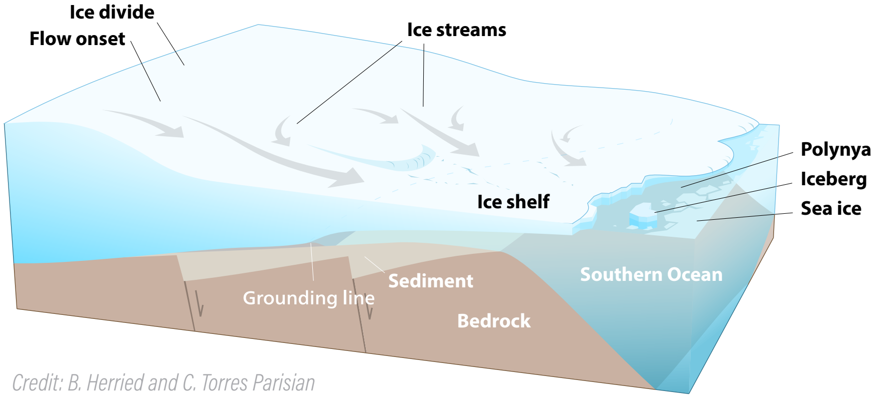
Because the bottom of the WAIS lies below sea level, ocean water can intrude far inland under the floating portion of the ice and melt it from below. If the melting is fast enough, it causes more of the ice to float, and the margin of the grounded ice retreats inland. Because the bed gets deeper inland, there is the potential for this process to accelerate. In addition, the floating ice shelf restrains the flow of grounded ice that is backed up behind it. As this floating ice is lost, the inland ice may accelerate. This destabilization could lead to rapid disintegration of the WAIS. If the WAIS were to melt entirely, this would cause global sea levels to rise, on average, approximately 16 feet.

Credit: R. Larter

Figure 3.2-4: Thwaites Ice Cliff

The ice cliff of Thwaites Glacier shows the point where the glacier meets the sea. Icebergs "calve" from the front of the cliff, giving a continually breaking edge the height of the glacier.

Melting of WAIS outlet glaciers is already making a significant contribution to measured sea-level rise. The Amundsen Sea embayment region alone contributes 10 percent of the current rise and the future trajectory of this region represents one of the biggest unknowns. It is thought that the WAIS melting has resulted from changes in air circulation patterns that have caused greater upwelling flow of relatively warm, deep ocean water along the coast of Antarctica. This warm water has increased melting of floating ice shelves at the edge of the ice sheet. Data collected from satellites support this hypothesis, suggesting that the WAIS is beginning to show signs of instability. These satellite images provide the first strong evidence that large Antarctic ice shelves respond to changes at their ocean edge in a similar way as observed in Greenland.



Credit: B. Herried and C. Torres Parisian

Figure 3.2-5: Ice Sheet Dynamics

Diagrammatic representation of the interface between an ice sheet, outlet glaciers, and the open ocean. Outlet glaciers flow out from the ice sheet over the grounding line, where they begin to float and break off at the calving front.

Under the West Antarctic Ice Sheet, increasing ocean temperature is accelerating the rate of melt under the floating ice and is creating the potential for ice sheet collapse.

ICE AROUND THE CONTINENT

THE DEEP FIELD: THE CRYOSPHERE

Found only in Antarctica, Greenland, and Canada, an ice shelf is a floating platform of ice that forms where glaciers or ice sheets flow down to the coastline and onto the ocean surface. The boundary between the floating ice shelf and the grounded ice (resting on bedrock), called the grounding line, follows the coast on the southern, western, and eastern edges of the Ross Ice Shelf. In places, the Ross Ice Shelf is hundreds of feet thick, with 90 percent of the floating ice below the water surface. The vertical ice front (Fig. 3.2-6) to the open sea measures more than 350 miles long with a face measuring between 50 and 165 feet above the water surface.

Figure 3.2-6: The Ross Ice Shelf meets the Ross Sea

Credit: J. Landis

EXPLORING UNDER THE ICE

Large portions of the Antarctic coastline, particularly in West Antarctica, are covered by ice shelves. Recent advances in robotics have allowed for the development and use of remotely operated vehicles (ROV) that can safely explore under ice shelves. These vehicles have been lowered down boreholes drilled with hot water through the ice shelf (Fig 3.2-8) as well as being launched from vessels in the open ocean to travel under the ice. One of these ROVs found lost experiments from the early days of diving under the Ross Ice Shelf and has made it possible for these experiments to be retrieved and analyzed. Other robots have explored right up to the grounding zone where the ice shelf goes afloat—helping scientists to understand the water conditions and ice-shelf geometry in these critical zones.

Despite the cold and dark environment, scientists have found thriving communities under the ice as far as 50 miles from the ice-shelf edge. ROV cameras have recorded surprisingly abundant corals, brittle stars, sponges, and tunicates under the ice near Heald Island, prompting researchers to wonder what all of these animals living in the dark are feeding on. The cameras also filmed surprisingly large sponges at the edges of areas recently scoured by icebergs, causing the researchers to wonder whether iceberg activity is less than previously thought or if juvenile sponges grow more quickly than expected. Recently, a species of sea anemone was found living under the Ross Ice Shelf (Fig. 3.2-7). It is the first species of sea anemone reported to live in ice. The anemones were discovered when a ROV was sent into holes that had been drilled into the ice. This revealed the presence of small creatures, less than 1 inch long, with most of their pale yellow bodies burrowed into the ice shelf and their roughly two dozen tentacles dangling into the frigid water below.

Credit: F. Rack

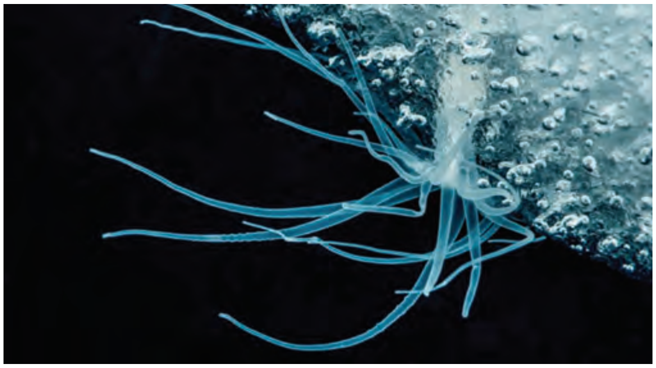


Figure 3.2-7: Life in the depths

Sea anemones on the bottom of the Ross Ice Shelf. The new species was discovered in 2010 by researchers using a camera-equipped robot to survey the ice shelf for a project to drill into the sea floor below.

Credit: E. Hood

Figure 3.2-8: IceFin

Scientists prepare the IceFin remotely operated vehicle to be lowered down a borehole through ice and into the ocean below.

3.3 South Pole Research

THE DEEP FIELD

Research at Amundsen-Scott South Pole Station includes glaciology, geophysics, meteorology, upper atmosphere physics, astronomy, astrophysics, neutrino physics, and biomedical studies. South Pole has been designated Antarctic Specially Managed Area No. 5. Within the identified Scientific Zone are four sectors: Dark, Downwind, Clean Air, and Quiet.

DARK SECTOR

In the Dark Sector, grid-northwest of the station, light pollution and electromagnetic noise are minimized to assist astronomical and astrophysical research. The South Pole is uniquely suited to astronomical research because of its high altitude and thin, dry, and stable atmosphere during austral winters. The centrifugal force of the Earth's rotation flattens out the atmosphere at both poles, and the extreme cold freezes water vapor out of the air. Microwave, infrared, and high-energy neutrino telescopes are located within the Dark Sector.

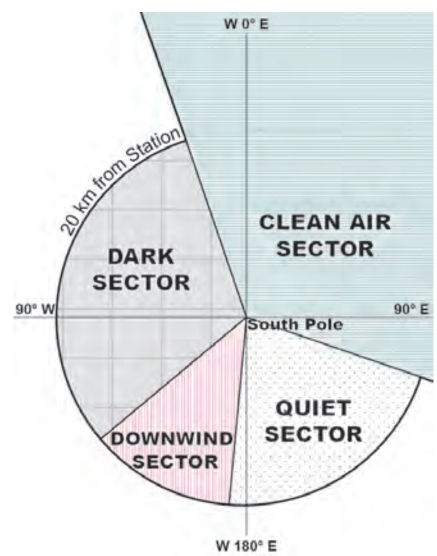
Within the Dark Sector, the 10-meter South Pole Telescope (Fig. 3.3-1) is designed for observations in the microwave, millimeter, and submillimeter regions of the electromagnetic spectrum. A primary research goal is to measure the faint and diffuse cosmic microwave background radiation and investigate "Dark Energy" that appears to be accelerating the expansion of the Universe. The telescope also searches for the signature of primordial gravitational waves and tests models for the origin of the Universe. In another part of the Dark Sector is the Background Imaging of Cosmic Extragalactic Polarization (BICEP) experiment designed to measure polarization of the cosmic microwave background to answer questions about the origin of the Universe. The Dark Sector's Martin A. Pomerantz Observatory, a two-story, elevated structure, has supported various astronomical telescopes and instruments over 25 years.

DOWNWIND SECTOR

In the Downwind Sector, no obstructions are allowed. This provides an area suitable for balloon launches, aircraft operations, and other "downwind" activities.

CLEAN AIR SECTOR

The Clean Air Sector ensures a pure environment for air and snow sampling at the Atmospheric Research Observatory Baseline Observatory, where routine measurements are made to determine long-term trends of important trace gases, aerosols, and solar radiation. These data are used to understand the influence of these gases and aerosols on Earth's climate. The Clear Air Sector is located grid east-northeast of South Pole Station. A critical research project that arose from sampling in the Clean Air Sector was identification of the thinning of the atmosphere's ozone layer or "ozone hole." In the Clean Air Sector, LiDAR (light detection and ranging) is also used to study the formation of polar stratospheric clouds, which act as the seeds for the depletion of ozone each spring.



Credit: S. Eckert

Figure 3.3-1: South Pole sector map

QUIET SECTOR

The Quiet Sector is grid southeast of the station. In this sector, activities and equipment emitting noise or vibration are limited to enable seismologic research and other vibration-sensitive activities, such as installing radio or natural emissions antennae. Because the Pole is at the spin axis of the Earth, it is uniquely situated to measure global seismography and long-period oscillations of the Earth at the South Pole Remote Earth Sciences Seismological Observatory (SPRESSO), located 4.5 miles from the station. Antarctica is seismically "quiet," and the seismometers are so sensitive that vibrations up to four times quieter than any previously observed can be recorded.

ICECUBE NEUTRINO OBSERVATORY

Also at the South Pole is the international IceCube Neutrino Observatory (IceCube). IceCube consists of 5,160 spherical optical sensors called Digital Optical Modules (Fig. 3.3-2) suspended on 86 strings, each with a photomultiplier tube and a single board data acquisition computer, which sends digital data to the counting house on the surface above the array. The series of detectors is distributed over a cubic kilometer of volume under the Antarctic ice and is designed to capture signals of high-energy neutrinos to explore the highest-energy astrophysical processes. When neutrinos interact with the ice, they create electrically charged secondary particles.

The observatory detects neutrinos through short flashes of blue light, Cherenkov radiation, caused by muons (the secondary particles produced after direct collision of a neutrino with an atom's nucleus) as they travel through the ice faster than light. The tracks of this blue light can indicate the type of neutrino involved, and its origins, thus providing insights into high-energy cosmic events such as exploding stars, gamma-ray bursts, and cataclysmic phenomena involving black holes and neutron stars.

In 2013, scientists observed the first evidence for astrophysical high-energy neutrinos with energies at and above the 100-TeV level, including two events with energies at the peta-electronvolt level—the highest-energy neutrinos ever detected. Twelve years after the IceCube completion, researchers have isolated about 1,000 high-energy cosmic neutrinos, with energies between 100 TeV and 10 PeV, from more than a million atmospheric neutrinos and hundreds of billions of cosmic-ray muons.

Credit: B. Eberhardt

Figure 3.3-2: IceCube Neutrino Observatory
The IceCube Neutrino Observatory studies the production of neutrinos in the universe. Neutrinos are detected by 5,160 digital optical modules (DOMs) buried in ice between 4,500 and 7,800 feet below the surface.

Credit: M. Young

Figure 3.3-3: Mapping the night sky
There are two telescopes located at the Dark Sector Laboratory in the proximity of the Elevated Station at the South Pole. The South Pole Telescope (SPT), shown to the left, is a 10-meter-diameter radio telescope designed to observe galaxy clusters in the deep universe, as well as look for the origins of the Universe.

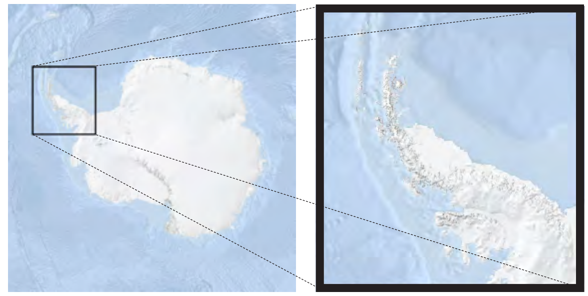
The telescope began science observations in February 2007. This telescope provides astronomers with a powerful new tool to explore dark energy, the mysterious phenomenon that may be causing the universe to accelerate, and the influence dark energy may have on the growth of galaxy clusters. SPT is also part of the global Event Horizon Telescope which has produced the first images of black holes inside and outside our galaxy.

The adjoined BICEP Telescope (not pictured) is designed to measure the polarization of the cosmic microwave background radiation to answer questions about the universe's inflationary epoch.

3.4 Marine Research

ANTARCTIC PENINSULA

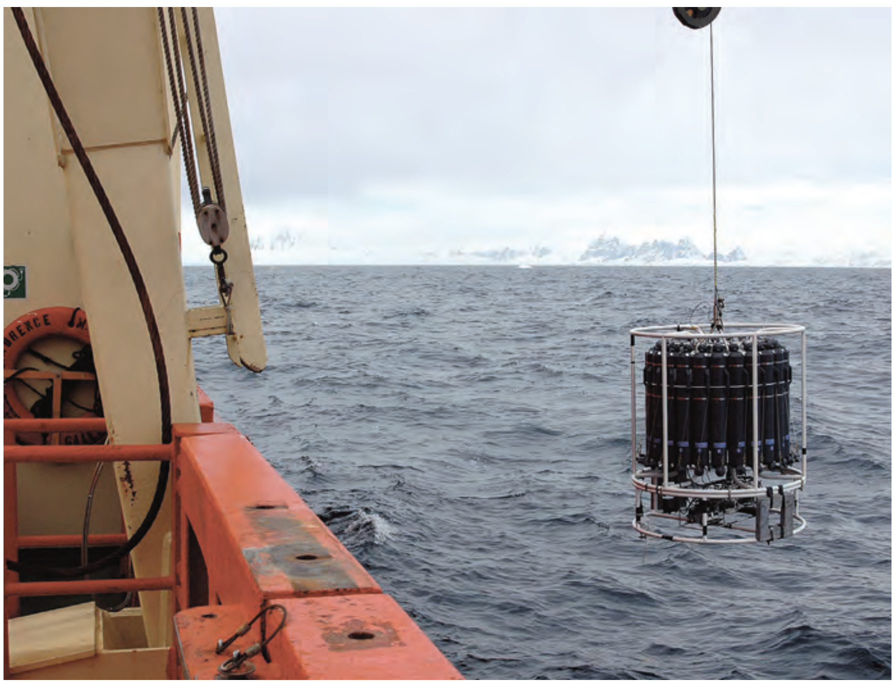
A large portion of marine research is conducted at Palmer Station during the austral summer (October to March), when days are long, ice cover is low, and organisms are most active. Scientists study the oceanography of the region, including the ecology of the marine and terrestrial organisms that inhabit the local area, including bacteria, algae, invertebrates, fish, marine mammals, and birds.



