antarctic journal OF THE UNITED STATES

May/June 1975
Vol. X—No. 3

National Science Foundation

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Antarctic Journal of the United States, established in 1966, reports on U.S. activities in Antarctica and related activities elsewhere, and on trends in the U.S. antarctic program. It is published every other month by the Office of Polar Programs, National Science Foundation, Washington, D.C. 20550, with the assistance of the Department of Defense.

Although the National Science Foundation attempts internally to make papers published in *Antarctic Journal* error-free, papers generally are not refereed for scientific content or merit.

Subscription matters, including address changes and new subscriptions ($8.60 per six issues, domestic; $10.75 per six issues, foreign; price of single copies varies), should be addressed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

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Photo by T. E. DeLaca

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Research ship *Hero* is 7 years old

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Arlington, Virginia 22209

In 1820 five ships from Stonington, Connecticut, crossed the Drake Passage to expand their hunt for southern fur seals. From an anchorage in the South Shetland Islands, the expedition leader sent Nathaniel B. Palmer to look for seals farther south aboard the 9-meter sloop *Hero.* Palmer is credited with having viewed the antarctic mainland on this voyage; he was one of the first persons to do so.

On March 28, 1968, a successor to Palmer's sloop was launched at South Bristol, Maine, for the National Science Foundation. This modern-day *Hero* is a diesel-driven, sail-equipped wooden research trawler with a length of 38 meters and a beam of 9.3 meters. The ice-strengthened *Hero* was built especially for work along the Antarctic Peninsula in conjunction with the U.S. research station Palmer, on Anvers Island.

Including a North Atlantic shakedown, which took the ship into Baffin Bay pack ice, and the

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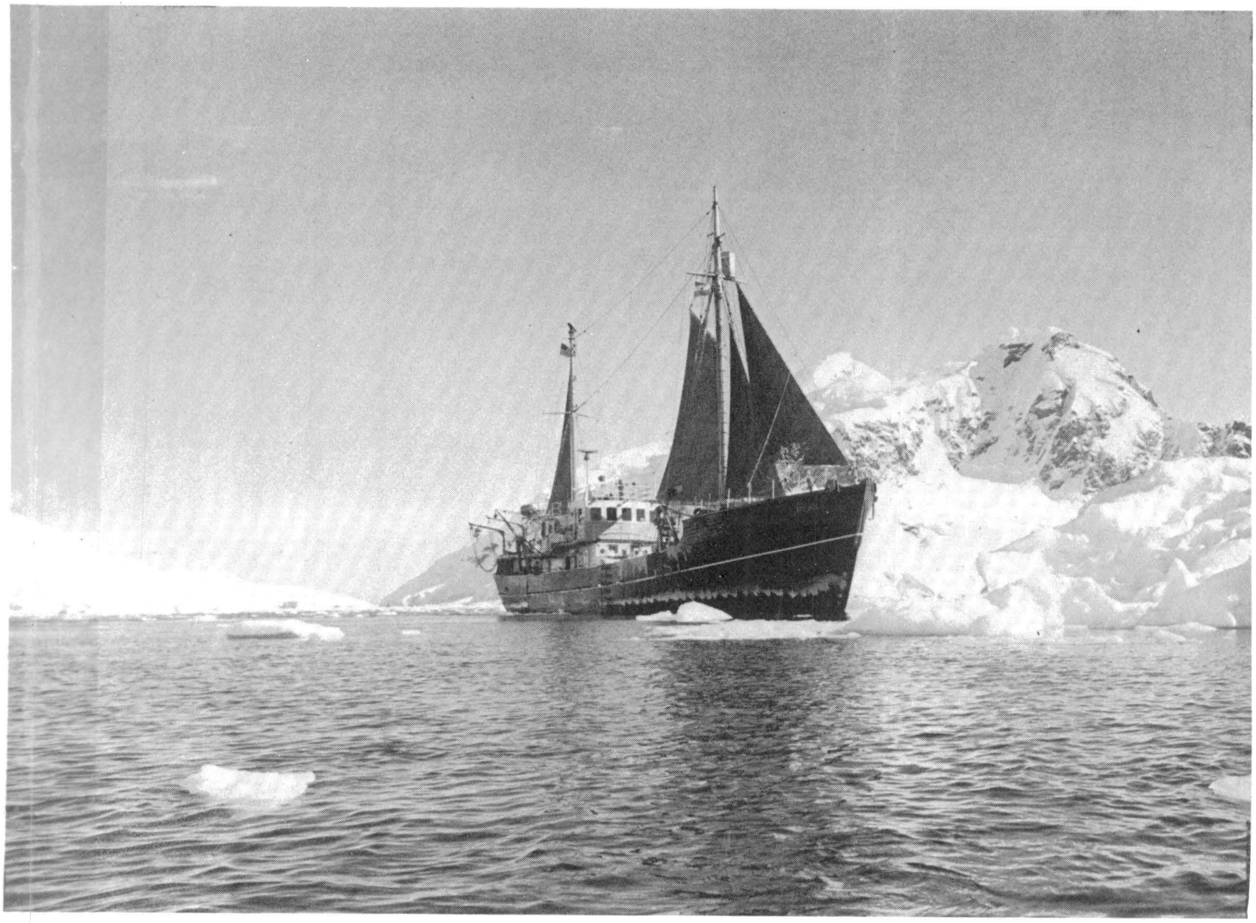
Mr. Mulcahy, associate editor of *Sea Technology,* served aboard R/V *Hero* from October 1971 to April 1974.



W. R. Curtsinger

R/V *Hero* under full sail along the Antarctic Peninsula.

initial cruise south (research was performed on both trips), *Hero* has made 36 cruises in support of research along the west side of the Antarctic Peninsula, in the South Shetlands, and along both coasts of southern South America. The ship has been essential to the operation of Palmer Station. It has left the Southern Hemisphere only once: for an overhaul in Long Beach, California, in 1974.

Hero's yearly pattern of operation is a marriage of convenience between research opportunities and logistics needs. Between November or December and April, her primary mission is generally to extend research far to the south: this includes transport of researchers to points in the South Shetlands and along the Antarctic Peninsula, resupply and personnel turnover at Palmer Station, and trawling operations both during and in addition to the logistics voyages. Marine and terrestrial biology, geology, and glaciology receive the greatest attention. In the austral winter, *Hero* operates along the coasts of southern South America, principally in support of biological projects. As much as possible, overhauls are scheduled to take place in the austral winter, when ice prevents most antarctic operations.

Unlike *Eltanin* (now *Islas Orcadas),* whose 10 years of circumantarctic research achievements are recorded in the May/June 1973 *Antarctic Journal, Hero* has not had the objective of systematically surveying all aspects of a defined area, and there would be little use in presenting a series of articles summarizing its accomplishments over the years. However, summaries of each cruise have appeared in *Antarctic Journal,* and scientific results have appeared in standard journals. Also, two articles in this issue present the results of specific research efforts that have taken place during one or more *Hero* cruises.

An article in the May/June 1968 *Antarctic Journal* (pages 53 to 60) describes the ship, its area of operation, and the present Palmer Station, which was commissioned March 20, 1968, 8 days before *Hero* was launched.

R/V *Hero:* specifications

Framed with large oak timbers and equipped with several dual systems for backup during emergencies at sea, R/V *Hero* was built to withstand regular operations in what many seafarers term the world's roughest waters.

Ketch-rigged, the ship can carry 160 square meters of sail to maintain control if the propulsion system fails, or to reduce roll and noise during over-the-side oceanographic operations. The mast and some interior work are made of Oregon fir; the keel and sides are sheathed with tropical greenheart from Guyana. *Hero*'s skeleton consists of a 46-by-46-centimeter keel and 15-by-15-centimeter framing spaced only 20 centimeters apart. Oak planking 5 centimeters thick covers the framing. The forward part of the hull is ice-strengthened with metal plating. There are two engines, two boilers, two standby heating and circulating pumps, two power plants, and two evaporators. There also is a spare shaft and propeller.

Hero, which normally carries a complement of 12 crew and 6 scientists, has two decks and a superstructure. The latter consists of a bridge, a chart and radio room, and a small afterdeck with a hydrographic winch. The main deck is enclosed at the bow to accommodate a portside hydrographic laboratory and storage areas; it is exposed amidships to permit entrance to the hold and to provide space for operations.

Immediately aft of the open deck is a compartment that contains a trawling winch. Farther aft and amidships there is an analysis laboratory, and adjoining this (on the port side) is a biology laboratory with access to a large freezer for storage of biological specimens.

Atop the pilot house is a secondary conning station, which provides increased visibility in ice and confined waters. A lower deck accommodates crew and scientist cabins, a mess and galley, and a small hold for storage. A microbiology laboratory, an engine room, and quarters for three more crew are located aft of the hold. Fuel and water tanks are located below.