Credit: C. Torres Parisian

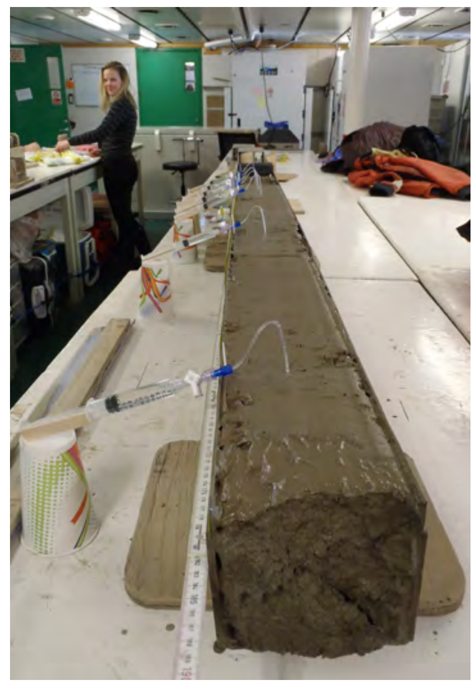
Figure 3.4-1 Location of the Antarctic Peninsula.

The Palmer area was designated a Long-Term Ecological Research (LTER) site by the National Science Foundation in 1990. Palmer LTER focuses on a region that is globally significant and is exhibiting one of the most rapid rates of winter warming. A primary research objective of the Palmer LTER is to define how seasonality, interannual variability, and long-term trends in sea ice extent and duration influence the structure and function of marginal ice zone ecosystems and the cycling of chemical elements by the organisms. LTER researchers engage in long-term observations and field experiments, as well as modeling across large spatial scales ranging from months to decades to centuries.



Credit: P. Rejcek

Figure 3.4-2: Water sampling
Deployment of a conductivity, temperature, and depth sensor (CTD) from the *LMG* in the Southern Ocean. Conductivity is measured because this value is easily converted to salinity. The CTD is mounted at the center of a rosette frame with an array of Niskin bottles surrounding the rosette to collect water samples at specific depths in the water column.



Credit: A. Chiuchiolo

Figure 3.4-3: Sediment core
This sediment core shows the top six feet of seafloor in the Amundsen Sea. The core was taken aboard the *Nathanial B. Palmer* as part of a ship-based and ice-based project examining the sedimentary records to reconstruct past changes in ocean conditions.

Beyond the region near Palmer Station, the RVIB *Nathaniel B. Palmer (NBP)* and ARSV *Laurence M. Gould (LMG)* support a variety of research projects in coastal waters and those of the Southern Ocean. For example, sediments in cores from the Southern Ocean (Fig. 3.4-3) preserve unique records of how climate and the ice sheets have evolved in the past.

This research has provided insights into ice sheet sensitivity to rapid melting when atmospheric CO2 concentrations are greater than 400 ppm, similar to current values. Sediment records have also demonstrated the existence of a warm period in Antarctica approximately 15.7 million years ago where summer land temperatures may have been as warm as 50° F with sea surface temperatures as warm as 53° F.

ANTARCTIC MARGIN

The opening of the Drake Passage between South America and the Antarctic Peninsula approximately 30 million years ago allowed for initiation of unrestricted circumpolar oceanic flow around the Antarctic continent. This Antarctic Circumpolar Current (ACC) formed a nearly impenetrable barrier that organisms could not cross. Because of ACC development, and the thermal isolation associated with cooling of waters around the Antarctic continent, Antarctic organisms have had to contend with extreme environmental conditions. The diversity of fish species present prior to opening of the Drake Passage is limited today to a single predominant group, the Antarctic notothenioid fishes (Fig. 3.4-4) whose ancestors evolved antifreeze and antimelt proteins that allow them to survive in the cold Southern Ocean.

Credit: P. Cziko

Figure 3.4-4: Ice Fish in ice

Notothenioid fish are distributed mainly throughout the Southern Ocean around the coasts of New Zealand, South America, and Antarctica in seawater temperatures between 28° F and 39° F with a depth range of approximately 5,000 feet. Many notothenioid fish are able to survive in the freezing, ice-laden waters of the Southern Ocean because of the presence of an antifreeze glycoprotein in blood and body fluids.

The Southern Ocean is the least observed and understood region of the world ocean. It is the primary gateway through which intermediate, deep, and bottom waters reach the ocean's surface and interact with the atmosphere. The Southern Ocean is also critical for regulating Earth's temperature by removing approximately 25 percent of anthropogenic carbon released into the atmosphere as well as most of Earth's excess heat. Because of low seawater temperatures, waters of the Southern Ocean are also susceptible to ocean acidification due to the ability of cold water to retain gases such as excess anthropogenic CO2.

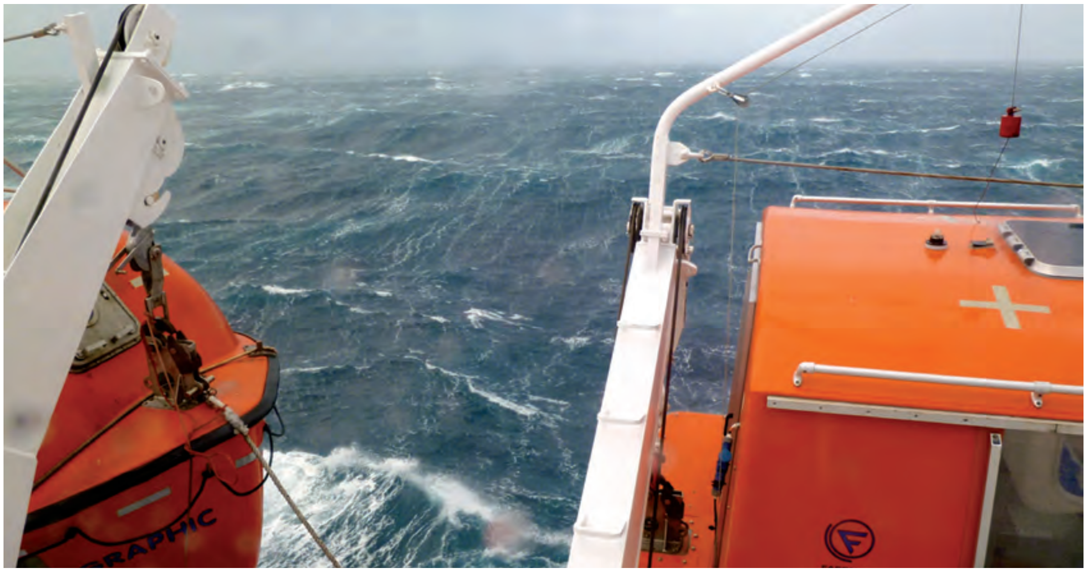
The ACC, which is driven by the circumpolar westerly winds, plays a unique role creating an oceanographic connection among the Atlantic, Pacific, and Indian oceans. On the continental margins of Antarctica, deep water derived from the ACC penetrates and interacts with the ice sheet margins, initiating melt and increasing the speed of glacial flow. The ACC is also important for global ocean mixing and air–sea exchange of heat and gases, including fluxes of CO2 and dimethyl sulfide.

Antarctic Bottom Water (AABW) forms close to the Antarctic coast, becoming a well-defined dense and cold water mass that fills the deepest basins of the global ocean. Studies indicate that because of climate change, AABW has been warming and decreasing in volume. This change will have important impacts on Earth's global conveyor of thermohaline circulation.

Southern Ocean ecosystems are highly dependent on nutrient- and sunlight-driven food production within sea ice and upper ocean waters. Rapidly changing physical conditions are impacting the biogeochemistry of and food supply in the Southern Ocean. Ecosystems are impacted by ocean acidification, warming waters and decrease of sea ice. Details of these impacts and the evolution of ecosystems to a changing environment are a major research topic.

Figure 3.4-5: Day at sea

Rough seas and storms while crossing the Drake Passage (from South America to the Antarctica Peninsula) can be challenging any time of year.



Credit: A. Isern

3.5 Penguins

Icons of the Antarctic, penguins are a group of flightless birds that are exceptionally adapted to aquatic life. Penguins have a thick layer of insulating feathers that keep them warm in water, and their wings have evolved into flippers. Penguins are extremely agile underwater. They have countershaded dark and white plumage so that a predator looking up from below has difficulty distinguishing between a white penguin belly and the reflective water surface. The dark plumage on their backs camouflages them from above. Most penguins feed on krill, fish, squid, and other marine organisms they catch in their forays underwater.

Within their plumage a layer of air is preserved, ensuring buoyancy and speed in the water. As they move faster in the water, feathers in the penguin plumage release bubbles that reduce the density of the water surrounding them; these bubbles act as a layer of lubrication to reduce drag in the water, allowing penguins to quickly propel themselves through and out of the water. Penguin eyes are adapted for underwater vision and are the primary means of locating prey and avoiding predators.

On land, penguins use their tails and wings to maintain balance when upright, giving them their characteristic "waddle." To move more efficiently they can slide on their bellies, which is often called "tobogganing."

Five penguin species (Figs. 3.5-3 to 3.5-7) breed in the Antarctic: emperor, Adélie, chinstrap, gentoo, and macaroni. The emperor and Adélie are the only species that are found around the entire Antarctic continent. Emperors are the largest penguin with an average height of 45 inches and weight of 88 pounds. Emperor penguins can dive to 1,850 feet. They breed in the winter on the open ice, where females lay a single egg and then promptly leave it behind as they go to sea in search for food.

Gentoo, chinstraps, and Adélie penguins are the most common penguins on the Antarctic Peninsula. During the past 60 years of research, the relative abundances of each of these species has changed in response to the warming of regional climate. Gentoo populations have increased significantly, while chinstraps and Adélie penguin populations have declined significantly in many locations. By contrast, Adélie penguin populations in East Antarctica and the Ross Sea appear to be increasing.

Credit: A. Isern

Figure 3.5-1: Deep divers
Sensor tags, like the one on the back of this Adélie penguin on Torgersen Island, provide fundamental data on penguin diving capabilities and water column properties.

Figure 3.5-2: Penguin colony
Adélie penguins ride recently broken-up chunks of ice at Cape Crozier. The penguin colony is one of the largest known Adélie penguin colonies in the world.

Credit: M. Lucibella

Figure 3.5-3: Adélie penguin (*Pygoscelis adeliae*)

Credit: penguinscience.com

Figure 3.5-4: Chinstrap penguin (*Pygoscelis antarcticus*)

Credit: A. Friedlaender

Figure 3.5-5: Emperor penguin (*Aptenodytes forsteri*)

Credit: K. Kuenning

Figure 3.5-6: Gentoo penguin (*Pygoscelis papua*)

Credit: A. Friedlaender

Figure 3.5-7: Macaroni penguin (*Eudyptes chrysolophus*)

Credit: P. Spindler

3.6 Whales

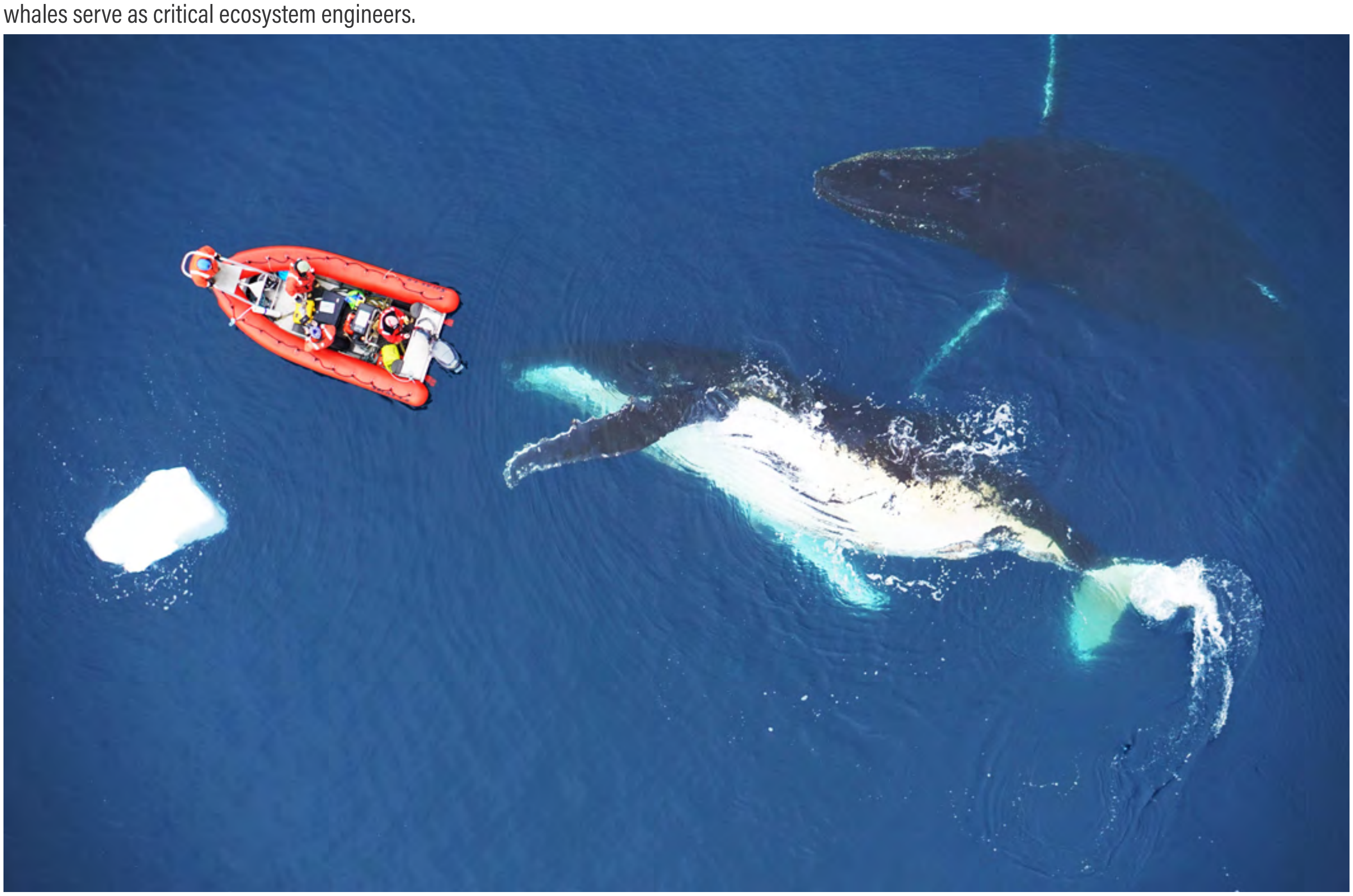
Over 2 million baleen whales were killed in the Southern Ocean in the 20th century by the commercial whaling industry. Since the cessation of most whaling in the late 1980s, some populations of these ocean giants have begun to recover, while others have yet to show such signs. In the waters around the Antarctic Peninsula, humpback whales (*Megaptera novaeangliae*, Fig. 3.6-2) and minke whales (*Balaenoptera bonaerensis*, Fig. 3.6-3) are the two most common species present, yet their population numbers, ecological roles, and susceptibility to changing environmental conditions remain poorly known.

STUDYING WHALES TODAY

Understanding the ecological role of baleen whales has been the focus of many NSF research efforts over the past 15 years (Fig. 3.6-1). Initially, studies linked the distribution of humpback and minke whales to features of their environment: Humpback whales are found in open waters where krill abundance is high, while minke whales are found in close proximity to sea ice and sheltered bays. As wildlife telemetry and tagging technology matured, so too has understanding of the movement patterns and feeding behavior of these species. Satellite-linked and motion-sensing tags have been deployed on a number of animals and provide critical insights as to how these two species of krill predators use the marine environment around the Antarctic Peninsula.

It has been found that humpback whales range broadly during summer months when krill are distributed similarly over the continental shelf. However, in autumn, as krill move inshore and coalesce in the sheltered bays that will eventually be their wintering havens, humpback whales follow the krill and aggregate in incredible densities to feed. Minke whales, on the other hand, tend to be more sparsely distributed, and remain in close contact with the diminishing sea ice throughout the summer months, where they forage on smaller patches of krill and seek shelter from predatory killer whales.

Figure 3.6-1: **Ecosystem engineers**
Researchers use boats and drones to study humpback whales near the Western Antarctic Peninsula. The research explores how baleen whales serve as critical ecosystem engineers.



Credit: Duke University Marine Robotics and Remote Sensing under NOAA permit 14809-03 and ACA permits 2015-011 and 2020-016

Figure 3.6-2: Humpback whale

Credit: A. Friedlaender

Figure 3.6-3: Minke whale

Credit: A. Friedlaender

WHALES IN A CHANGING CLIMATE

As a consequence of rapid changes around the Antarctic Peninsula, there are nearly 80 more ice-free days annually than 40 years ago. This provides significant opportunities for humpback whales to remain in ice-free waters for an extended summer feeding season that now spans from December through June. Then they start the long migration to winter breeding grounds off of the western coast of Central America and the tropical waters of Oceania. Increases in the amount of time humpbacks spend in Antarctica feeding on a vast supply of krill has, in part, allowed this population to grow at rates approaching the biological maximum for the species. In fact, conditions are currently favorable enough for some humpback whales to give birth annually. The consequences for minke whales that have a strong affinity for sea ice is less clear and remains one of the great challenges for whale research moving forward in Antarctica.

The study of whales in Antarctica is on a steep upward trajectory, taking advantage of a number of new technologies to better understand the biology of the animals, their behavior, and the impacts of rapid climate change on them. Along with new tagging technologies, new molecular and chemical techniques are being used to determine pregnancies in individual whales from skin and blubber samples. Unoccupied aerial systems (UAS) are now being used to remotely measure the body condition of whales to determine seasonal and interannual changes in animal health that may be driven by environmental conditions, such as changes in sea ice or krill abundance.

Figure 3.6-4: Powerful tail

Humpback whales slap their flukes on the surface, creating a loud, resonant underwater noise, possibly to serve as a warning. The markings on their flukes are used as a unique identifier because each fluke has different patterns that can help researchers identify individuals over many years.

Credit: A. Friedlaender

3.7 The McMurdo Dry Valleys

THE MCMURDO DRY VALLEYS

The McMurdo Dry Valleys are an Antarctic anomaly. While most of the continent is covered in a thick layer of glacier ice, these dry, frigid valleys are almost entirely ice-free, an arid expanse of exposed soil, small rocks, and large boulders. The valleys are dotted with a few frozen lakes and, during the austral summer, are etched with short-lived streams that link the lakes with surrounding glaciers, some of which reach the valley floors.

Why are the Dry Valleys so different from the rest of the continent? The answer lies in the mile-high Transantarctic Mountains. The valleys are nestled between the mountains, which serve as a barrier, largely blocking them from the East Antarctic Ice Sheet. Several tongue-like glaciers creep through the gaps, but any ice that breaks off the glaciers quickly sublimates in the arid atmosphere.

RESEARCH HISTORY

Explorer Robert Falcon Scott discovered the valleys in 1903. Later research teams measured the breadth and depth of the Dry Valleys from photographs, but it was unclear why these areas of bare ground existed on a continent covered with ice. During the IGY of 1957–58, while massive efforts went into setting up an airfield at McMurdo Station (Fig. 3.7-1) to supply a planned South Pole Station, three biologists and a geology student were dropped off in one of the then nameless valleys. Their only maps were the ones of the coastline from early explorers Robert F. Scott and Ernest Shackleton. Looking at terrain nobody had seen before, they were challenged with the unknown and unexplored. The legacy of Scott's early research efforts and those of scientists during IGY is the rich interdisciplinary research taking place in the McMurdo Dry Valleys today.

Credit: U.S. Navy

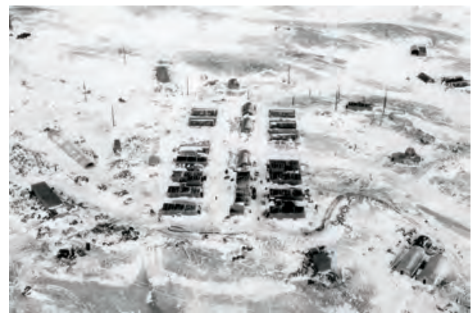


Figure 3.7-1: A new base
This photo from 1956 shows McMurdo Station, then called Williams Air Operating Facility and operated by the U.S. Navy. It was established to support IGY.

MUMMIFIED SEALS

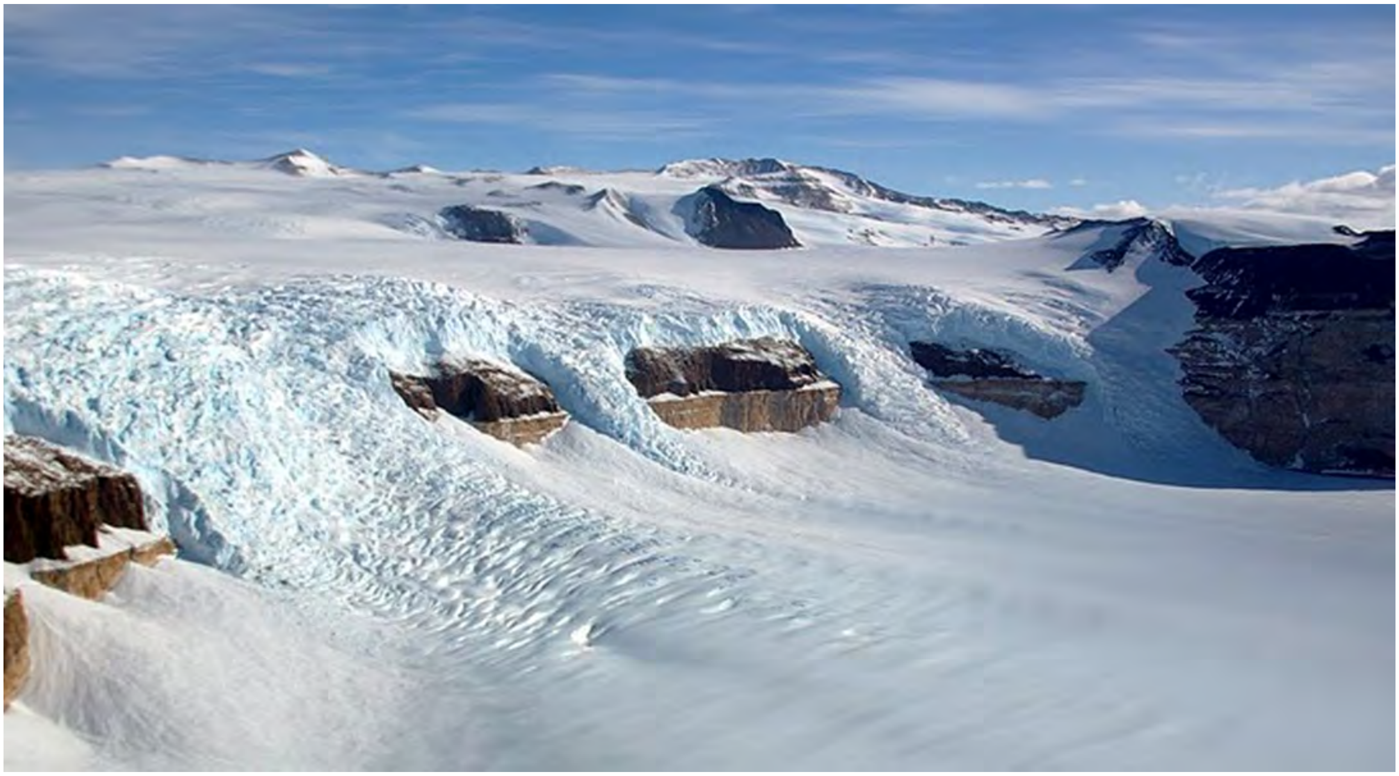
Parts of Wright, Victoria, and Taylor valleys are zoologically interesting. Scattered over several miles are mummified, rock-hard carcasses of Weddell and crabeater seals. The locations of the carcasses are highly unusual: many at elevations well above sea level and scattered throughout a desolate terrain. There are even carcasses frozen on top of the ice in the middle of lakes (Fig. 3.7-2). Radiocarbon dating of the remains is difficult, but scientists estimate that the carcasses are between 2,500 and 3,500 years old. Their travel inland so far from their coastal habitat is something of a mystery. Some scientists have suggested that they were on a suicidal migration or, more likely, their internal navigation system had gone awry. Some of the seals' tracks have been left intact, noting their direction of travel.

Credit: Z. Malolepszy

Figure 3.7-2: Mummified seal on Lake Bonney

Figure 3.7-3: Asgard Range, McMurdo Dry Valleys

Credit: Z. Malolepszy



Credit: Z. Malolepszy

Figure 3.7-4: Airdevronsix Icefalls
The East Antarctic Ice Sheet spills into the Dry Valleys at Wright Upper Glacier via the Airdevronsix Icefalls, with a vertical drop of over 1,000 feet.

Credit: Z. Malolepszy

Figure 3.7-5: Taylor Glacier
Looking west down Taylor Valley, this view from a helicopter shows the terminus of Taylor Glacier (also the location of Blood Falls) extending past Pearse Valley and the Friis Hills (back right). Several other alpine glaciers spill down the sides of the valley walls.

MICROCLIMATE ZONES AND PROCESSES AT THE SURFACE

Entering the McMurdo Dry Valleys is like being transported to an ancient world where geologic processes and time itself appear to have stopped. However, looks can be deceiving. On close inspection, the McMurdo Dry Valleys contain at least three distinct environmental zones (Fig. 3.6-8), each with a unique range of microclimate conditions, surface processes, and landscape ages. The Coastal Thaw Zone, Inland Mixed Zone, and Upland Stable Zone have different geographic, hydrological, and weather characteristics.

COASTAL THAW ZONE

Near the coast and in low-lying valley floors, streams cascade from the melting margins of glaciers and cut channels in loose debris. The soils are wet and, when alternately frozen and thawed, produce a dynamic land surface that changes annually. Surface deposits in this region are all relatively young, with most being less than approximately 18,000 years old.

Figure 3.7-6: Streams near Lake Hoare *Credit: Boston University*

INLAND MIXED ZONE

Traveling further inland, the widespread melting of the coastal thaw zone gives way to isolated patches of meltwater and a significant reduction in short-lived stream flow. Apart from a few sparse, locally wetted regions, soils are very dry with small areas where old landscapes, possibly millions of years old, exist at the surface.

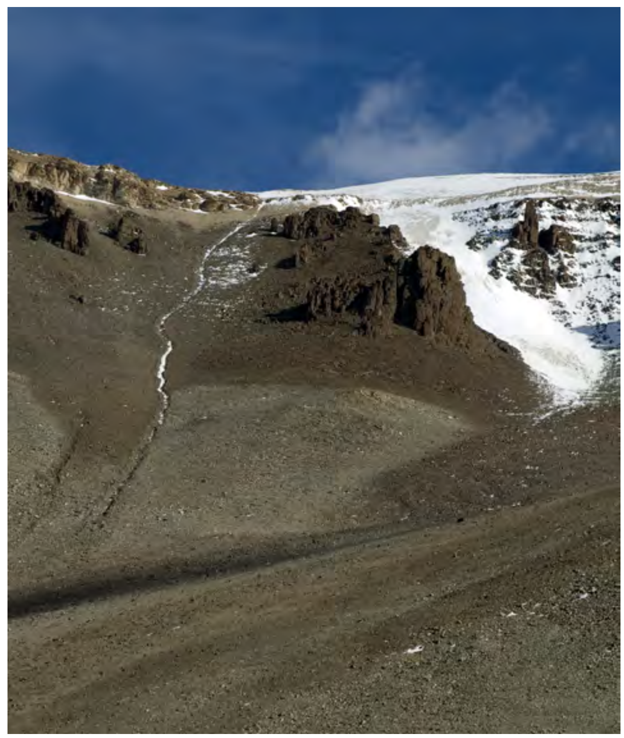


Figure 3.7-7: North slope of Taylor Valley *Credit: Boston University*

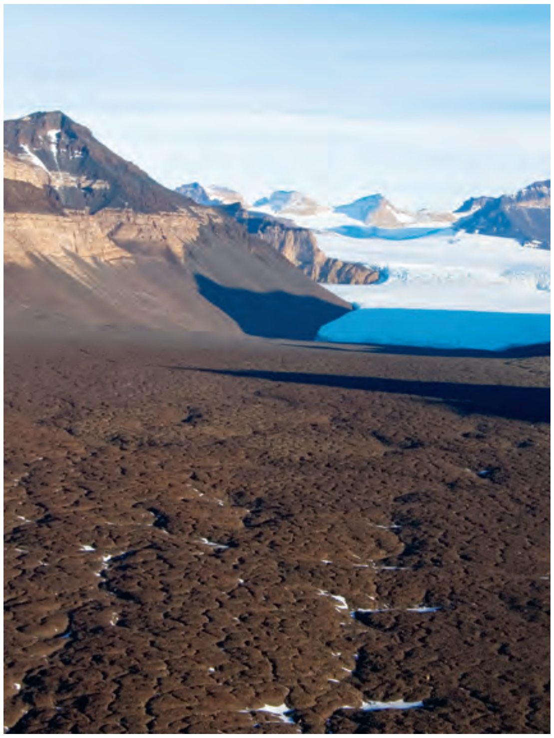
UPLAND STABLE ZONE

Continuing westward and flying higher into the McMurdo Dry Valleys offers a sense of awe and stillness. The glaciers here are too cold to melt, snow and ice evaporate, and soils are among the driest on earth. Air temperatures rarely, if ever, rise above 32° F. It is here, in the upland stable zone, that time seems to stand still. Volcanic ashes that dot the landscape demonstrate that the ground on which they landed has changed very little in the last 10-plus million years.

Dominating the landscape are channeled scablands from megafloods that formed beneath glacier ice more than 12.5 million years ago, ancient debris-covered glaciers that formed from the compaction of snow that fell more than 8.1 million years ago and thin moraines and glacial sediment drifts that mark the passage of alpine glaciers and ice sheets as far back as about 20 million years ago.

Even the large boulders that dot the landscape have remained in place for millions of years, essentially unchanged except for minor scour associated with katabatic winds, salt weathering, and episodic fracture that results when the rocks are heated and cooled. The upland stable zone represents a snapshot of the world as it existed before humans evolved.

The stability of landforms in the upland zone suggests that the East Antarctic Ice Sheet in this sector of Victoria Land has been stable for at least the last 10 million years. Ocean sediments in the Ross Sea record a more dynamic picture of the ice sheet. Recent modeling has demonstrated the feasibility of maintaining frozen conditions in the upland stable zone even with receded or collapsed ice sheets during climatic warm periods.