Hero is 38 meters long and 9.3 meters wide. Its draft is 5 meters, and its gross weight is 270 metric tons. Two engines, which drive a single propeller through a reverse reduction gear, provide a cruising speed of 10 knots and a range of 9,300 kilometers.

The following list gives the dates, areas of operation, senior scientists, and major research objectives of each *Hero* cruise, August 1968 to May 1975:

Shakedown. August 6 to 26, 1968. Boston to Labrador Sea, Baffin Bay, Newfoundland, and return. John H. Dearborn (University of Maine). Invertebrate zoology.

Southward passage. August 27 to September 4, 1968. Boston to Woods Hole, Massachusetts, and

Washington, D.C. Official and public inspection at Washington, September 4 to 10.

Southward passage. September 10 to 15, 1968. Washington, D.C., to Miami, Florida. Miles S. Alton (U.S. Bureau of Commercial Fisheries): biological trawling. Outfitting at Miami, September 15 to October 23.

Southward passage. October 23 to November 11, 1968. Miami, Florida, to Valparaíso, Chile.

Cruise 68-1. November 12 to December 11, 1968. Valparaíso to Punta Arenas, Chile. Kenneth S. Norris (University of California at Los Angeles) and Anelio Aguayo (Estación de Biología Marina, Montemar, Chile): distribution and variation of marine mammals.

Cruise 69-1. December 19, 1968, to March 5, 1969. Punta Arenas, Chile, to Antarctic Peninsula waters, Bransfield Strait, Deception Island, and return to Punta Arenas. Numerous science parties and logistics assignments.

Cruise 69-2. March 25 to May 21, 1969. Patagonia to Drake Passage and Strait of Magellan. H.A. Fehlmann (Smithsonian Institution) and Miles S. Alton (Bureau of Commercial Fisheries): midwater trawling.

Cruise 69-3. June 15 to August 7, 1969. Punta Arenas to coasts of Argentina and Uruguay and return. Raymond M. Gilmore (San Diego Natural History Museum): population, distribution, and behavior of whales. Norberto Bellisio (Museo Nacional, Buenos Aires): ichthyology.

Yard overhaul. August 7 to September 18, 1969. Talcahuano, Chile. Installation of enclosed conning station and other work.

Cruise 69-4. September 18 to October 10, 1969. Chilean archipelago from Puerto Montt to Punta Arenas. Henry A. Imshaug (Michigan State University): terrestrial plants. Wladimir Hermosilla and René Covarrubias (University of Chile, Santiago): soil invertebrates.

Cruise 69-5. October 18 to November 5, 1969. Chilean archipelago, Punta Arenas to 50°S., and return. Roger L. Kaesler (University of Kansas) and Richard H. Benson (Smithsonian Institution): biogeography and systematics of benthic ostracods. Steven B. Young (Ohio State University): vascular plants. José R. Stuardo and Victor Gallardo (University of Concepción): intertidal organisms, macro-infauna.

Cruise 69-6. November 15 to December 21, 1969. Punta Arenas to Chilean archipelago, 50°-55°S., and return. Martin Halpern (University of Texas), Raúl Cortés (Empresa Nacional del Petroleo, Chile), Ian W. D. Dalziel (Columbia University), Estanislao Godoy (University of Chile, Santiago), and Jorge Parra: geological and geophysical reconnaissance.

Cruise 70-1. January 9 to February 17, 1970. Punta Arenas to Palmer Station, Antarctic Peninsula area, South Shetland Islands, and return. Numerous science parties and logistics assignments.

Cruise 70-2. March 4 to April 30, 1970. Punta Arenas to South Shetland Islands, Neumayer Channel, Strait of Magellan, Dawson Island, and return. H. Adair Fehlmann (Smithsonian Institution) and Miles S. Alton (Bureau of Commercial Fisheries): trawling for natural history specimens.

Cruise 70-3. May 15 to July 6, 1970. Punta Arenas to southwestern and central coasts of Chile, to Juan Fernandez and San Felix-San Ambrosio Islands, to Valparaíso, to Talcahuano, Chile. Raymond M. Gilmore and Joseph R. Jehl Jr. (San Diego Natural History Museum), William C. Cummings and Paul O. Thompson (Naval Undersea Research and Development Center, San Diego), Anelio Aguayo-Lobos (University of Chile, Santiago): marine mammal and bird observations.

Cruise 70-4. July 9 to September 5, 1970. Chilean archipelago, Talcahuano to Punta Arenas. Harold T. Hammel (University of California at San Diego), Fred T. Caldwell (University of Arkansas), Frits W. Went (University of Nevada), Oscar Parra (University of Concepción), and Edmundo Pisano and Brent Markham (Instituto de la Patagonia, Chile): reversible freezing in plant tissue.

Yard overhaul. September-November 1970. Talcahuano, Chile.

Cruise 71-1. December 17, 1970, to March 31, 1971. Punta Arenas to Antarctic Peninsula area, South Shetland Islands, South Orkney Islands, and return. Numerous science parties and logistics assignments, including international volcanology expedition to Deception Island.

Cruise 71-2. April 19 to May 30, 1971. Punta Arenas to Isla de los Estados, Tierra del Fuego, and return. Oliver S. Flint (Smithsonian Institution) and Richard A. Ronderos (University of La Plata, Argentina): survey of vertebrate, arthropod, and marine biotas.

Cruise 71-3. June 11 to July 16, 1971. Punta Arenas to Argentine coast and return. William C. Cummings (Naval Undersea Research and Development Center) and Joseph R. Jehl, Jr. (San Diego Natural History Museum): bioacoustics of marine mammals, distribution and ecology of marine birds.

Cruise 71-4. August 3 to 29, 1971. Punta Arenas to Buenos Aires via Isla de los Estados. Haydee Lena and Sara Souto (Ciudad Universitaria, Nuñez, Argentina): sampling for plankton, bottom life, fishes, and bacteria.

Yard overhaul. September 1971. Buenos Aires.

Cruise 71-5. October 11 to November 14, 1971. Punta Arenas to Isla de los Estados and return. Henry A. Imshaug (Michigan State University): survey of terrestrial plants.

Cruise 72-1. Late November 1971 to early April

An autumn cruise aboard *Hero*

Hero cruises in some of the world's stormiest waters, and the weather taxes both the ship and its crew. Here is Captain Pieter Lenie's log for an especially rough crossing of the Drake Passage in 1973:

4 April

0810. Depart dock at Palmer Station—make passage through Old Palmer Channel (unofficial name) to Hero Passage and Gosling Islands.

0835. Raise mizzen and forestaysail.

1000. Set course 320°gyro—weather deteriorated—wind northwest, force 7—heavy seas and swells.

1200. Wind increases to force 7/8 and swells are breaking—heavy snow lowers visibility to zero, and spray coming on decks freezes on contact. Vessel covered with ice.

1700. Lull in wind at twilight allows tightening of the sheets and the halyards.

1900. Winds resumed in force after sundown—temperature came up to minus 2°C., and no new ice formed during the last 2 hours.

5 April

0330. Lost forestaysail in gust of wind up to 80 knots. Damaged fastenings on main trysail—crew worked 3 hours in howling storm and bitter cold water on deck to secure sails.

0600. Light fixture over the galley stove exploded and started fire—got fire under control and disconnected the galley and forward crew quarters lights from the distribution panel—water and sugar mix all over the galley and the passageways—galley stove is in operating condition—rigged extension cords and served breakfast.

0810. Another fire in the galley—butter spilled on the stove. Vessel is hove to in heavy northwesterly seas and swells with breaking crests, wind 65 knots with gusts of more—vessel losing ground.

1000. Mainsail repaired and raised—vessel riding better, still hove to.

1300. Wind shifts to westerly—set storm jib and change course to 350° gyro—vessel rolling heavily but making 3 to 4 knots headway—sails hold her from falling off in the wind.

1800. Seas breaking under vessel—swells all day running 7 to 10 meters and curling—crew is kept busy securing, and all hands are getting tired.

2200. Temperature dropped below −2°C., and vessel is getting new ice all over again.

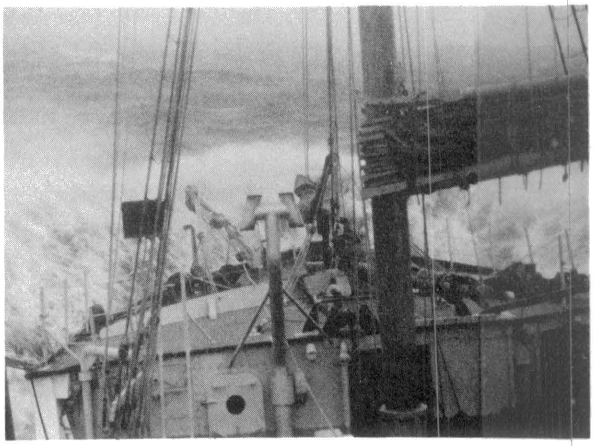
2400. Wind stays north by west, and vessel is making good headway in spite of heavy rolling.

6 April

0700. Wind back to westerly—vessel still riding easily—most all hands managed to get some sleep.

0800. Star fix shows vessel at (Antarctic) Convergence.

0900. Wind shifts to northwest—change course to 360° gyro.



W. R. Curtsinger

1100. Rolling heavily but making headway—increased to 240 rpm.

1330. Noon fix shows steady progress—set course for 350° gyro—vessel rides easier.

1630. In center of Convergence. Making good headway in spite of heavy rolling. Temperature came up to 0°C., and all the ice melted quickly.

2100. Star fix shows good progress—wind shifts to north-northwest—lowered speed to 200 rpm.

7 April

0800. Wind shifts to northwest and diminishes to 20 to 30 knots. Temperature north of Convergence is 4°C. Estimate distance to Cape Horn to be 160 kilometers. Increase to 240 rpm.

1200. Wind shifts to northwest. Closehauled in heavy seas. Estimate 4 knots.

1400. First soundings south of Cape Horn. Making little or no headway. Leaks in galley getting bad.

1600. Set course 050° gyro. Soundings indicate 120 fathoms.

1730. Radar indicates land is 65 kilometers away. Speed 4 to 5 knots.

2000. Making little headway trying to round Cape Horn. Temperature is up to 1°C.—very hot.

2340. Rounded Cape Horn. Took down jib and mainsail. Heading north for Isla Nuevo.

8 April

0045. Getting in the lee of Cape Horn. Vessel riding easier.

0400. Entered passage through the islands south of Canal Beagle. Vessel riding easy.

0900. Stopped at Puerto Williams and dropped mail from the Chilean and Russian stations.

1200. Argentine pilot aboard. Depart Puerto Alamanza.

1530. At dock in Ushuaia. Vessel cleared.

2000. Weather moderate. Clear sky prevails.

1972. Punta Arenas to Palmer Station, with sorties to the South Shetlands and elsewhere, and return. Numerous science teams and logistics assignments.

Cruise 72-2. April 25 to June 1, 1972. Punta Arenas to Isla de los Estados, to Tierra del Fuego, and to Rio Gallegos, Argentina. Ian W. D. Dalziel (Columbia University), Roberto Caminos and Francisco Nollo (Dirección Nacional de Geología y Minería, Buenos Aires), and Riccardo Cassanova (Universidad de Buenos Aires): structural geology.

Yard overhaul. June and July 1972. Buenos Aires.

Cruise 72-3a. July 17-25, 1972. Buenos Aires to coastal Uruguayan waters and return. Robert G. Brownell, Jr. (Smithsonian Institution) and José Olazarri and Federico Achaval (Museo Nacional de Historia Natural de Montevideo): marine mammal and bird observations and trawling.

Cruise 72-3b. July 26 to August 30, 1972. Buenos Aires to Punta Arenas. Joseph R. Jehl, Jr. (San Diego Natural History Museum) and Maurice Rumboll (Museo Argentina de Ciencias Naturales, Buenos Aires): winter populations of marine birds. William C. Cummings (Naval Undersea Research and Development Center): behavior and bioacoustics of marine mammals.

Cruise 72-4. September 10 to October 13, 1972. Punta Arenas to southern Chilean archipelago and return. Lisandro Chuecas and Hugo Saelzer R. (Universidad de Concepción, Chile): biological studies of the fjord region. Robert W. Risebrough (University of California): pollutants in the peregrine falcon.

Cruise 72-5. October 26 to November 30, 1972. Punta Arenas through Chilean archipelago north to 43°S. and return. Paul K. Dayton (University of California at San Diego): kelp communities. Richard B. Searles (Duke University): benthic marine algae.

Cruise 73-1. December 12, 1972, to April 8, 1973. Punta Arenas to South Shetland Islands, Palmer Station, to Ushuaia, Argentina, plus second round trip, Ushuaia to Palmer. Numerous science parties and logistics assignments.

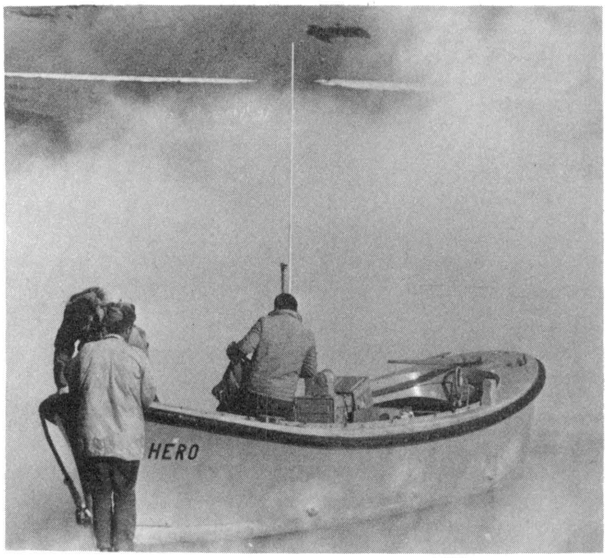
Cruise 73-2. May 3 to 25, 1973. Ushuaia to Isla de los Estados, Tierra del Fuego, Beagle Channel, north to Puerto Montt, Chile, and return to Ushuaia. Paul K. Dayton (University of California, San Diego): kelp communities. Richard B. Searles (Duke University): seaweeds.

Yard overhaul. May to November 1973. Buenos Aires.

Cruise 74-1. November 12 to 29, 1973. Ushuaia to South Shetlands, Palmer Station, and return. Numerous science teams and logistics assignments.

Cruise 74-2. December 4 to 17, 1973. Ushuaia to South Shetlands, Palmer Station, and return. Numerous science teams and logistics assignments.

Cruise 74-3. December 25, 1973, to February 20, 1974. Ushuaia to South Shetlands, Antarctic Peninsula area, and return. Numerous science teams and logistics assignments.



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Scientists debark from a *Hero* shoreboat at Deception Island.

Cruise 74-4. February 24 to March 30, 1974. Ushuaia to Drake Passage and return. Escort deep sea drilling ship *Glomar Challenger* during drilling operations.

Cruise 74-5. April 8 to 18, 1974. Ushuaia to Palmer Station, Deception Island, and return. Logistics only.

Cruise 74-6. May 4 to June 6, 1974. Ushuaia to Puerto Williams, Navarino Island, Washington Channel, and return. R. H. Dott (University of Wisconsin): structural geology.

Northward passage. June 13 to July 18, 1974. Ushuaia to Long Beach, California.

Yard overhaul. July 18 to November 14, 1974. Long Beach, California.

Southward passage. November 14, 1974, to January 3, 1975. Long Beach to Ushuaia via Manzanillo, Mexico.

Cruise 75-1a. January 3 to March 11, 1975. Ushuaia to Palmer Station, other Antarctic Peninsula areas, and return. Numerous science teams and logistics assignments.

Cruise 75-1b. March 15 to 26, 1975. Ushuaia to Palmer Station, Almirante Brown Station, and return. Logistics cruise.

Cruise 75-1c. April 12 to 21, 1975. Ushuaia to Palmer Station and Argentine Islands Station and return. Logistics only.

Cruise 75-2. Cancelled.

Cruise 75-3. May 13 to 26, 1975. Ushuaia to Argentine Basin and return. Frederick Siegel (George Washington University): sediment sampling.

The Scotia Arc tectonics project, 1969-1975

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The region of the Drake passage and the Scotia Sea in which R/V *Hero* has operated since her first cruise late in 1968 has long been of interest to earth scientists. Charles Darwin made the first geologic observations in the region from aboard HMS *Beagle* during the 19th century (Darwin, 1846). Earlier, in the time of the original *Hero,* it was first suggested that the Andean Cordillera, which disappears into the waters of the Scotia Sea at the eastern tip of Tierra del Fuego, reappears in the Antarctic Peninsula and its offshore islands (Barrow, 1831). In fact, the voyages of Nathaniel Palmer and others were instrumental in the recognition of the "Antarctandes." Subsequent work at sea, including that of the brig *Scotia* of the Scottish National Antarctic Expedition (Bruce, 1906), led to the discovery of a discontinuous submarine ridge—the Scotia Ridge—joining the Andes to the Antarctandes in the eastward-facing loop that has come to be known as the Scotia Arc (figures 1 and 2).