Credit: Boston University

Figure 3.7-8: Beacon Valley

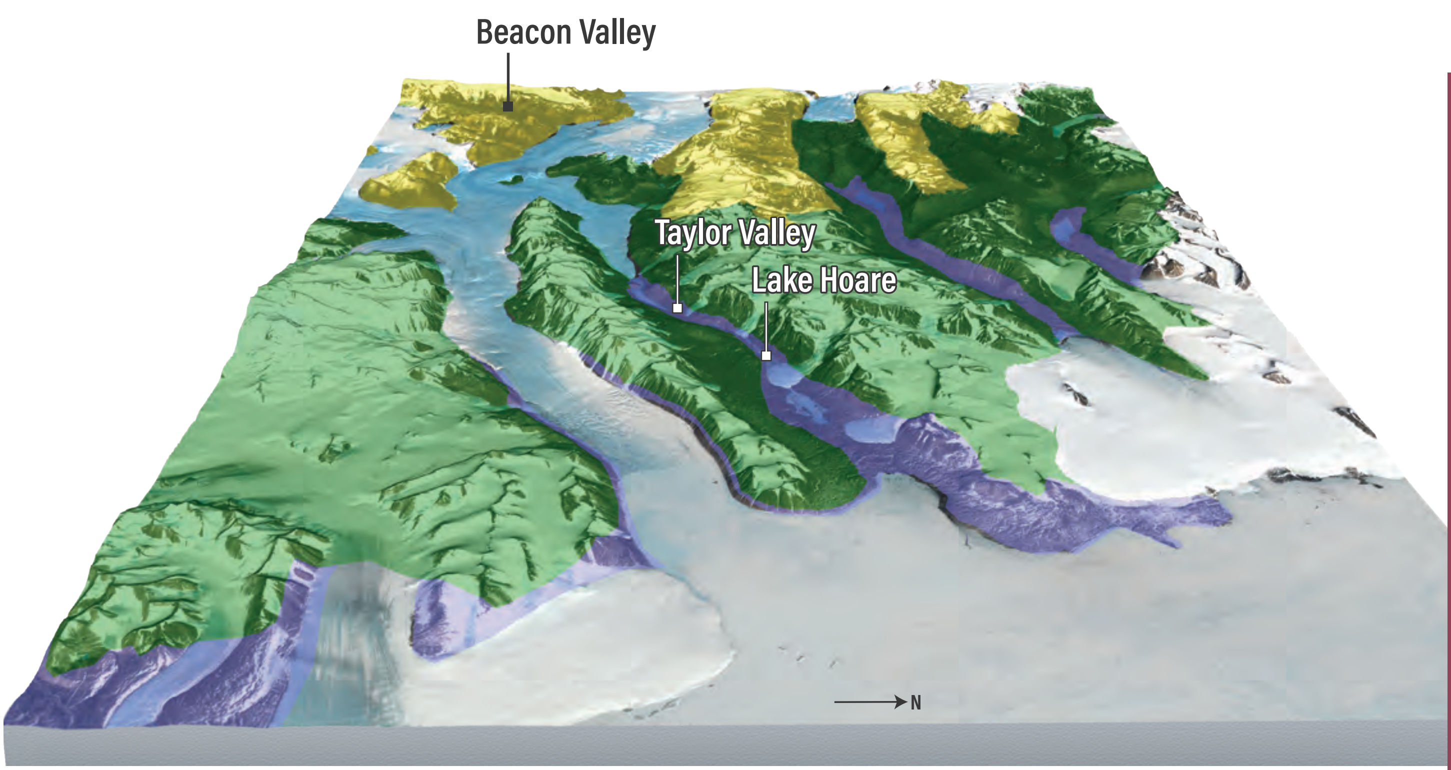


Figure 3.7-9: Dry Valleys Microclimate Zones

Credit: B. Herried

The three microclimate zones overlaid on a satellite image of the McMurdo Dry Valleys. The Coastal Thaw Zone (blue) drapes the valley bottoms and borders the coast, the Inland Mixed Zone (green) hugs the valley walls, while the Upland Stable Zone (yellow) is far in the higher and colder regions.

3.7.1 Dry Valleys Ecology

THE MCMURDO DRY VALLEYS

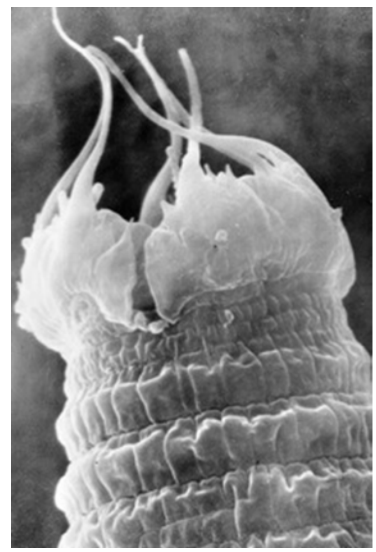
LIFE IN THE ROCKS AND SEDIMENT

In intense cold desert ecosystems, such as the McMurdo Dry Valleys, life is primarily hidden from the eye, as it is mostly microscopic. Because of this, these very special organisms remained unexplored until the mid-1900s. The harsh environment and low availability of carbon or water supports a simplified below-ground microscopic community of invertebrates. These rotifers, tardigrades (Fig. 3.7.1-1), nematodes, and microarthropods exist near lakes and short-lived streams, and even simpler communities exist in the arid soils (Fig. 3.7.1-3) that occupy the majority of the landscape.

Soil nematodes in the McMurdo Dry Valleys region generally represent the apex of two complementary food chains, one based on contemporary algal and moss productivity and one based on decomposition. Nematodes are by far the most dominant group, with one microbe-feeding species, Scottnema lindsayae (Fig. 3.7.1-2), occurring in high abundance in the drier, salty soils across the landscape. Near melt streams, where mosses and algae are found, is where the diversity is greatest, two other nematode species are found along with rotifers and tardigrades. Also, microarthopods (represented by a couple species of springtails and mites) are present under rocks and near water, at the base of glaciers, and across the landscape where snow melt is visible.

Credit: U. Nielsen

Figure 3.7.1-1: Tardigrade
Hypsibius antarcticus is a species of tardigrade found in the Dry Valleys. The common name of the tardigrade is water-bears, because of their slow, bear-like "walk." Tardigrades are often found in lichens and mosses and they, like nematodes and rotifers, can survive at extremely low temperatures, near –250° F, and can go decades without water.



Credit: D. Wall

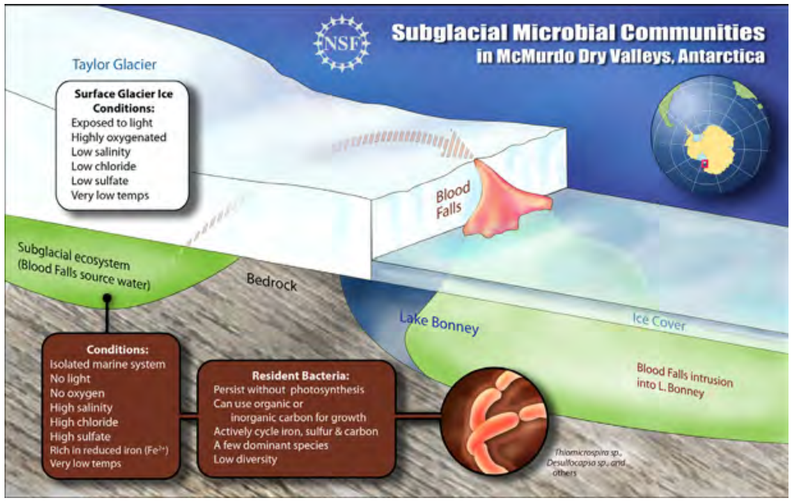
Figure 3.7.1-2: Nematode
A shot under a microscope of the dominant nematode found in the McMurdo Dry Valleys, *Scottnema lindsayae*, shows the organism close up. This species is endemic to Antarctica; it does not exist anywhere else on Earth. In fact, these nematodes are ideally suited for this environment because of their survival mechanisms in low temperatures and little moisture.

Figure 3.7.1-3: Soil sampling near Lake Hoare

Credit: H. Zedah

BLOOD FALLS

The bright red waterfall-like feature at the terminus of the Taylor Glacier is commonly referred to as Blood Falls (Fig. 3.7.1-5). The source of this distinct coloration is an iron-rich brine that seeps from below the glacier. Radar data suggest the source of the brine is located under Taylor Glacier approximately 2.5 miles up-glacier. It is still unclear what triggers the release of fluids to the surface. The chemistry and biology of this outflow have provided a glimpse into a unique sub-ice ecosystem and microbial community. As with the McMurdo Dry Valleys lakes, the salts in the brine came from the sea.



Credit: Z. Deretsky / NSF

Figure 3.7.1-4: Conditions in glacial and subglacial ecosystems around Blood Falls

Blood Falls is believed to be ancient, possibly formed during the last major advance of the Taylor Glacier about 1.5 million years ago. The microbial life detected in the brine retains its marine heritage as the majority of organisms are related to cold-loving marine organisms. Microorganisms below the glacier are isolated from the surface for extended periods, confined to life in permanently cold and dark conditions. Despite these extreme conditions, the microbes have survived and grow over extended isolation by consuming a limited supply of organic matter, fixing their own organic material from inorganic carbon, and by harnessing the chemical energy from nutrients in the underlying bedrock. These microbes grow very slowly, but the net result of their activity is the highly visible iron-stained face of the glacier. Blood Falls is an important "laboratory" under the ice available for scientists to ask new questions about these microorganisms living under the glaciers and what they may tell us about life on other icy worlds, such as the polar ice caps of Mars.

Figure 3.7.1-5: Blood Falls, Taylor Valley

Credit: E. Mockbee

3.7.2 Dry Valleys Hydrology, Glaciology, and Geomorphology

HYDROLOGY

There are five major lakes (Fig. 3.7.2-1) in the McMurdo Dry Valleys, all of which have perennial ice cover: Lakes Fryxell (Fig. 3.7.2-4), Hoare, and Bonney in Taylor Valley; Lake Vanda in Wright Valley; and Lake Vida (Fig. 3.7.2-2) in Victoria Valley. Also in the Dry Valleys are the Onyx River (Fig. 3.7.2-3) and several smaller lakes, such as Lake Chad, Don Juan Pond, and Mummy Pond. Lake Vida has the thickest ice cover of all the lakes (approximately 45 feet). Don Juan Pond is at the other extreme. It never freezes because of its high level of dissolved salts.

CHARACTERISTICS

The surfaces of these lakes are frozen much of the year; therefore, there is little mixing between surface and deep water. Some lakes are more than 80 feet deep with average depths of 25 to 60 feet. Because there is no outflow from any of the lakes, they have become very saline as salts from the sea have been transported by wind and precipitation over time. Since the advent of gauged stream flow measurements in 1969, it has become apparent that lake levels are rising in the McMurdo Dry Valleys. The increase is possibly a response to increased precipitation resulting from changes in climate.

HEAT AND LIFE

Despite the lakes' frozen surfaces, scientists have noted elevated water temperatures in the lakes, with some bottom waters as warm as 75° F. These high temperatures are due entirely to solar heating of the water through the ice and not to any heat from rocks beneath the lakes.

Explorations of lake bottoms by scuba-equipped researchers and remotely operated vehicles, including core sampling of bottom sediments, have disclosed the existence of algal life forms that are similar to the earliest forms of life found on Earth.

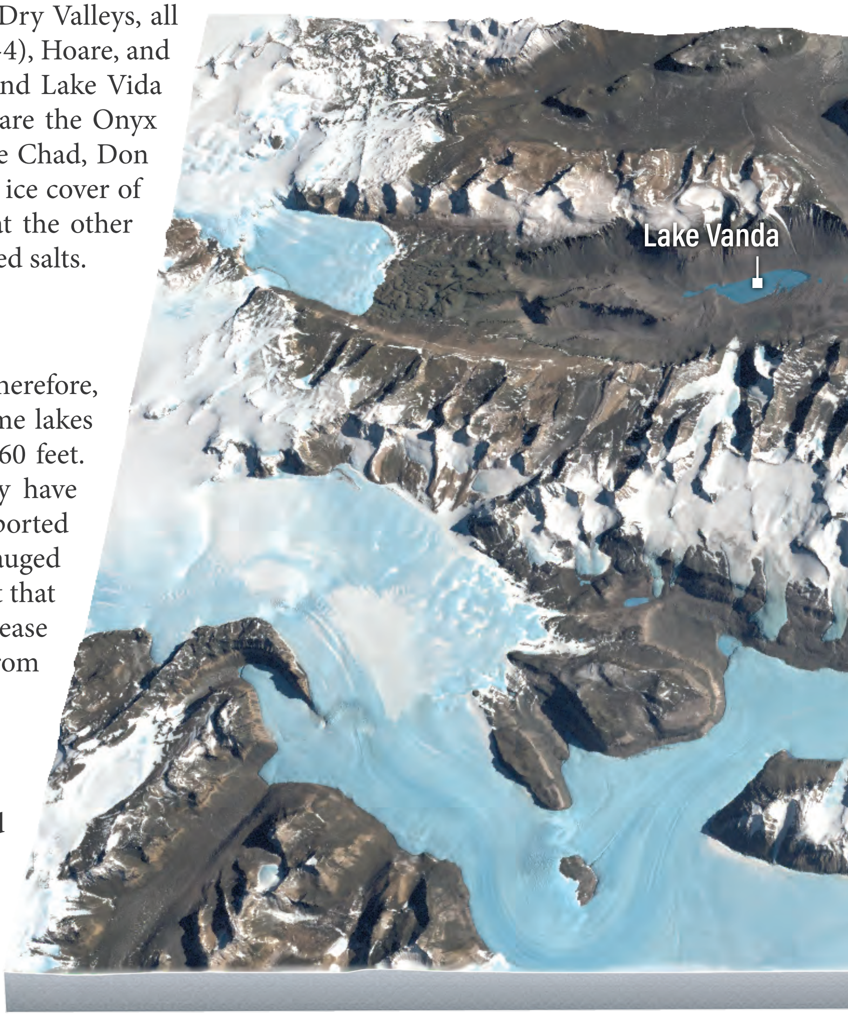


Figure 3.7.2-1: Lakes of the McMurdo Dry Valleys
The graphic above depicts the locations of the major lakes in the McMurdo Dry Valleys. The lakes are located in the bottom of the major ice-free valleys. The shores of these lakes are home to many of the field camps in the McMurdo Dry Valleys.

Credit: Imagery © 2010 DigitalGlobe, Inc.