The Scotia Arc region, which is here taken in a broad sense to extend from latitude 46°S. in Chile (where the Chile Rise intersects South America) to the base of the Antarctic Peninsula (figures 1 and 2), is still of outstanding geologic significance. Global problems relevant to research in this region were recently identified by the International Geodynamics Commission and by the geology and geophysics panel of the Committee on Polar Research, U.S. National Academy of Sciences:

(1) The boundary between two of the half-dozen or so major lithospheric plates into which is divided the world's 100-kilometer-thick, rigid outer shell passes through the region. The boundary between the American plate and the antarctic plate extends from the Chile Rise south to the tip of Tierra del Fuego, along the north Scotia Ridge, south around the active South Sandwich volcanic arc, and eastward along the South Sandwich Fracture Zone to the Mid-Atlantic Ridge. However, as shown in figure 1, the boundary is poorly defined by earthquakes between the Chile Rise and the northern end of the South Sandwich arc.

(2) Not only is the region situated along a presently active plate boundary, but it also has been an active plate boundary for over 200 million years; hence it is an excellent place to study tectonic and igneous processes.

(3) While the geologic relations of Africa and South America, and of Australia and Antarctica, are well established in the reconstruction of Gondwanaland, the former positions of the "eastern" (Antarctica-Australia) and "western" (Africa-South America) parts of the ancient southern supercontinent relative to one another and to India are still uncertain. The Scotia Arc region is the key to this puzzle.

(4) The timing of events during the breakup of Gondwanaland in the Scotia Arc region is crucial to several important developments in earth history (*e.g.,* the migration of marsupials from South America to Australia and the inception of a full circumpolar current with its effects on global climate).

Modern U.S. involvement in the terrestrial geology of the region, and the current Scotia Arc tectonics project, began in the early 1960s when Robert H. Dott, Jr., University of Wisconsin, initiated a program funded by the National Science Foundation to study in greater detail than ever before the geologic relationship of South America and the Antarctic Peninsula. The work of Kevin Scott, U.S. Geological Survey, and the initial work of Martin Halpern, University of Texas at Dallas, were part of this program (see bibliography). In 1963 it became apparent to Professor Dott and me that the geology of South Georgia Island at the eastern end of the North Scotia Ridge was critical in understanding the geologic relationship between South America and the Antarctic Peninsula. It was not possible to visit the island at the time; in fact, it was not until 1973 that a detailed comparative geologic study of South Georgia and southernmost South America was undertaken. With the onset of R/V *Hero* cruises late in 1968, the well exposed but previously inaccessible rocks of the Scotia Arc region were finally reached for study and the potential of this remarkable laboratory of tectonic and igneous processes began to be realized. The use of inflatable boats launched from *Hero* and from temporary camps ashore finally enabled landings to be made virtually anywhere in the region.

Scientific achievements

Scientists involved in the Scotia Arc tectonics project have taken a problem-oriented approach to their research. Geologic mapping has been directed toward solving a particular problem rather than covering a given area. The program's achievements thus can best be described in terms of the elucidation of the geologic evolution of the region, particularly as this affects global problems and the understanding of tectonic processes.

"Basement" complexes. The deformed rocks underlying the widespread Upper Jurassic silicic volcanic sequence of the Scotia Arc region (table) are here referred to as "basement." They have been studied extensively during the project in the South Shetland Islands, the South Orkney Islands, the Antarctic Peninsula, and southern South America. It has been clearly established that the Jurassic volcanic sequence rests unconformably on the basement complex or complexes throughout the region. Comparison of the fossiliferous Upper Paleozoic Madre de Dios sequence with the unfossiliferous

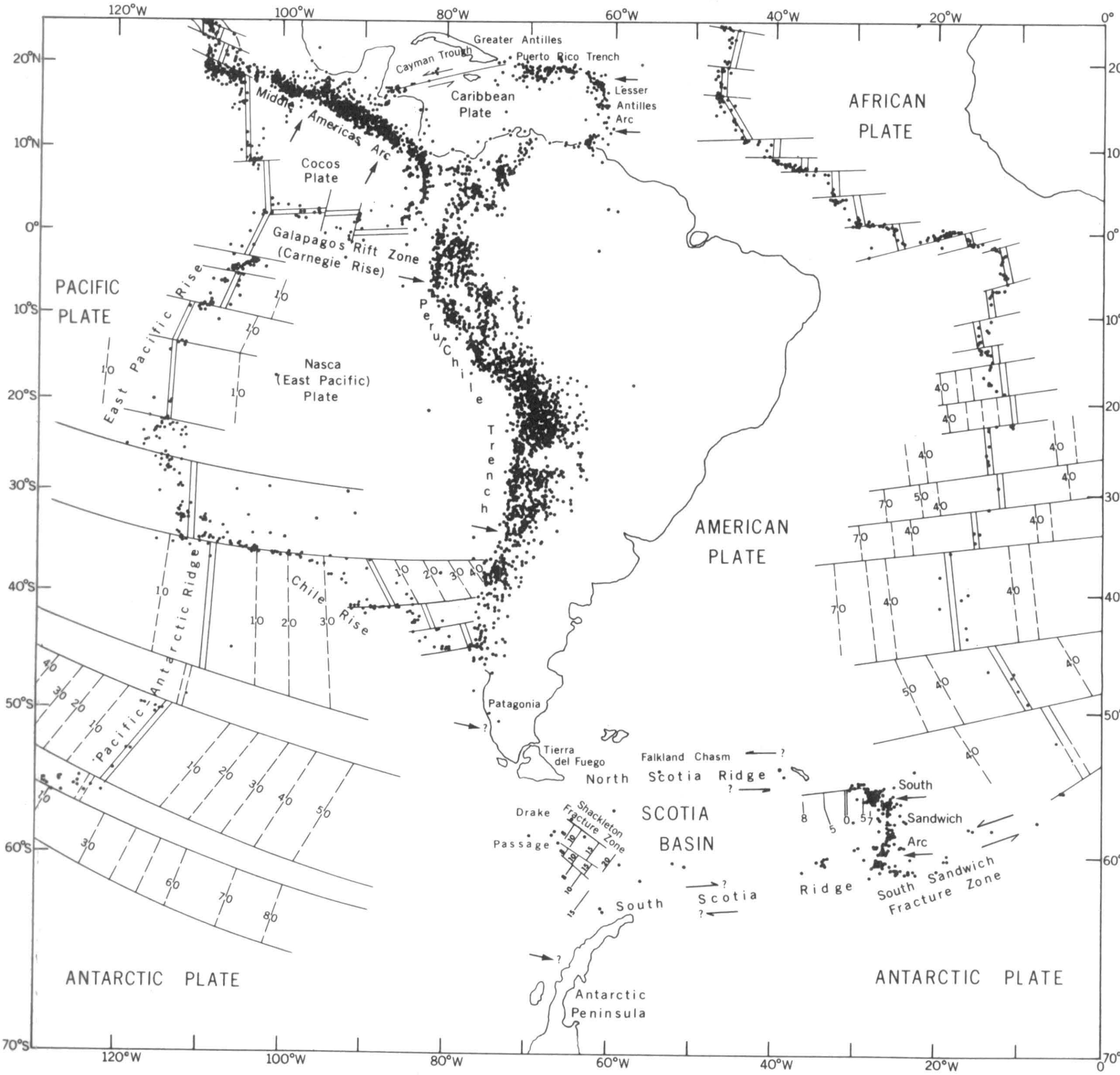


Figure 1. Geotectonic setting of the Scotia Arc (after Dalziel and Elliott, 1973). Earthquake epicenters for the 1961 through 1967 period at a depth of 0 to 700 kilometers are shown by black dots. The approximate age (in millions of years) of the floor of the Atlantic and Pacific oceans also is shown. Arrows indicate inferred relative motion of the lithospheric plates on which they are drawn.

rocks elsewhere in the region (including in the Trinity Peninsula "Series" of the Antarctic Peninsula) (Dalziel, 1972) has strengthened the likelihood that these rocks in fact are Late Paleozoic. While relationships in the South Orkney Islands still suggest that part of the basement is older than Upper Paleozoic (Dalziel, 1974), two sequences previously assigned to the basement (Adie, 1964) are now believed to be younger. Dr. de Wit's recent observations of the rocks at Marguerite Bay indicate that they probably form the roots of an early Mesozoic calc-alkaline volcanic arc or chain; the Sandebugten graywacke and shale sequence of South Georgia is now believed, on structural and sedimentologic grounds, to be Lower Cretaceous (Dalziel *et al.*, in press).

The structure of the basement complex or complexes has an important bearing on the reconstruction of Gondwanaland in the South Atlantic region where the "fit" has never been well established (Smith and Hallam, 1970; Dietz *et al.*, 1971), and also on the nature and plate tectonic implications of the early Mesozoic Gondwanian orogeny that resulted in the deformation of the Upper Paleozoic sedimentary sequences of the Sierra de la Ventana (Argentina), the Cape Fold belt (South Africa), the Ellsworth and Pensacola mountains (Antarctica), and the Scotia Arc region. The basement of the Scotia Arc region seems to have been first deformed during the Gondwanian orogeny and in many places reactivated during the main (mid-Cretaceous) Andean orogenesis. Recent work

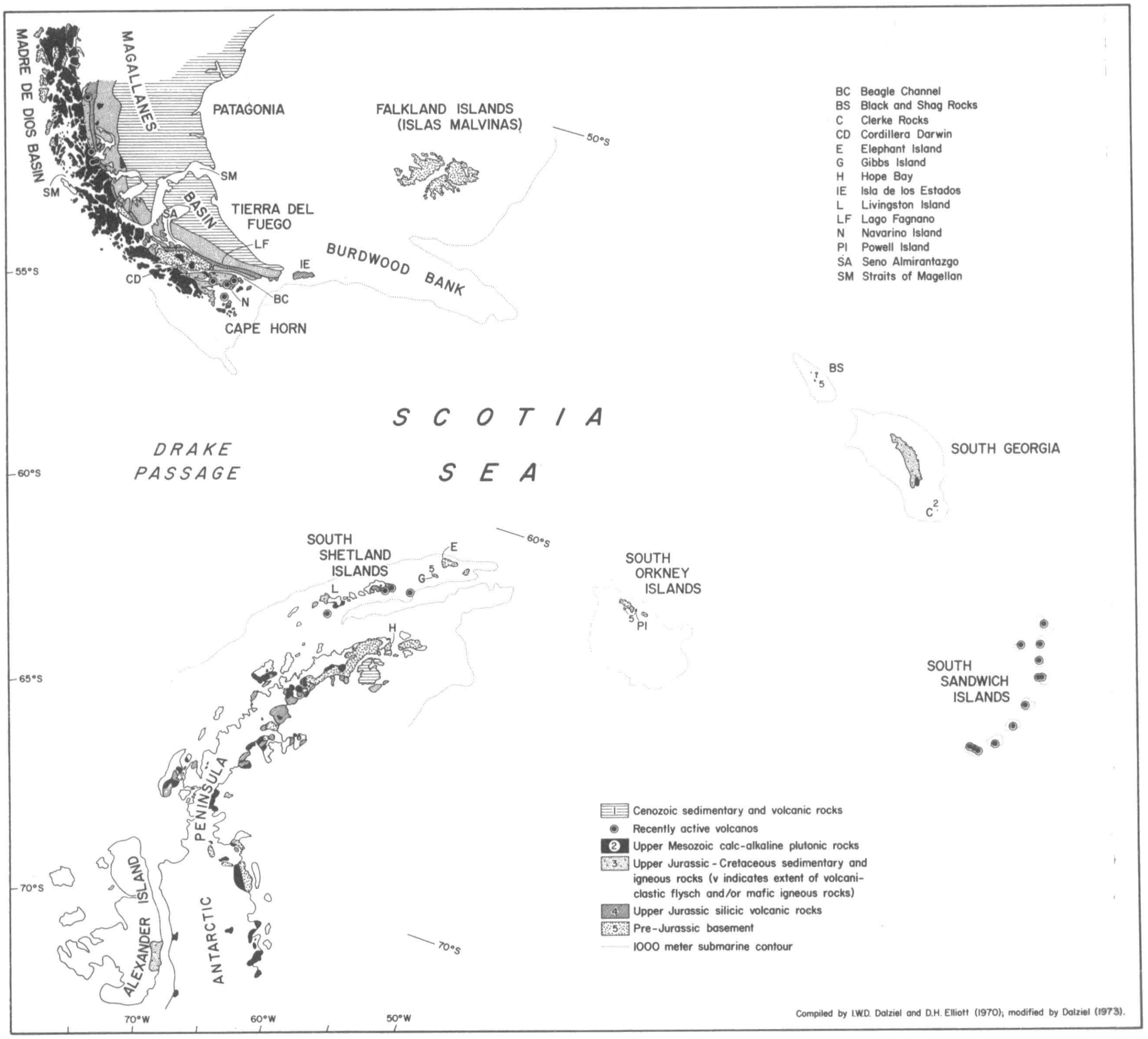
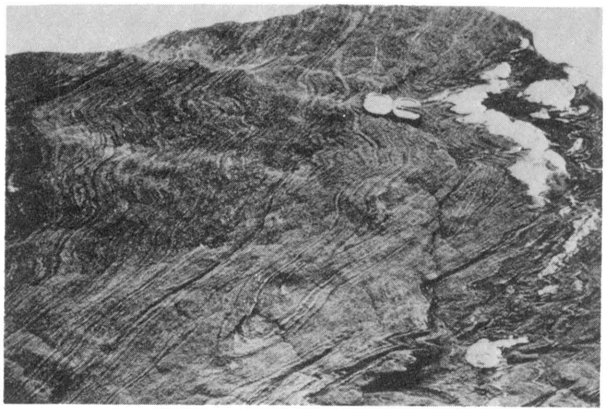


Figure 2. Geologic and location map of the Scotia Arc (after Dalziel, 1974).

has shown that the ultramafic rocks of Gibbs Island in the South Shetland Islands were likely emplaced during the Gondwanian orogeny, possibly in the trench environment. Work undertaken during this project is helping to establish the nature of the Gondwanian orogeny. It appears to have resulted either from the collision of an island arc with the main part of Gondwanaland, or from subduction beneath the margin of the supercontinent.

Upper Jurassic volcanic sequence. Silic volcanic rocks of Upper Jurassic age have long been known to occur widely in the Scotia Arc region. Recent work in the Antarctic Peninsula and in South America make it clear that most of these volcanics are related to Late Mesozoic subduction of oceanic crust beneath the South American-west antarctic segment of Gondwanaland. In South America the main outcrop that occurs in a narrow belt along the High Cordillera of the Andes now appears to represent a remnant arc left behind when a small ocean basin opened up during the latest Jurassic



"Refolded" folds in the metamorphic rocks of Elephant Island, South Shetland Islands. The tight early folds may have resulted from the early Mesozoic Gondwanian orogeny, and the more open (later) folds from the late Mesozoic Andean deformation.