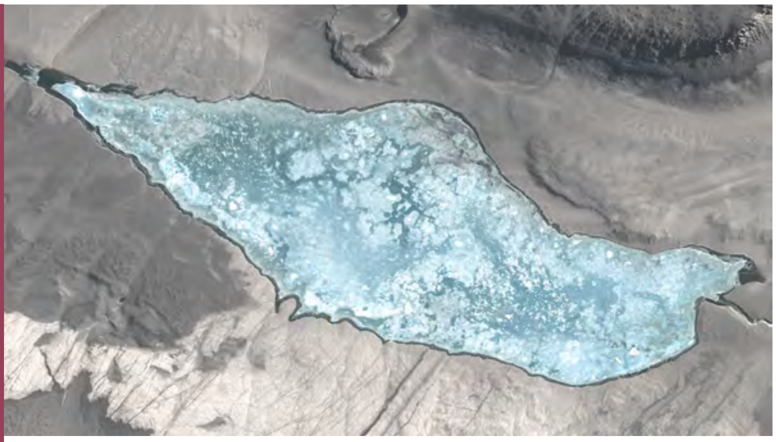
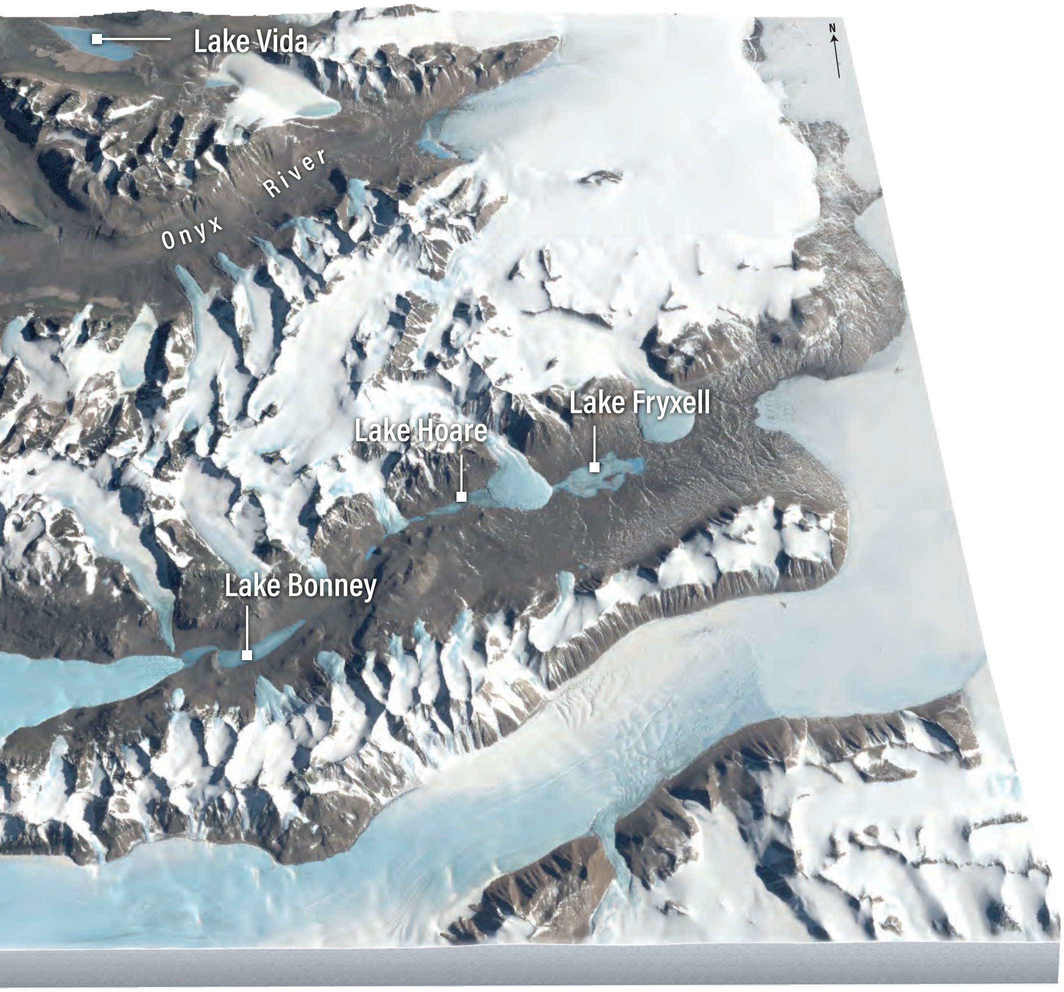


Figure 3.7.2-2: Lake Vida From space
Recently, the McMurdo Dry Valleys have been mapped at an unprecedented resolution, exemplified by this satellite image collected by the QuickBird sensor on Jan. 21, 2010, at a spatial resolution of approximately 8 feet. Using high-resolution imagery from multiple dates and years, scientists can detect ice coverage, lake level change, and lake seepage into the shoreline over time.

Figure 3.7.2-3: Onyx River

The Onyx River is the largest and longest river in Antarctica. It flows eastward as a meltwater stream through the Wright Valley during a few months of the Antarctic summer. The river is unusual in that it flows away from the ocean because the Wright Glacier blocks the entrance to the valley.

The Onyx River and its tributaries are monitored by multiple meteorological stations to study environmental conditions. Flow levels are highly variable, both during the day and between summers, with the river failing to reach the lake some years. In contrast, the Onyx River can cause significant erosion in flood years, and also supports microscopic life that sometimes causes extensive algal blooms.



Credit: B. Herried

Credit: B. Pellinen

Credit: J. Mastroianni

Figure 3.7.2-4: Lake Fryxell

A frozen Lake Fryxell sits adjacent to Canada Glacier in Taylor Valley. The clear blue ice can be several feet thick.

THE LABYRINTH

THE MCMURDO DRY VALLEYS: HYDROLOGY, GLACIOLOGY, AND GEOMORPHOLOGY

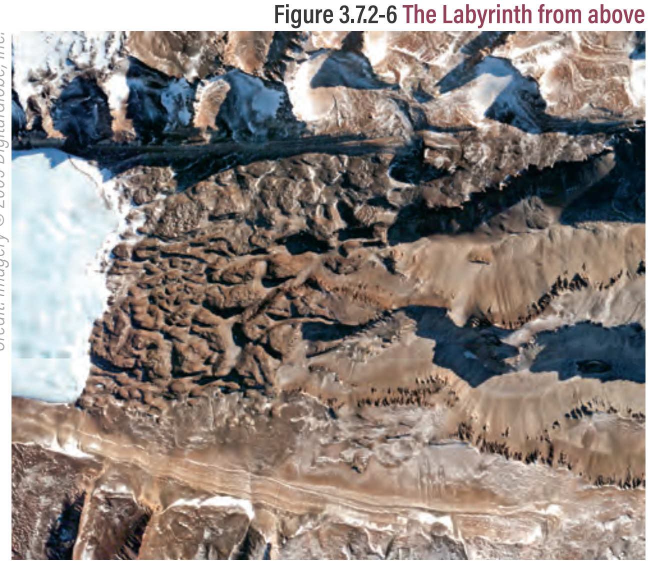
The Labyrinth, at the head of Wright Valley, is a spectacular series of bedrock channels and potholes carved by floodwaters beneath an expanded East Antarctic Ice Sheet between 12.4 million and 14.4 million years ago. It is one of several erosional features in the McMurdo Dry Valleys that reflect catastrophic drainage of one or more subglacial lakes from interior East Antarctica. When the Labyrinth formed (Fig. 3.7.2-7), the East Antarctic Ice Sheet covered all but the highest peaks in the Dry Valleys and terminated within the outer Ross Sea several hundred miles to the north.

The bedrock channels (Fig. 3.7.2-5) of the Labyrinth are incised in Ferrar Dolerite, the same rock that makes up the dark layers easily seen in the exposed rock of the McMurdo Dry Valleys. Most channels are more than 300 feet deep and several miles in length. They converge and diverge in a braided pattern. Potholes typically occur at channel confluences. Maximum discharge estimates are based on the size of boulders transported within the Labyrinth and range from 5.6 million to 7.8 million cubic feet per second. This discharge is in accord with the largest known floods worldwide and with the inferred discharge for megafloods that carved the well-known channeled scablands of western Washington state. Meltwater released from beneath the East Antarctic Ice Sheet on multiple occasions could have been a contributing factor in the evolution of modern deep-water ocean circulation patterns and the frozen Antarctic continent.

Figure 3.7.2-5: Incised channels

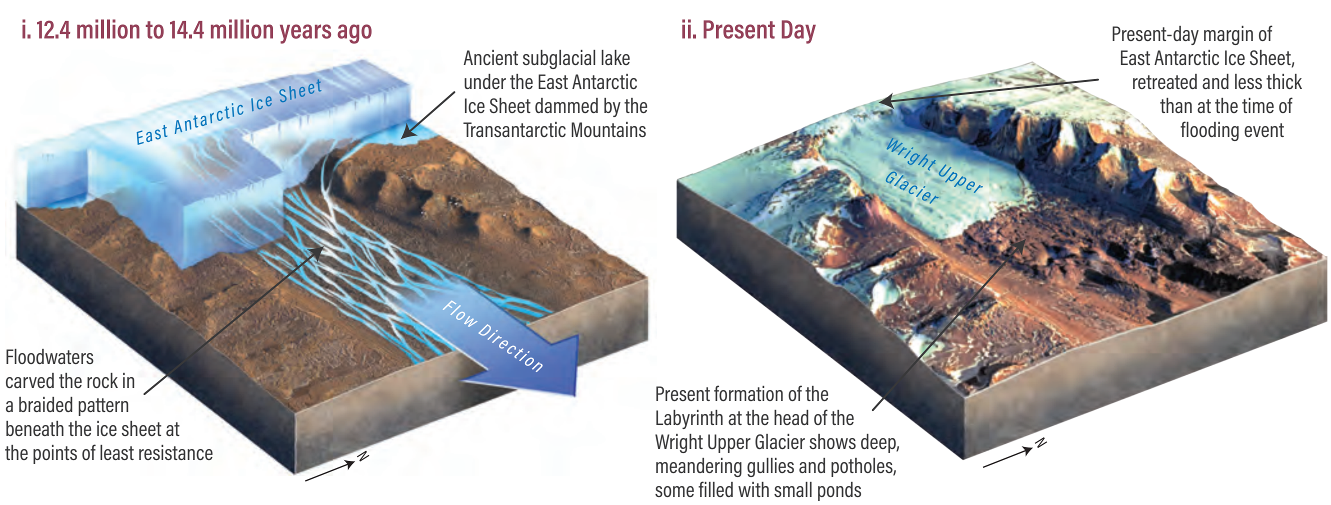
Credit: P. Rejcek

Figure 3.7.2-6 The Labyrinth from above



Credit: Imagery © 2009 DigitalGlobe, Inc.

Figure 3.7.2-7: Formation of the Labyrinth
i. The Antarctic Ice Sheet covered the entire area. A large subglacial lake burst over its lip and sculpted the rock underneath the ice.
ii. The present state of the Labyrinth reflects its erosional history.



Credit: C. Carter

DRY VALLEYS GLACIERS

The ridges flanking the McMurdo Dry Valleys support many small glaciers, most originating in shallow cirques along the ridge crests. Most of these glaciers flow only partway down the valley sides (Fig. 3.7.2-8), but several, like the Commonwealth and Canada glaciers (Fig. 3.7.2-9) in the lower Taylor Valley, extend onto the valley floors.

In more temperate latitudes, typical mountain glaciers contain considerable rock material that forms large moraines along their sides and termini. Unlike these, Antarctic Dry Valley glaciers are clean and white with a minimum of rock debris and few crevasses because of the slower movement of the ice in extreme cold. The glaciers also are older than those in temperate regions. For example, the Meserve Glacier in Wright Valley is believed to have existed for at least 3.4 million years.

Figure 3.7.2-8: Alpine Glaciers
Sollas Glacier (left) and Hughes Glacier (right) drop from the Kukri Hills on the south slope of Taylor Valley. These glaciers are part of the inland mixed zone and have small meltwater streams.

Credit: Z. Malolepszy

Figure 3.7.2-9: Canada Glacier
On the north slope of lower Taylor Valley spills the Canada Glacier. The glacier face measures up to 100 feet in some locations and feeds into Lake Hoare and Lake Fryxell.

Credit: A. Isern

PATTERNED GROUND

THE MCMURDO DRY VALLEYS: HYDROLOGY, GLACIOLOGY, AND GEOMORPHOLOGY

Patterned ground landforms generate intricate mosaics on the floors of many of the McMurdo Dry Valleys. These polygons are composed of a network of cracks that form when permafrost (frozen soil) shrinks during winter cooling and cracks—literally pulling itself apart. As the cracks intersect, they form familiar polygon shapes. These "thermal-contraction cracks" (Fig. 3.7.2-11) are usually less than 1 inch across. Sand or meltwater commonly trickles into the open fracture, filling the crack. Repeated cracking at the same location and repeated filling by sand or ice results in the formation of thick polygon boundaries (more than three feet wide) that are underlain by a wedge of ice or sand. When the permafrost warms in summer, it expands, pushing against these ice- or sand-wedges, and raising the polygon shoulders near the wedge (the same way that compressive ridges can form in a rug on a slippery floor). Figure 3.7.2-13 shows the processes in three types of polygons. Some thermal contraction cracks form annually, while mature Antarctic polygon networks can be thousands, or even millions, of years old.

Patterned ground is an important part of the environment of the McMurdo Dry Valleys. Variations in polygon shape and structure are very sensitive to environmental conditions. For that reason, modifications to polygon morphology are an ideal tool for studying the climate history of the McMurdo Dry Valleys. Thermal contraction cracks also can direct the flow of shallow groundwater and can even change the course of small streams and gullies.

Credit: J. Levy

Figure 3.7.2-10: Sand-wedge polygons
Polygons in Beacon Valley measure 50 feet in diameter.

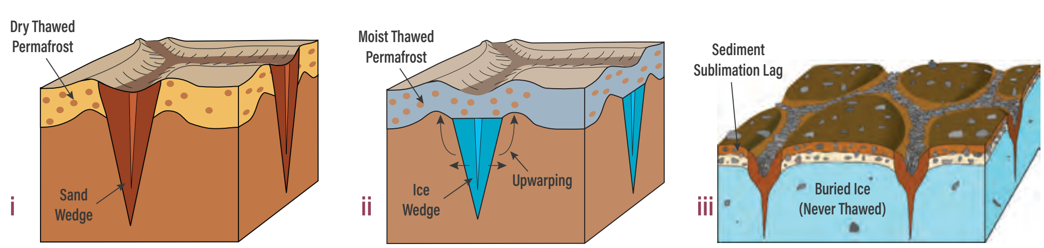
Credit: J. Levy

Figure 3.7.2-12: Sublimation polygons
Snow-filled polygons in Beacon Valley measure 30 to 50 feet in diameter. Sublimation polygons are unique to Antarctica.

Credit: J. Levy

Figure 3.7.2-11: Thermal-contraction cracks
An open thermal-contraction crack in buried ice permafrost in Beacon Valley. Sediment from the surface soil lag has winnowed into the fracture.

Figure 3.7.2-13: Polygon classification
Three polygon types found in the McMurdo Dry Valleys:
- i. Sand-wedge Polygon
- ii. Ice-wedge Polygon
- iii. Sublimation Polygon



Credit: Boston University

Figure 3.7.2-14: Feature reconstruction
Sand-wedge polygons redirecting gully streams in a zig-zag pattern and cross-cutting alluvial fans in Wright Valley.

Credit: J. Levy

Credit: J. Levy

Figure 3.7.2-15: Onyx River
Classic sand-wedge polygons along the Onyx River in Wright Valley. Dramatically upwarped shoulders can be seen on many polygons. Each polygon measures approximately 30 feet in diameter.

The landscape of many of the McMurdo Dry Valleys is rich in landforms that are created and modified by aeolian, or wind-shaped, processes. The slopes above the valley floors are littered with ventifacts, some of which are quite large (Fig. 3.7.2-16). A ventifact is formed by the abrasion of rocks when sand-sized particles transported by the wind collide with its surface and sculpt the rock into interesting forms. The orientations of the rock facets record the directions from which the most abrasive sand-transporting winds have originated.

Equally impressive in form are the boulders and rock outcrops that have been altered by cavernous weathering processes to create what is termed tafoni (Fig. 3.7.2-17). This type of weathering hollows out rocks from the inside where conditions are most favorable for disintegration of the rock. Wind removes the loose material released by the weathering process, with the resultant form often being quite fantastical in appearance.

On the valley floor below Bull Pass, in Wright Valley, one can see wind-formed ripples of gravel-sized material. These subtle but quite beautiful bedforms, evocative of small waves gently washing up on a beach (Fig. 3.7.2-18), represent an unusual member in the family of wind ripples: their form is strikingly different than those composed of sand. The gravel sediments are very poorly sorted, unlike any other rippled sediment. It is theorized that these ripples are formed as the gravel is rolled forward by sand that bombards it during high wind events in the austral fall and winter months. Records of particle movement suggest an incredibly slow and intermittent process of formation.