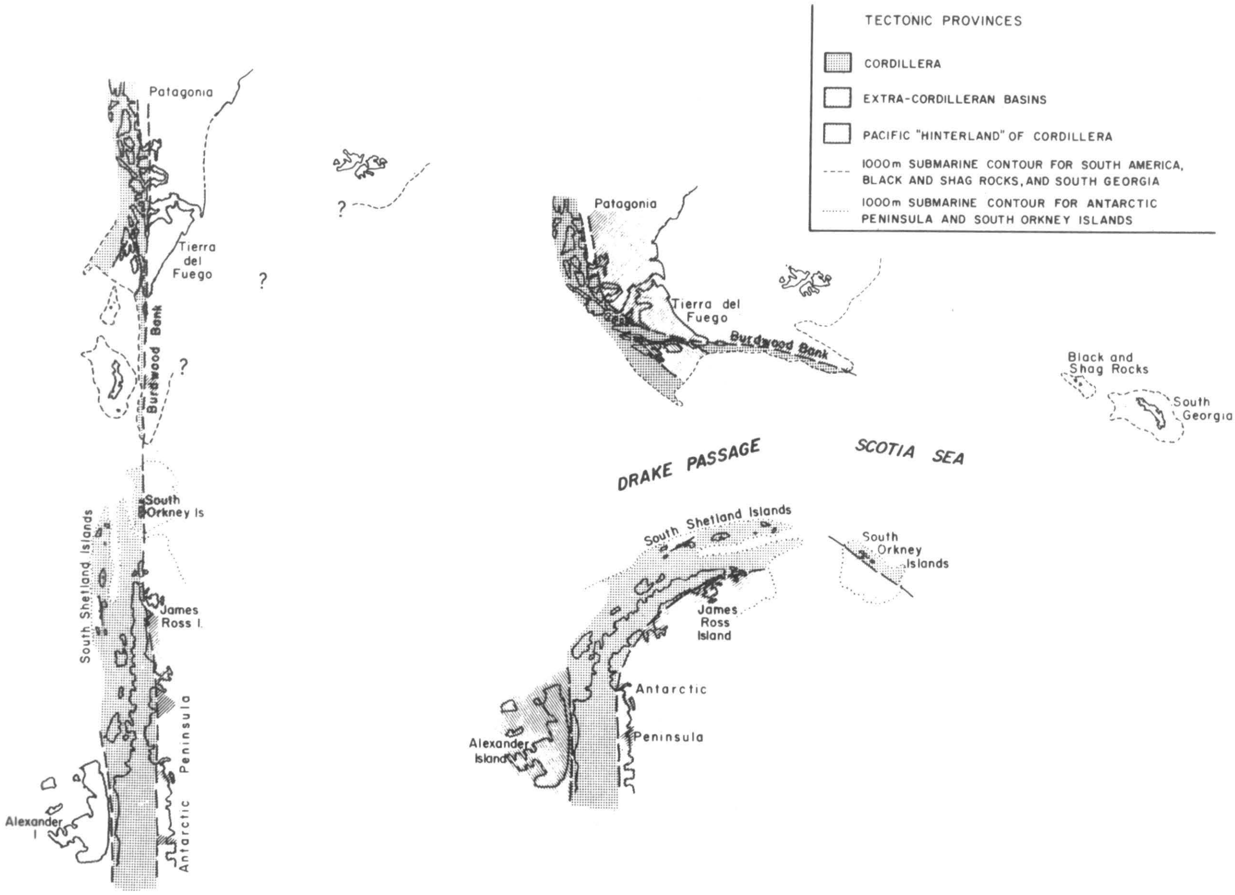


Figure 3. Model for the evolution of the Scotia Arc proposed by Dalziel and Elliot (1973).

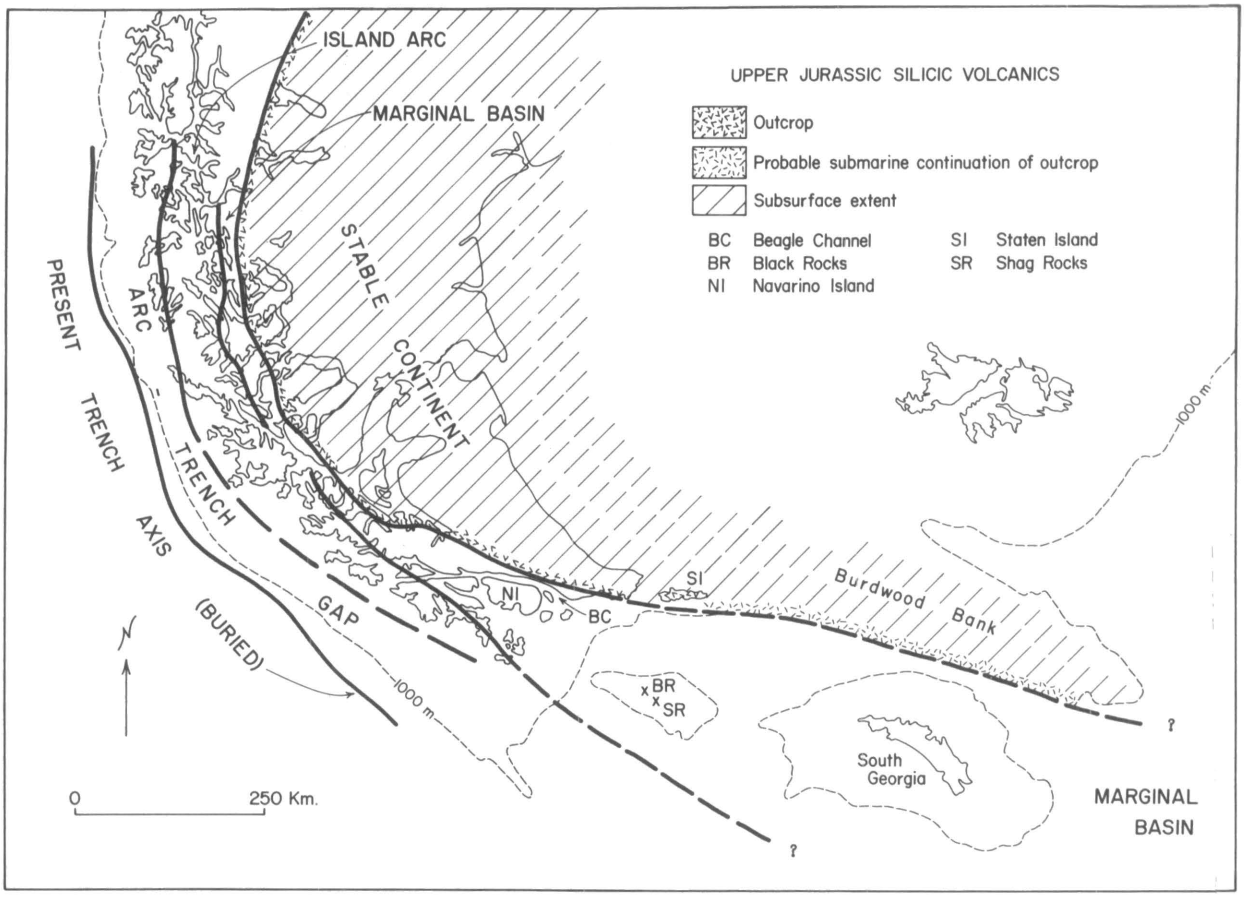
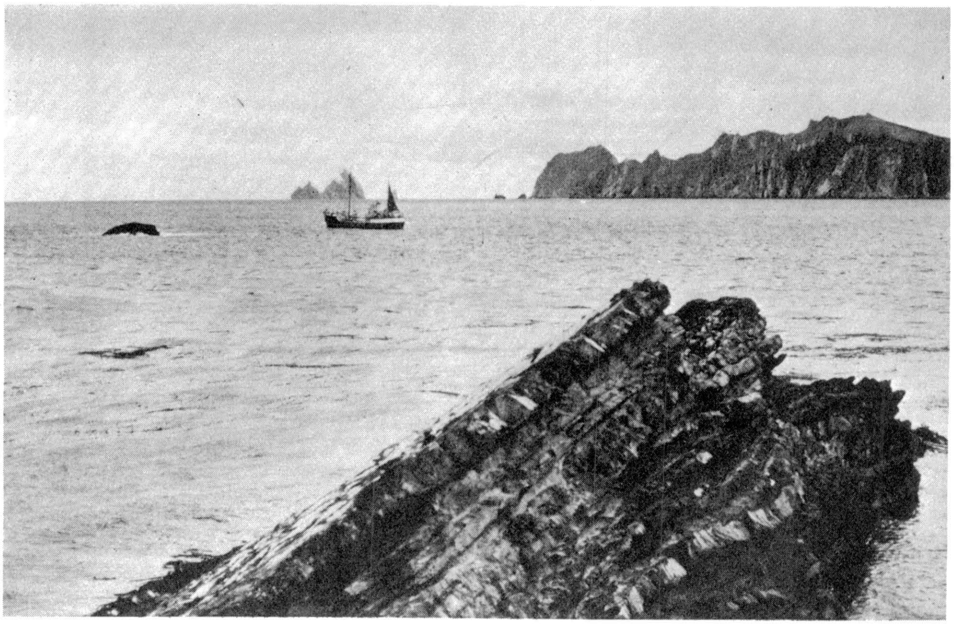


Figure 4a. Reconstruction of north limb of the Scotia Arc (after Dalziel *et al.*, in press).

Principal tectonostratigraphic units and geologic events in the Scotia Arc region.

CENOZOIC	Sedimentary and volcanic sequences (Upper Cretaceous-Cenozoic) with local unconformities		ACTIVE VOLCANISM CENOZOIC VOLCANICITY
CRETACEOUS	u (local) u Sedimentary and volcanic sequences (Lower Cretaceous)	ANDESITIC VOLCANISM AND BATHOLITH EMPLACEMENT (mainly Late Jurassic-Late Cretaceous)	ANDEAN OROGENY (mid-Cretaceous) MAFIC IGNEOUS ACTIVITY (Early Cretaceous: South America only)
JURASSIC	Silicic volcanic and sedimentary sequence (Upper Jurassic)		CALC-ALKALINE VOLCANISM
TRIASSIC	u~~~~~~~~~~~~~~u		GONDWANIAN OROGENY Deformation and low-grade metamorphism
PALEOZOIC	Sedimentary sequence(s) (Upper Paleozoic) (?)~~~~~~u~~~~~~u~~~~~~(?) Metamorphic complex (Paleozoic, possible in part Precambrian)		
PRECAMBRIAN	(?)~~~~~~u~~~~~~u~~~~~~(?) ? Metamorphic complex		

u~~~~ u - unconformity.



Southward-dipping inverted strata on the steep limb of the large synclinal fold affecting the rocks of Isla de los Estados (see figure 5).

within the continental margin calc-alkaline volcanic chain.

Ophiolite complex. Long known by Chilean geologists as the "roccas verdes," the mafic rocks on the Pacific side of the silic volcanic belt in the southern Andes have now been recognized as the upper part of an ophiolite complex representing the floor of a small ocean basin (comparable to the Japan Sea of today) that opened up along the western margin of South America in the Early Cretaceous (figure 4). This is particularly significant since it means that at least this part of the eastern Pacific Ocean margin once looked like the western Pacific margin does today with festoons of island arcs and marginal ocean basins separating the volcanic arcs from the continent proper. It is also significant in terms of mountain building processes: the main uplift of the southern part of the Andean Cordillera occurred at the time when the volcanic arc on the Pacific side of the basin moved back toward South America thus "closing" the marginal basin in an island arc-continent "collision."

Lower Cretaceous sedimentary and volcanic sequences. The most important aspect of these rock sequences is that their recognition in South America as the sedimentary detritus infilling the Japan Sea-like marginal basin has led to a detailed reconstruction of the North Scotia Ridge. It has long been recognized that the rocks of South Georgia are similar to those of Navarino Island in southernmost Chile (Wilckens, 1933; Katz and Watters, 1966). Only recently, however, with the sedimentologic studies of Professor Dott and of Robert Winn, have the details of this comparison been made clear. It can now be appreciated that South Georgia was, until at least the mid-Cretaceous, situated immediately

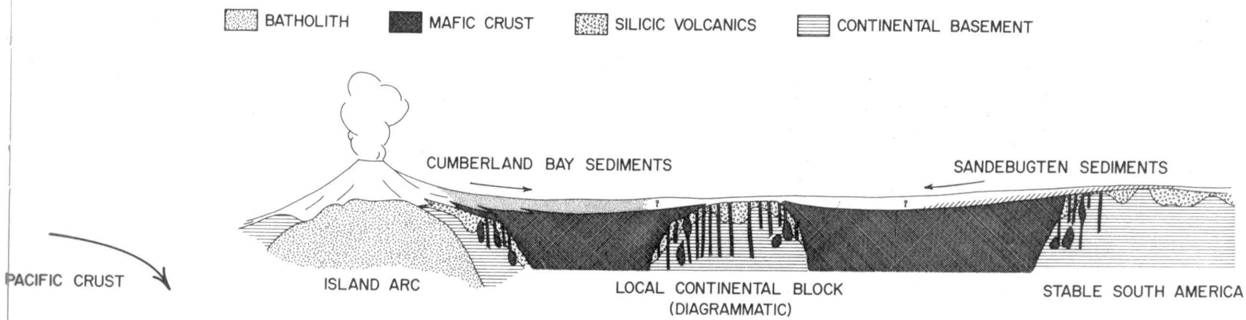


Figure 4b. Interpretative cross section of the northern limb of the Scotia Arc in the Early Cretaceous prior to the opening of Drake Passage and the Scotia Sea (after Dalziel *et al.*, in press).

Participants in the Scotia Arc tectonics project

The scientists listed below, all with interests in the tectonic evolution of the Scotia Arc, have participated in programs either directly or indirectly involving the use of the R/V *Hero* as a base of operations. No attempt has been made here to provide a comprehensive list of individuals interested in the geology of the Scotia Arc region.[1]

Argentina

Servicio Geologico Nacional
Roberto Caminos
Francisco Nullo

Chile

Universidad de Chile
Oscar Gonzalez-Ferran
Estanislao Godoy
Instituto de Investigaciones Geologicas
Riccardo Fuenzalida
Adela Aguilar
Empresa Nacional del Petroleo
Raúl Cortés

Switzerland

ETH Zurich
William Lowrie

United Kingdom

University of Birmingham
John Tarney

United States

Lamont-Doherty Geological Observatory of Columbia University
Ian W. D. Dalziel
Maarten J. de Wit
Charles R. Stern
Keith F. Palmer
Keith O'Nions
Neil Opdyke
University of Wisconsin
Robert H. Dott, Jr.
The Ohio State University
David H. Elliot
University of Texas at Dallas
Martin Halpern

[1]Such a list is being prepared by the Scotia Arc study group of working group number 2, International Geodynamics Commission: Oscar Gonzalez-Ferran (Chile), chairman; Ian W. D. Dalziel (United States), executive secretary and corresponding secretary for Australia, New Zealand, and the United States; Peter F. Barker (United Kingdom), secretary for the Soviet Union, the United Kingdom, and Western Europe; Roberto Caminos (Argentina), corresponding secretary for Argentina; Riccardo Fuenzalida (Chile), corresponding secretary for Chile.

east of Navarino Island and south of the Burdwood Bank (Dalziel *et al.*, in press) (figure 4).

Andean orogeny. Work undertaken in the course of the Scotia Arc tectonics project has led to a more detailed understanding of the processes involved in the uplift of the southernmost Andes and the Antarctandes. The uplift took place as a result of subduction of the Pacific Ocean floor beneath the South American-antarctic sector of Gondwanaland. In the South American case it took place as a result of the "closure" of the marginal basin in the mid-Cretaceous; this in turn resulted in island arc-continent "collision." The effects of uplift, horizontal shortening, and strike-slip displacement can all be recognized: the floor of the marginal basin (the ophiolite complex) is now up to 2 kilometers above sea level; tight folds (mostly overturned toward the continent) and thrusts striking parallel to the Cordillera are in evidence; large shear zones (including some that are still active such as the Straits of Magellan-Seno Almirantazgo-Lago Fagnano lineament) have been identified. The uplift and horizontal shortening have been shown to result in tectonic thickening of the continental margin, for example on Staten Island at the southeastern extremity of the Andean Cordillera (Dalziel *et al.*, 1974; Dalziel and Palmer, in press) (figure 5). The shears are probably at least in part responsible for the bending of the Andean Cordillera to an east-west trend south of the Strait of Magellan.

Evolution of the Scotia Arc. Early in the project D. H. Elliot and I proposed a model for the evolution of the Scotia Arc that was based on the similarity of the geology north and south of the Drake Passage (figure 3). Subsequent developments, including those outlined above, have shown that this and other recent models (such as that of Barker and Griffiths, 1971, who suggested an eastward-pointing cusp as the original shape of the Andean-Antarctandean Cordillera in the region) are probably highly oversimplified. Specifically, the recognition of the Early Cretaceous marginal basin in the southernmost Andes indicates that the configuration of the South American-Antarctic Peninsula connection at the time could well have been as complex as is today's Alaskan Peninsula-Aleutian Kamchatka connection across the Bering Strait.

Future prospects

The data base and hypotheses that have been generated by the Scotia Arc tectonics project since the inception of R/V *Hero* cruises provide an excellent opportunity for future study, not just of the Scotia region for its own sake, nor even of the region as it bears on global tectonic problems, but as an almost unique laboratory for the study of tectonic and igneous processes. The Mesozoic and