Credit: J.A. Gillies

Figure 3.7.2-16: Granite boulders
A large wind-abraded ventifact stands on the north slope of Wright Valley below Bull Pass. The ventifact measures approximately 20 inches high and the curved surface faces southwest. Boulders like this dot the landscape in Bull Pass.

Credit: J.A. Gillies

Figure 3.7.2-17: Tafoni processes
Cavernous weathering processes of a boulder in Bull Pass. The inside of the boulder is hollowed out first, creating a unique appearance. With the absence of water erosion, landforms are altered only by aeolian and tafoni processes in the McMurdo Dry Valleys.

Figure 3.7.2-18: Aeolian waves
The wind-formed gravel ripples of Wright Valley.

Credit: C. Kannen

MARTIAN ANALOG

THE MCMURDO DRY VALLEYS: HYDROLOGY, GLACIOLOGY, AND GEOMORPHOLOGY

Research has shown that the McMurdo Dry Valleys offer scientists more than a laboratory for studying Earth. The valleys are Earth's closest terrestrial analogs to Mars. Both Mars and the McMurdo Dry Valleys show modification from surface and subsurface ice, as well as wind erosion, salt weathering and possibly even water as shown by features associated with incision by short-lived streams (Fig. 3.7.2-19).

Indeed, the debris-covered glaciers, surface polygons and large-scale gullies of the stable upland zone and inland mixed zones of the McMurdo Dry Valleys appear strikingly similar to morphologic counterparts on Mars (Fig. 3.7.2-20). Antarctic researchers who study these landforms do so with an eye toward understanding Antarctic geomorphology as well as elucidating the range of potential surface processes that may be operating on Mars, both now and in the recent past.

EXTRATERRESTRIAL LIFE?

Another intriguing comparison concerns the potential for life on Mars: If it exists, could it be similar to organisms found in the coldest regions of the McMurdo Dry Valleys? The Mars-like topography and hyper-arid cold desert environmental conditions of the valleys also make them an ideal place for testing the maneuverability of unmanned rovers and for astronaut training and conditioning.

Credit: Boston University

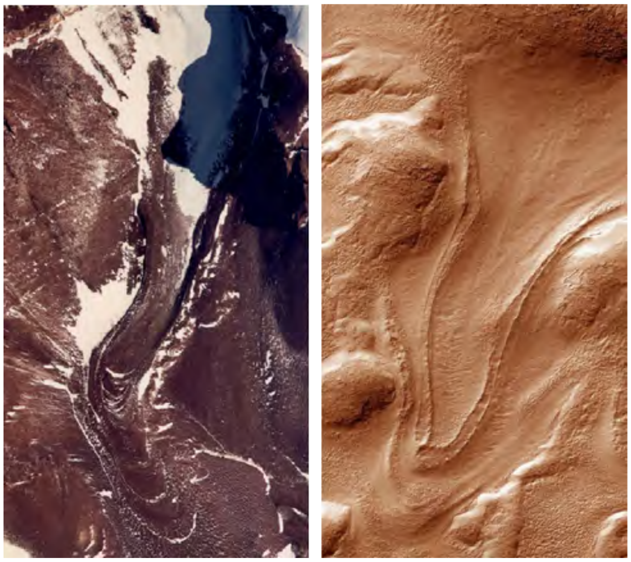


Figure 3.7.2-19: Subsurface ice
Left, an unnamed debris-covered glacier in upper Beacon Valley. Buried ice lies several feet below the surface.

Right, a lobed viscous-flow feature on the interior of an impact crater wall on Mars (M18/00898). The width of both features is similar at approximately 0.5 miles.

Credit: Boston University

Figure 3.7.2-20: Gullies
Left, a gully in the inland mixed zone on the north wall of Wright Valley. Windblown and precipitated snow accumulates preferentially in the alcoves and channels and melts during peak summer insolation to form active channels and to erode and deposit sediments in distal fan.

Right, a gully on the interior of a crater wall on Mars. The gully consists of an alcove at the top and a channel emerging from the alcove and descending down the crater wall and bifurcating on the distal sedimentary fan. Mars gullies are interpreted to represent conditions of Mars' recent past when climate change supported accumulation of snow in alcoves, melting and flow and erosion to produce channels and fans. Scale is similar for both images.

3.8 Mount Erebus

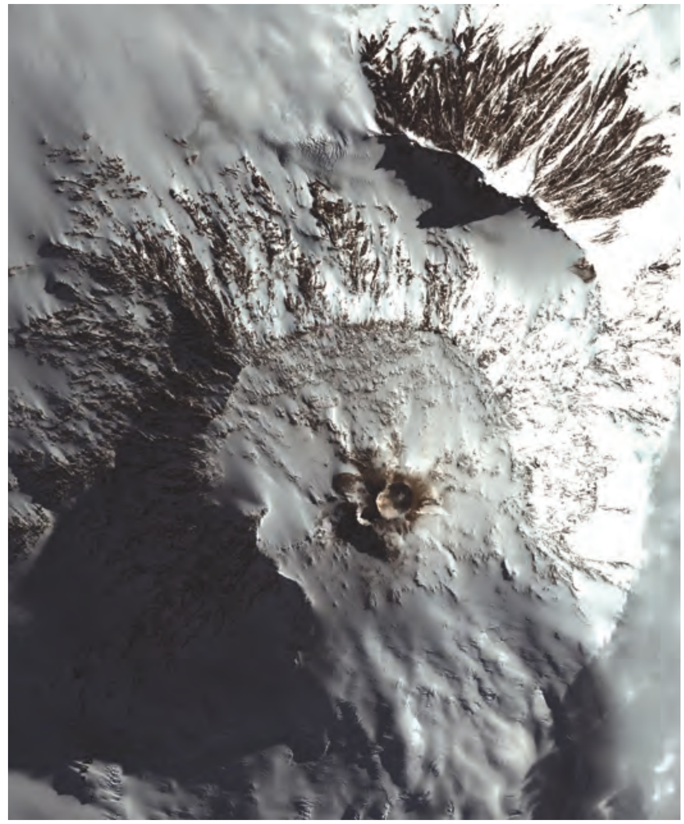
Ross Island is home to three volcanic peaks: the inactive Mount Terror and Mount Terra Nova, and the southernmost active volcano on Earth, Mount Erebus. Mount Erebus (Fig. 3.8-1) is believed to be the most active volcano in Antarctica. Its summit reaches the elevation of 12,448 feet.

Members of Shackleton's expedition first visited the summit of Mount Erebus in March 1908. The volcano constantly sputters hot gas and lava, resulting in sculpted ice caves and towers. Most volcanoes have a deep central chamber of molten rock that is typically capped by cooled, solid rock that makes the hot magma inaccessible. Mount Erebus is unique in Antarctica because the magma is exposed at the top of the volcano in a 1,700° F lake perhaps miles deep. The lava lake may be a periodic occurrence, depending on the degree of volcanic and thermal activity in the crater. For example, during Operation Deep Freeze in 1955, geologist Robert Forbes observed only solid rock fragments in the crater.

Strong eruptions from the crater have thrown lava bombs as high as 300 feet and as far as 250 feet onto the snow surface. Exploration of the slopes of Mount Erebus has unearthed several layers of ice interbedded with lava flows, which indicate that in the distant past, lava eruptions occurred over glaciers without completely melting the ice. Mount Erebus is remotely monitored most of the year using seismometers, tiltmeters, GPS signals, video cameras, and microphones.

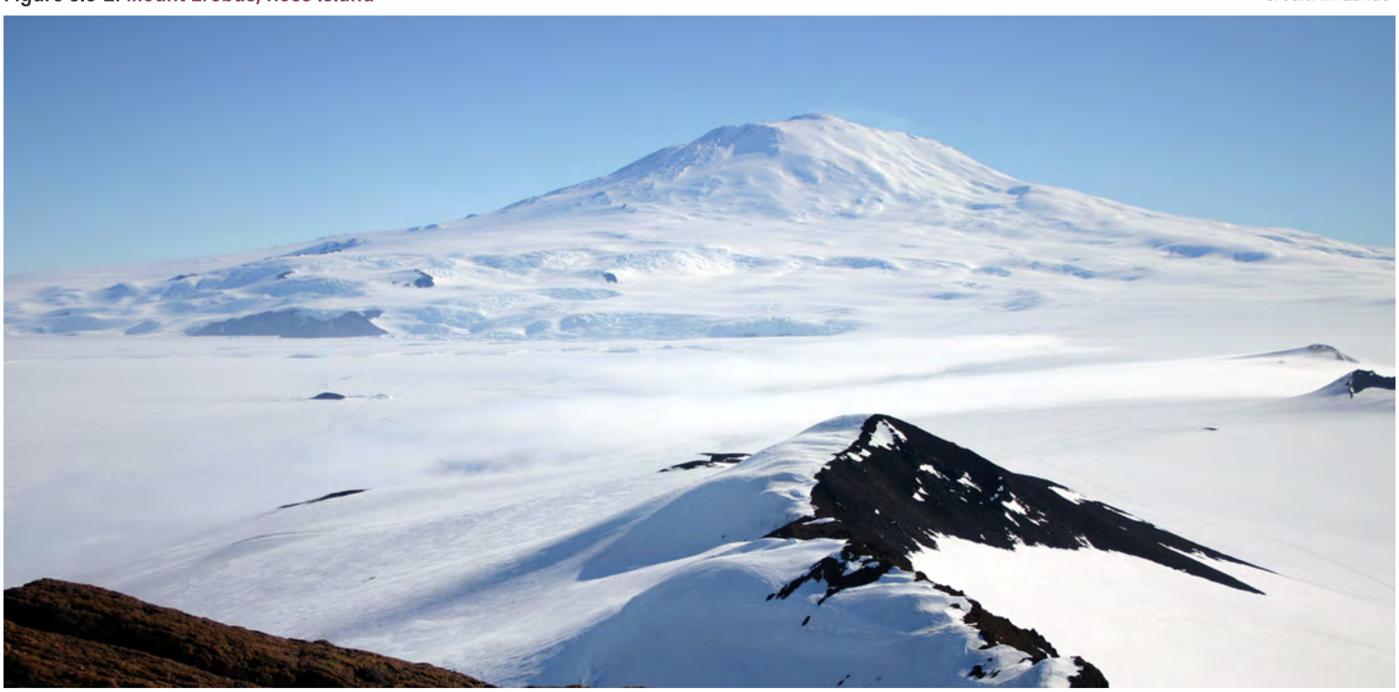
Figure 3.8-1: Molten mountain

A satellite shot of Mount Erebus taken by the QuickBird satellite on Oct. 29, 2005, shows the internal cone on a relatively cloud- and plume-free day. Fang Ridge (top right) is the remnant of an old caldera.



Credit: Imagery © 2005 DigitalGlobe, Inc.

Figure 3.8-2: Mount Erebus, Ross Island *Credit: M. LaRue*



3.9 Long Duration Balloons

Long duration balloons (LDB) have long been used to support scientific research because they provide a low-cost platform for conducting experiments and a stable platform for long duration instrument deployments. Long duration balloon deployments include the balloon, parachute, and a payload with scientific instruments (Fig. 3.9-1). Payloads are typically large instruments or clusters of instruments, with onboard computers, radio telemetry equipment, and ballast. Scientific balloons are constructed of polyethylene film, similar to that used for plastic bags, with a thickness akin to sandwich wrap. For standard, zero-pressure balloons the film is cut into sections and heat sealed to form the balloon. Balloons are vented at the bottom and, when launched, a measured amount of helium is put into the balloon to give it enough lift so it can ascend to the desired float altitude. As the balloon rises, the gas inside the balloon expands as the atmospheric pressure surrounding the balloon drops.

Long duration balloons can carry payloads of up to 8,000 pounds and can move at elevations of up to 26 miles. Higher elevations allow experiments to avoid atmospheric interference. Scientists on the ground can actively control the LDB payload during flight. After science measurements are completed, flight controllers send a radio command that separates the payload from the balloon. Payload separation creates a large tear in the balloon material releasing the remaining helium. The payload returns on a parachute so it can be retrieved (Fig. 3.9-2) and flown again. Data collected during LDB flights primarily support high-altitude atmospheric research, aeronomy, astrophysics, and geospace science.

USAP supports the NASA-led Long Duration Balloon (LDB) program in Antarctica. The program has been operating in Antarctica since 1989. Up to three payloads are supported annually. Each payload has a flight duration of approximately 20 to 40 days. Flying in a polar region during full sunlight limits altitude variations resulting from thermal changes due to day/night variations.

Credit: P. Somers

Figure 3.9-1: Balloon launch
A Long Duration Balloon (LDB) lifts off from McMurdo Ice Shelf. The balloon carries scientific instruments into the upper atmosphere where it circles around Antarctica at least once.

Credit: N. Duncan

Figure 3.9-2: Payload recovery
Long duration balloon payloads are designed to protect the instrument package as it returns to Earth by parachute. In this example, the GRIPS payload can be seen in its landing position prior to being disassembled so it can be returned to researchers. The Twin Otter aircraft shown provides passage for the instrumentation and passengers to these remote locations.

SECTION 4: PRESERVATION AND PROTECTION

Flags of the 12 treaty-signing nations wave over a bust of Admiral Byrd.

Credit: C. Linder

4.1 Environmental Stewardship and the Antarctic Treaty

USAP PRACTICES

Antarctica is commonly portrayed as the last true wilderness, yet it has not been a pristine environment since the early days of exploration. At some locations, particularly around long-standing research stations and popular tourism sites, evidence of human activity is clear. USAP recognizes the important responsibility for the protection of the environment from future impacts and remediation of areas that were previously impacted. The program makes great efforts to reduce and remove waste from Antarctica, and to prevent and clean up any releases of waste into the Antarctic environment.

Program-wide, the USAP logistics and environmental teams work together to minimize the impact of human activities (Fig. 4.1-1) on the Antarctic environment, including the incorporation of alternative energy sources (Fig. 4.1-2), fuel-efficient technologies, and advanced waste management and treatment facilities.

ENVIRONMENTAL PROTOCOL

With the adoption of the Protocol on Environmental Protection to the Antarctic Treaty in 1991 in Madrid, parties committed themselves "to the comprehensive protection of the Antarctic environment and dependent and associated ecosystems" and designated Antarctica "as a natural reserve, devoted to peace and science." The Protocol and its six Annexes achieve comprehensive protection for the Antarctic environment through rules on environmental protection and restrictions on human activities.

Each Treaty party is responsible for enforcing these rules through its own domestic legislation, and in the United States, protection of the Antarctic environment was established through the Antarctic Conservation Act of 1978 as amended by the Antarctic Science, Tourism, and Conservation Act of 1996 (ACA), and other pertinent regulations.

Credit: M. LaRue

Figure 4.1-1: Footsteps in the sand
To determine the impact of walking on the McMurdo Dry Valleys ecosystem, scientists analyzed soil samples gathered over a 10-year period in Taylor Valley. Samples were taken from paths that were highly trampled (50 to 80 walks per year), moderately trampled (10 to 15 walks per year), or undisturbed.

Populations of two species of nematodes were reduced by 52 percent and 76 percent in highly trampled paths. Differences were likely caused by decreased mortality and/or fecundity associated with human trampling effects. Even the low amount of foot traffic in this remote environment can impact nematode populations.

Figure 4.1-2: Power from the sun
The USAP has established five alternative energy stations in Taylor Valley, including those shown in the photos below. The wind and solar power systems save 60 drums of fuel per season, reduce air emissions from gas generators, and have greater indirect effects, such as reducing the number of helicopter flights into the McMurdo Dry Valleys and their associated emissions from flying fuel into the camps.

Credit: B. Koch, P. Rejcek, K. Hutchinson

4.2 Specially Protected Areas

MINIMIZING IMPACT

Area protection in Antarctica was first established in 1964, and through Annex V of the Protocol, a new system was created to allow for the designation of Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA). An area of Antarctica may be designated as an ASPA to protect outstanding environmental, scientific, historic, aesthetic, and/or wilderness values. An ACA permit is required to enter and conduct activities within an ASPA.

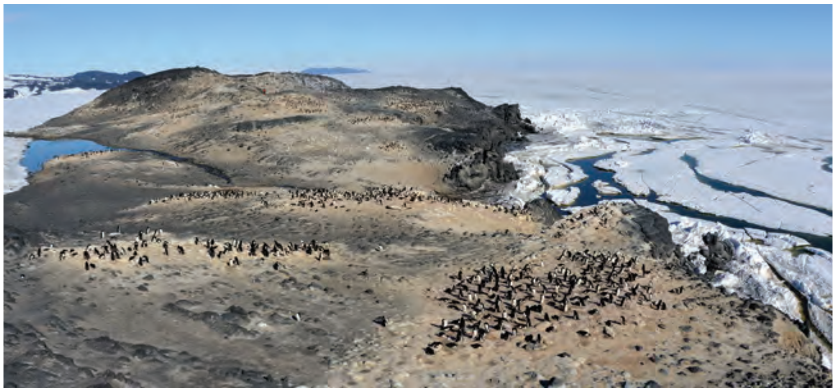
In designating each ASPA, Treaty parties adopt a specific management plan that is reviewed every five years to ensure that the values that merited the designation continue to be effectively protected. Currently, over 75 ASPAs have been designated across almost all regions of Antarctica. The following two ASPAs in the McMurdo region are sites where U.S. scientists have conducted research for many years.

CAPE ROYDS (ASPA 121)

Cape Royds (Fig. 4.2-1) supports the southernmost Adélie penguin colony and is a site of long-term scientific interest. Between 2,500 and 4,500 pairs of Adélie penguins breed (Fig. 4.2-2) at the Cape Royds colony depending on the sea ice extent. The long-term time series of population data on the penguin colony at Cape Royds is of unique and outstanding scientific value.

The ASPA protects the area by preventing unnecessary human disturbance and minimizing the possibility of introductions of non-native species that could damage the environment and the fauna.

Figure 4.2-1: Cape Royds Adélie Penguin Colony



Credit: P. Rejcek

Figure 4.2-2: Adélie penguin and chick

Credit: P. Rejcek

LOWER TAYLOR GLACIER AND BLOOD FALLS (ASPA 172)

Blood Falls (Fig. 4.2-3) is an iron-rich saline discharge at the terminus of the Taylor Glacier in the McMurdo Dry Valleys. The source of the discharge is a subglacial marine salt deposit and brine reservoir located beneath the Taylor Glacier, which is at least 1.5 million years old.

The unique characteristics of the Area provide an important site for research in glaciology, microbiology, and geochemistry.

The ASPA management plan includes protection of not only the falls and stream delta but also the subglacial environment.

Figure 4.2-3: Blood Falls, Taylor Valley *Credit: K. Falkner*

4.3 Specially Managed Areas

Areas where multiple parties and often non-governmental groups are conducting activities may be designated as Antarctic Specially Managed Areas (ASMA). The ASMA framework provides for the planning and coordination of activities to avoid possible conflicts, improve cooperation between parties, and minimize environmental impacts.

ASMAs may employ a variety of management tools including scientific, operations, and restricted zones, as well as Codes of Conduct, to manage certain activities. Additionally, an ASMA may include ASPAs or Historic Sites and Monuments within its boundary. The United States is a member of the management group of five Antarctic Specially Managed Areas including the McMurdo Dry Valleys (ASMA 2), Amundsen-Scott South Pole Station (ASMA 5), and Southwest Anvers Island and Palmer Basin (ASMA 7).

MCMURDO DRY VALLEYS (ASMA 2)

The McMurdo Dry Valleys was officially designated as ASMA 2 in 2004. This Area represents a cold desert ecosystem and is the largest relatively ice-free region in Antarctica. The arid, windy environment is of great importance to the study of climate change and the region serves as an important analogue for the conditions of ancient Earth and contemporary Mars, where similar climates may have dominated the evolution of landscape and biota.

The McMurdo Long Term Ecological Research site (LTER) within the ASMA has addressed important questions related to the influence of physical and biological constraints on the structure and function of this unique ecosystem. The Area has several unique features and includes multiple ASPAs including Blood Falls, an iron-rich saline discharge at the terminus of the Taylor Glacier. The Area is highly vulnerable to disturbance, and each year numerous scientists from multiple National Antarctic Programs work in the McMurdo Dry Valleys. Therefore, the Area requires special management (Figs. 4.3-1, 4.3-2) to ensure that its scientific, wilderness, ecological, and aesthetic values are protected.

Credit: A. Colhoun

Figure 4.3-1: Field collection
A researcher collects soil samples from a cleanup site on the shores of Lake Vida in the McMurdo Dry Valleys.

Credit: P. Rejcek

Figure 4.3-2: Management practices
USAP environmental staff reviews containment and waste management practices at a remote glacier camp in the McMurdo Dry Valleys.

AMUNDSEN-SCOTT SOUTH POLE STATION (ASMA 5)

Amundsen-Scott South Pole Station (ASMA 5) was officially designated in 2007. The ASMA encompasses an area of approximately 10,000 square miles around the geographic South Pole. The Area is located high up on the polar plateau on a shifting ice sheet at an elevation of 9,300 feet and is extremely cold, with a mean annual temperature of –56.7°F.

The South Pole holds enormous scientific value and the facilities at the South Pole Station provide opportunities for exceptional research and international collaborations. The remoteness of the South Pole station enables atmospheric research of the cleanest air on Earth (Fig. 4.3-3), astronomical and astrophysical observations, electromagnetic interference measurements, seismology, and neutrino detection.

The Area also contains significant historical value including the ceremonial South Pole and Amundsen's Tent from the first expedition to reach the Pole. The management plan of the Amundsen-Scott South Pole Station ASMA provides important guidelines that coordinate scientific, support, and non-governmental activities within the Area.

Credit: P. Rejcek

Figure 4.3-3: Clean air
The South Pole's Atmospheric Research Observatory (ARO) lies upwind of ASMA 5's Clean Air Sector. The ARO is one of the key sites in the world for collecting climatological data (such as gases and aerosols), and is void of any human influence due to its extreme remoteness and protection.

SOUTHWEST ANVERS ISLAND AND PALMER BASIN (ASMA 7)

Southwest Anvers Island and Palmer Basin (ASMA 7) was designated in 2008 and is the site of terrestrial and marine research, tourism, and potentially marine harvesting activities. Anvers Island is the largest and most southerly island in the Palmer Archipelago. The ASMA, located approximately 15 miles west of the Antarctic Peninsula, incorporates part of the heavily glaciated Anvers Island, including Palmer Station, as well as rocky coastline, island groups such as the Rosenthal and Joubin islands, and associated marine areas.

The Area provides breeding habitat for 11 species of seabirds and is an important foraging area for many species of birds, seals, and cetaceans. The Palmer Long Term Ecological Research site (LTER) within the ASMA has addressed important questions surrounding ecosystem research and environmental change for several decades, including sea ice dynamics and associated effects on the function of marine ecosystems, including breeding success. The terrestrial environment contains the two native Antarctic vascular plants and many invertebrate species. The Southwest Anvers Island and Palmer Basin ASMA management plan ensures the protection of scientific and ecological values through minimizing and coordinating use of the Area (Fig. 4.3-4).

Figure 4.3-4: Tourism and science
The Southwest Anvers Island and Palmer Basin area is a popular tourist destination in the austral summer season. A limited number of tourists are invited to Palmer Station from their tourist vessel to receive a tour of the station, as well as to learn about Antarctic Peninsula science and the U.S. Antarctic Program.

Credit: P. Rejcek

4.4 Ross Sea Region Marine Protected Area

BACKGROUND

Antarctica's Ross Sea in the Southern Ocean is considered by many scientists to be the last intact marine ecosystem on Earth. The largest marine protected area (MPA) on the planet was established in the Ross Sea region by unanimous agreement of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the part of the Antarctic Treaty System that oversees the waters around Antarctica. CCAMLR aims to conserve all Antarctic marine living resources, particularly by regulating commercial harvesting.

The Ross Sea region MPA (Fig. 4.4-1) is the world's largest MPA (598,000 square miles) and provides protection for critical habitats, including breeding and foraging grounds for a multitude of penguins, seals, krill, whales, and other species. It is estimated that 16,000 species make their home in the Ross Sea region. Many of these species are uniquely adapted to the cold environment.

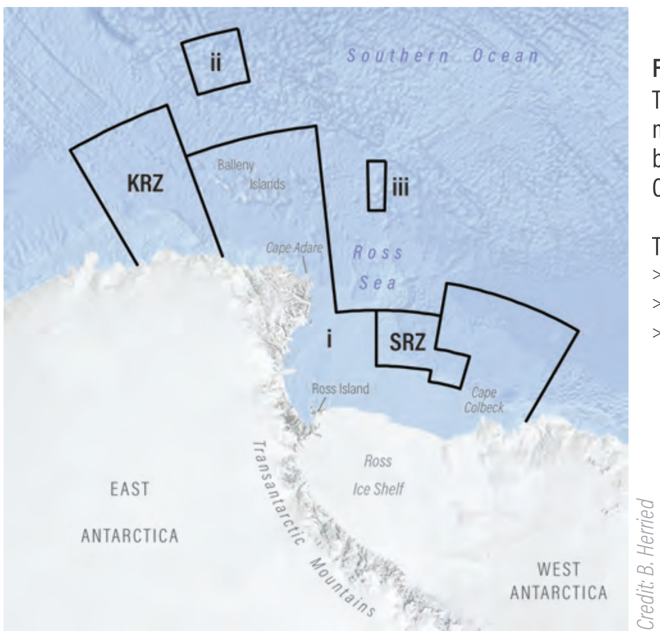


Figure 4.4-1: Ross Sea Region MPA
The Ross Sea region MPA is the world's largest marine protected area that was recently established by unanimous agreement by the Commission for the Conservation of Antarctic Marine Living Resources.

The Ross Sea MPA is composed of:
> General Protection Zone areas i, ii, iii
> Special Research Zone (SRZ)
> Krill Research Zone (KRZ)

IMPACTS

The RSRMPA limits, or entirely prohibits, certain activities to meet conservation, habitat protection, ecosystem monitoring, and fisheries management objectives. Seventy-two percent of the MPA is a "no-take" zone in which commercial fishing will be prohibited, while other sections permit some prescribed harvesting of Antarctic toothfish and krill for scientific research.

Scientists can compare organisms, populations, and communities in areas closed to fishing, or in which fishing activities are restricted, to those in areas that are open to fishing. The facilitation of such comparisons is intended to enable scientists to determine the relative impacts of fishing and other environmental impacts, such as those arising from climate change. This will increase understanding of the range of variables affecting the overall status and health of marine ecosystems. Protections will not decrease the total amount of Antarctic toothfish and krill that can be caught in the Ross Sea, but it will move the industry away from the crucial habitats on the continental shelf.

The agreement also establishes a 124,000-square-mile "krill research zone" that allows for research harvesting of krill but prohibit fishing for toothfish. Additionally, a 42,000-square-mile "special research zone" was established on the outside of the no-take zone, allowing harvesting of krill and toothfish that is purposefully designed to provide important information on these target populations.

4.5 Historic Sites and Monuments

EARLY ANTARCTIC EXPLORATION AND HISTORIC HUTS

An international focus on the scientific and geographical exploration of Antarctica began at the end of the 19th century and ended after World War I. During this period, the Antarctic continent was the focus of numerous international scientific and geographic expeditions. As a result, much of the continent's coastline was mapped, and significant areas of its interior were explored. These expeditions also generated large amounts of scientific data and sample collections that would be analyzed for many years after.

EARLY ACHIEVEMENT AND HARDSHIP

The first significant expedition to the McMurdo Sound region was the British National Antarctic (Discovery) Expedition of 1901–04 (Fig. 4.5-1) led by Robert Falcon Scott. This expedition launched the Antarctic careers of many who would become leading figures in early Antarctic exploration. Significant achievements included discovering the polar plateau and setting the farthest south record of 82° 17' S.

It is on this expedition that a rift between Robert Falcon Scott and Ernest Shackleton, then Third Officer for the expedition, is rumored to have taken place after Scott ordered Shackleton, suffering the lingering effects of scurvy acquired during the southward journey, home on the relief ship in 1903 because he felt that Shackleton "ought not to risk further hardships in his present state of health."

Credit: Royal Geographical Society

Figure 4.5-1: Southward
The Discovery Expedition, with skis and sleds, starting toward the South Pole.

Credit: Scott Polar Research Institute

Figure 4.5-2: Scott's 1910-1913 Expedition
Lieutenant Victor Campbell works at a desk in a small hut near Cape Adare.

Credit: Project Gutenberg

Figure 4.5-3: Planting the flag
Norwegian Roald Amundsen and his party were the first to reach the South Pole in December 1911.

RACE TO THE POLE

Shackleton returned in 1907 as the leader of the British National Antarctic (Nimrod) Expedition (1907–09). This expedition pioneered the Beardmore Glacier route toward the South Pole. During the expedition, the Southern Party set a new farthest south record of 88° 23' S, 97 miles from the Pole. The Northern Party reached the location of the South Magnetic Pole, which at that time was on land near Cape Adare. Today it is offshore in the Southern Ocean.

The Race to the Pole in 1911 was between the British National Antarctic (Terra Nova) Expedition of 1910 led by Scott and the Norwegian Expedition (1910–12) led by Roald Amundsen. Scott established his expedition base at Cape Evans on Ross Island, whereas Amundsen set up camp on the Ross Ice Shelf Barrier at the Bay of Whales. Amundsen's goal was to take advantage of a new route to the polar plateau via the Axel Heiberg Glacier.

Scott once again made his attempt along the established Beardmore Glacier route. Scott and four companions reached the South Pole via the Beardmore route on Jan. 17, 1912, 33 days after Amundsen (Fig. 4.5-3). All five died on the return journey from the Pole, through a combination of starvation and cold.

DISCOVERY HUT AT HUT POINT

HISTORIC SITES AND MONUMENTS

Credit: M. LaRue

Figure 4.5-4: Supplies in Discovery Hut

Discovery Hut was built during the British National Antarctic (Discovery) Expedition of 1901–04 (Fig. 4.5-5), and used again by other expeditions in 1907–09, 1910–13, and 1914–17. It was designed by an Australian member of Scott's expeditionary party and prefabricated in Sydney. Insulation in the hut was provided by felt placed between the inner and outer plank walls.

There is some disagreement as to whether Scott intended to have the expedition party reside in Discovery Hut or whether it was solely built for storing food, fuel, and equipment (Fig. 4.5-4). In either case, permanent sleeping quarters were never erected. Discovery Hut was a crucial safe haven and storehouse of food and equipment for four Antarctic expeditions. Without it, many of the explorers would have perished on their return from journeys south.

Subsequent to the Discovery Expedition, when Shackleton returned to McMurdo Sound in February 1908 during the Nimrod Expedition, he discovered that the hut door had opened, most likely as a result of a southerly blizzard, and the hut was filled with snow and ice. Similarly, members of the Terra Nova Expedition found Discovery Hut full of snow and ice in 1911. Scott's team removed the snow from Discovery Hut and used the hut during 1911 and 1912 as a staging and rendezvous point for field parties trekking south to lay caches for the Race to the Pole.

Figure 4.5-5: Preparation for the journey
Discovery Hut in 1902, with the main ship, *Discovery,* at anchor in Winter Quarters Bay. The future site of McMurdo Station is in the background.

Credit: Canterbury Museum

NIMROD HUT AT CAPE ROYDS

HISTORIC SITES AND MONUMENTS

Some of the earliest advances in the study of earth sciences, meteorology, flora, and fauna in Antarctica are associated with the British National Antarctic (Nimrod) Expedition of 1907–09. After having failed to land on King Edward VII Land, Ernest Shackleton decided to build the Nimrod Expedition hut (Fig. 4.5-6) at Cape Royds, a small promontory 23 miles north of Hut Point. Construction of the prefabricated hut took 10 days, plus an additional three weeks to insulate it. The hut was lit using an acetylene gas plant, and coal stoves provided heat.

In 2006, five crates of MacKinlay's Rare Old Highland Malt Whisky were found buried under the hut. One crate was sent to Canterbury Museum in Christchurch, New Zealand, to undergo restoration and analysis. Samples were sent to Whyte & Mackay Ltd., the distiller who took over MacKinlay's operations. Whyte & MacKay Ltd. succeeded in duplicating "Shackleton's" whisky and has produced two versions for public sale.

The Nimrod expedition made many successful journeys from the hut. These include the first ascent of Mount Erebus and the first trek to the South Magnetic Pole. The main objective of the expedition was to reach the South Pole. As a testament to Shackleton's excellent leadership capabilities, his team turned around at 88° 23' S, 97 miles from the Pole, as it was clear that they could reach their objective, but it was unlikely they would safely return to Cape Royds.

Credit: New Zealand Antarctic Heritage Trust

Figure 4.5-6: **Nimrod Hut**
Interior of Ernest Shackleton's hut at Cape Royds from the British National Antarctic (Nimrod) Expedition of 1907–09.

TERRA NOVA HUT AT CAPE EVANS

HISTORIC SITES AND MONUMENTS

Scott's Hut (Terra Nova Hut) was built in 1911 by the ill-fated British Antarctic Expedition of 1910–13. Twenty-five men of the Terra Nova shore party shared the hut and used it as the base for their attempt to reach the South Pole. The hut (Fig. 4.5-8) was prefabricated in England and brought south on their ship, the Terra Nova.

The hut was insulated using seaweed sewn into a quilt that was placed between the inner and outer walls. The roof was composed of three layers of planking separated by two layers of rubber and quilted seaweed. The acetylene gas lighting system can still be seen in the hut today. Coal stoves supplied heat for the hut.

Connected to Scott's Hut is a stable that housed the 19 Siberian ponies that were used, rather unsuccessfully, by the expedition to move cache stores on the route to the South Pole. Scott was an officer in the Royal Navy and, as such, the hut was divided into separate areas for crew and officers. This is contrasted with the Nimrod Hut at Cape Royds where Shackleton, a seaman of the merchant marine, lived in the same space as his men.

Credit: Z. Malolepszy

Figure 4.5-7: Rations
Supplies left at the Terra Nova Hut at Cape Evans by expedition members from the Heroic Age of Antarctic exploration.

After a season of laying depots of food and fuel along the route to the South Pole, which coincides with the current route flown from McMurdo to Amundsen-Scott South Pole stations, Scott and four other men reached the Pole on Jan. 17, 1912. Upon their return, the men found that their stores of cooking oil had diminished from evaporation. Exhaustion, hypothermia, and lack of fuel resulted in the death of all members of the party, three of whom were found within one day's trek of One-Ton Depot. Scott's Hut was abandoned in 1913 and left well supplied with stores that Shackleton's "Lost Party" used to survive after their vessel, the Aurora, broke and went adrift in May 1915.

Credit: R. Maestas

Figure 4.5-8: Hut exterior
External view of the Terra Nova Hut at Cape Evans.

PRESERVING HISTORY

HISTORIC SITES AND MONUMENTS

Sites or monuments of recognized historic value, such as the huts from the turn of the 20th Century, are protected and preserved through the designation of Historic Sites and Monuments (HSM) under Annex V of the Protocol. Historic Sites and Monuments can be designated under the Antarctic Treaty to commemorate and protect sites associated with events important to the history of science and exploration of Antarctica.

In addition, all pre-1958 historic remains and artifacts present in Antarctica before the signing of the Antarctic Treaty automatically receive special protection. The United States proposed several HSMs that were adopted by the Antarctic Treaty, including a monument located at McMurdo Station which commemorates the polar achievements of Richard E. Byrd (HSM 54), and East Base (HSM 55), located on Stonington Island in Marguerite Bay, western Antarctic Peninsula.

Credit: P. Rejcek

Figure 4.5-9: Admiral Byrd HSM

RICHARD E. BYRD HISTORIC MONUMENT

Rear Admiral Richard Evelyn Bird, Jr. (1888–1957) was a pioneering U.S. explorer and aviator. Admiral Byrd led the First Antarctic Expedition from 1928–1930, setting up a base camp named "Little America" on the Ross Ice Shelf.

During this expedition on Nov. 19, 1929, Byrd completed the first flight to the South Pole. Admiral Byrd went on to lead the Second Antarctic Expedition, the U.S. Antarctic Service Expedition, Operation Highjump, and Operation Deep Freeze I, which established the permanent U.S. presence in Antarctica.

A bronze bust (Fig. 4.5-9) of Admiral Byrd was erected at McMurdo Station in 1965 to commemorate his contributions to Antarctic science and exploration.

Credit: USAP

Figure 4.5-10: Huts at East Base

EAST BASE, STONINGTON ISLAND

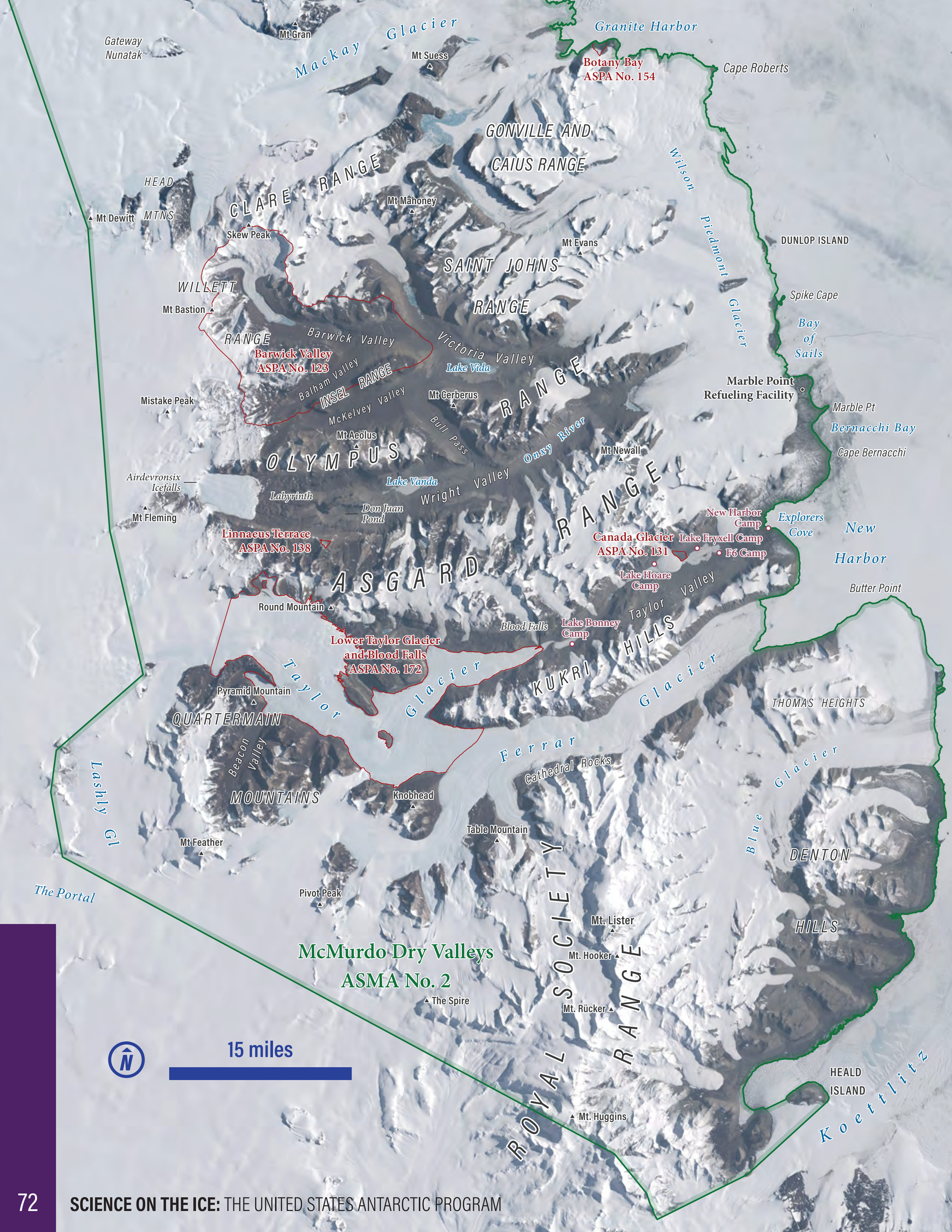
East Base (Fig. 4.5-10) was established by the U.S. Antarctic Service Expedition (1939–1941). The location of Stonington Island, paired with a glacial ramp to the continent, provided an excellent location to map the unexplored lower Antarctic Peninsula.

East Base was subsequently used by Norwegian-born U.S. citizen Finn Ronne when he led the Ronne Antarctic Research Expedition between 1947–1948 for further exploration and mapping of this region. This expedition, which employed three airplanes, mapped previously unknown land totaling 450,000 square miles, and charted the Weddell Sea coastline, the last uncharted coastline in the world.

SECTION 5: MAPS AND ACKNOWLEDGMENTS

Emperor Penguins stand tall on the sea ice.


Credit: G. Grant



Mt Gran
Gateway Nunatak
Mackay Glacier
Mt Suess
Granite Harbor
Botany Bay ASPA No. 154
Cape Roberts
GONVILLE AND CAIUS RANGE
Wilson Piedmont Glacier
HEAD MTNS
Mt Dewitt
CLARE RANGE
Mt Mahoney
Skew Peak
Mt Evans
DUNLOP ISLAND
SAINT JOHNS RANGE
WILLETT RANGE
Mt Bastion
Spike Cape
Bay of Sails
Barwick Valley
Victoria Valley
Barwick Valley ASPA No. 123
Lake Vida
Balham Valley
INSEL RANGE
Marble Point Refueling Facility
Mistake Peak
McKelvey Valley
Mt Cerberus
Marble Pt
Bernacchi Bay
Bull Pass
Onxy River
Mt Aeolus
OLYMPUS RANGE
Mt Newall
Cape Bernacchi
Airdevronsix Icefalls
Lake Vanda
Wright Valley
Labyrinth
Mt Fleming
Don Juan Pond
New Harbor Camp
Explorers Cove
New Harbor
Linnaeus Terrace ASPA No. 138
Canada Glacier ASPA No. 131
Lake Fryxell Camp
F6 Camp
ASGARD RANGE
Lake Hoare Camp
Butter Point
Round Mountain
Taylor Valley
Blood Falls
Lake Bonney Camp
Lower Taylor Glacier and Blood Falls ASPA No. 172
KUKRI HILLS
Taylor Glacier
Pyramid Mountain
THOMAS HEIGHTS
QUARTERMAIN MOUNTAINS
Beacon Valley
Ferrar Glacier
Lashly Gl
Cathedral Rocks
Blue Glacier
Knobhead
Table Mountain
Mt Feather
DENTON HILLS
The Portal
Pivot Peak
Mt. Lister
McMurdo Dry Valleys ASMA No. 2
Mt. Hooker
ROYAL SOCIETY RANGE
The Spire
Mt. Rücker
N
15 miles
HEALD ISLAND
Mt. Huggins
Koettlitz

Credit: B. Herried

5.2 USAP Logistics Chain

2500 passengers/year
move between Christchurch and McMurdo

~400 passengers each summer
move between McMurdo and South Pole

3 trips to South Pole per summer season delivering about
140-170K gallons of 40 fuel/trip

2.5M lbs/year
between Christchurch and McMurdo

1.8M lbs/year
of cargo moves via commercial air/commercial surface from Port Hueneme to Christchurch

Ice pier
is used for vessel operations at McMurdo

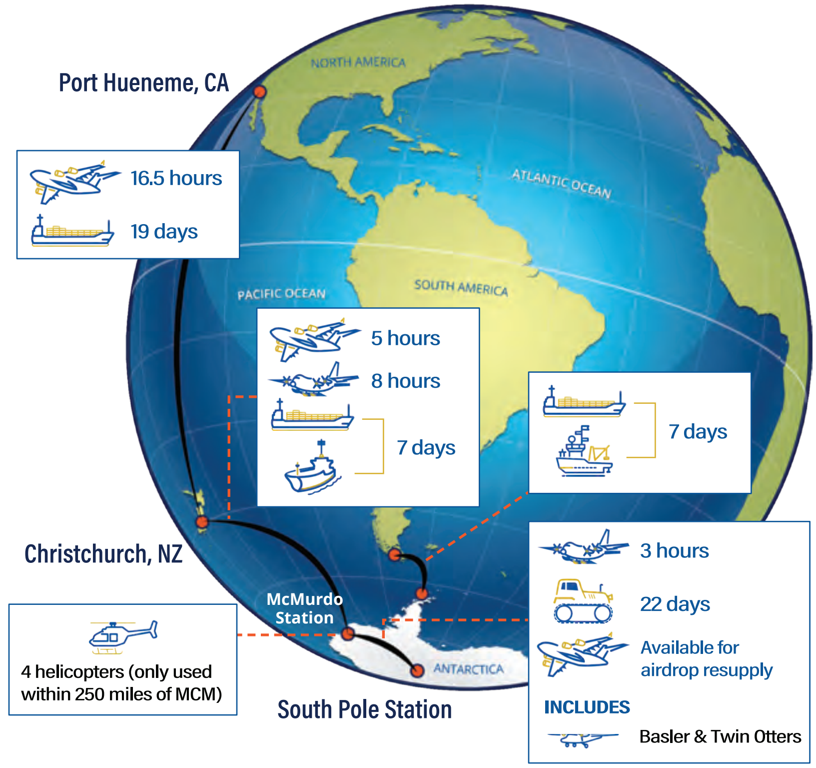
Avg. ~9M lbs/year
offloaded at McMurdo

2 runways
are used for airlift at McMurdo – Phoenix and Williams (ski aircraft only at Williams) airfields, Phoenix is maintained to be operational year-round, if needed

Winter flights to/from McMurdo occur each August (3-5 missions)

March-September is considered Winter and there are no planned flights in out of South Pole during that time....and very few in/out of McMurdo

Summer “Season” starts in October and runs through February each year



Air Force C-17
Traverse
Cargo vessel
Fixed-wing aircraft
LC-130
Helecopter
Tanker
Research vessel

USAP PARTNERS FOR TRANSPORTATION AND LOGISTICS

1. U.S. Air Force (airlift)
2. U.S. Navy (stevedore operations)
3. U.S. Army (modular causeway if ice pier fails)
4. New Zealand Defense Force (ground distribution at McMurdo, airport ops in Christchurch and 757/C-130 airlift support)
5. Italian Air Force (C-130 airlift support)
6. Antarctic Support contract (Leidos)
7. Military Sealift Command
8. Air New Zealand (Commercial Air Cargo to NZ)
9. Various commercial shipping operators (Commercial Surface Cargo to NZ)
10. Kenn Borek Air
11. Air Center Helicopters Inc.
12. U.S. Navy Naval Information Warfare Center (all weather forecasting and air traffic control)

Credit: NSF

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Credit: Joshua Swanson