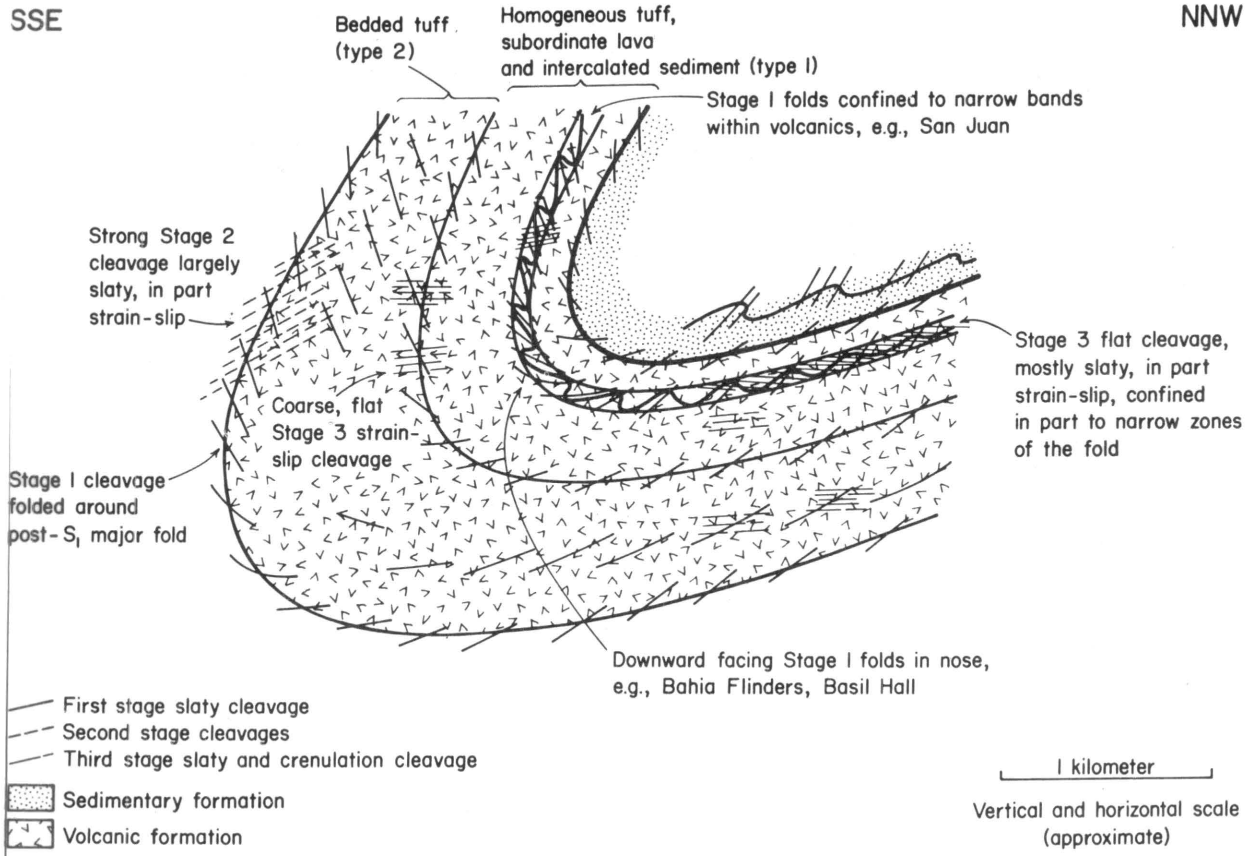
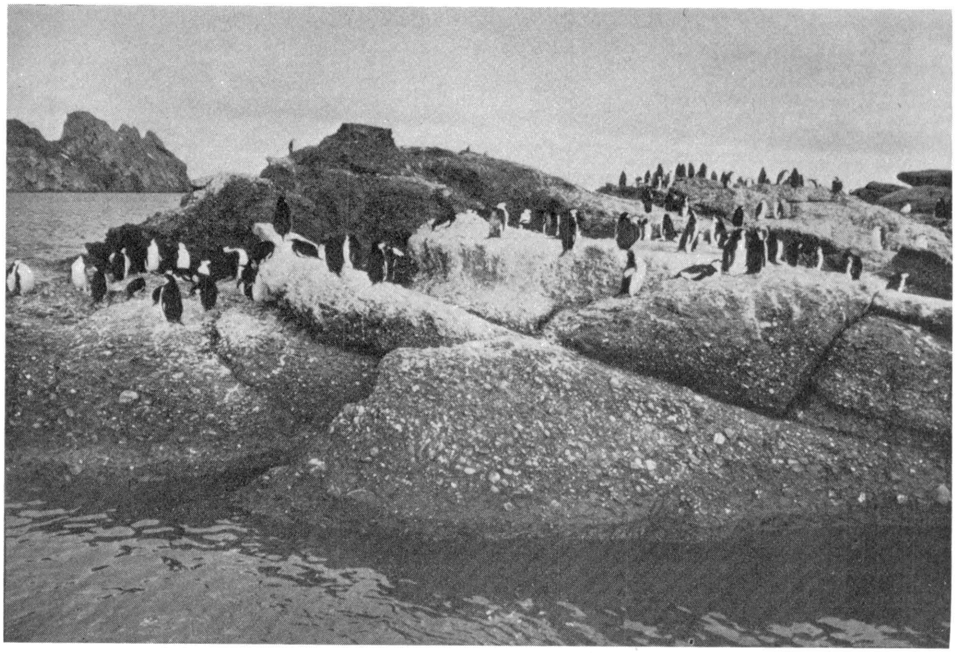
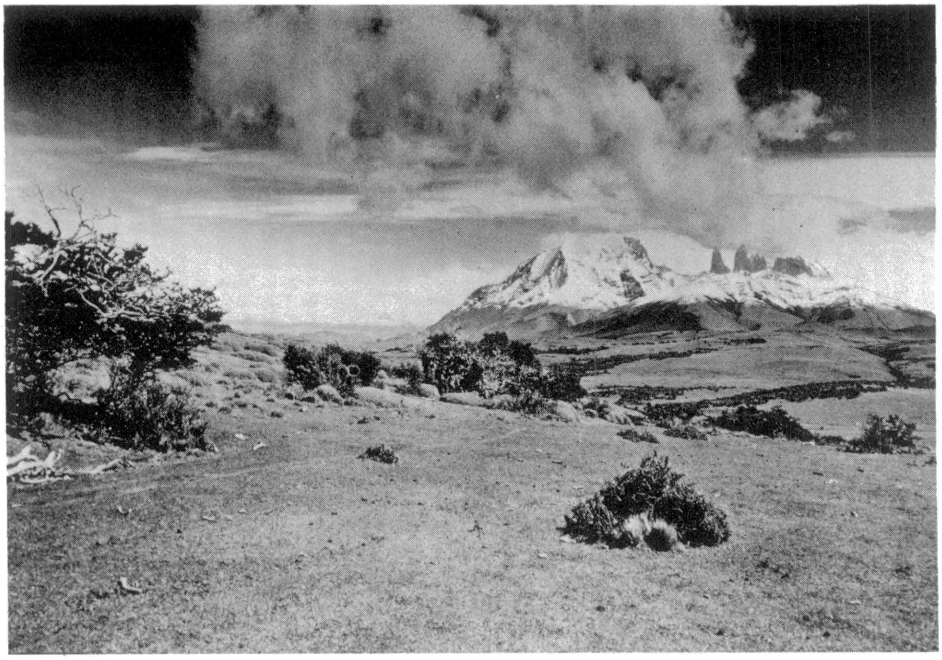


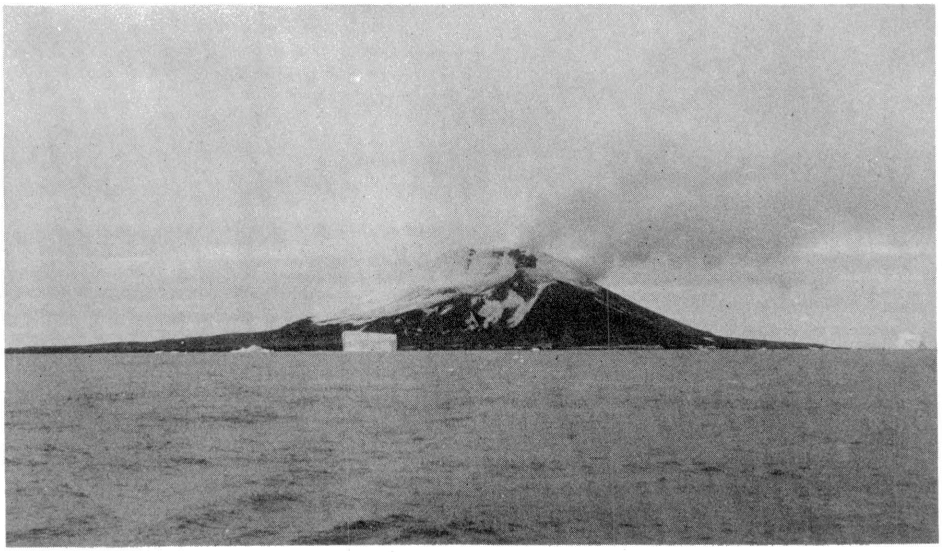
Figure 5. Structural cross section of the rocks of Isla de los Estados, Argentine Tierra del Fuego. The island, which has an elevation of 800 meters, is situated in the core of the fold (after Dalziel *et al.*, 1974a).



Flat-lying undeformed Cretaceous conglomerates in the South Orkney Islands (Powell Island).



The late Miocene (12 million years before present) calc-alkaline pluton of Cerro Paine in the Andean Precordillera north of the Straits of Magellan.



Zavadovski Island, an active volcano northernmost of the South Sandwich Islands (photograph courtesy of Andrew Saunders).

Cenozoic geotectonic setting is clearly established, yet many of the rocks of this age have been uplifted and eroded so that processes currently going on thousands of meters below sea level and up to several kilometers beneath the sea floor can be studied with precision.

Acknowledgments

The Scotia Arc tectonics project has been supported by the Office of Polar Programs and the Office for the International Decade of Ocean Exploration, National Science Foundation. Invaluable logistic support in South America has been supplied by the Departamento de Exploraciones, Empresa Nacional del Petróleo, Chile. The British Antarctic Survey provided transportation to and from South Georgia as well as logistic support on the island.

Special thanks are due to *Hero*'s master, Captain Pieter Lenie, and to former masters Hartschorn, Rogers, Hochban, and Deniston, for their willingness to operate the vessel under difficult conditions, thereby providing us with an unprecedented op-

portunity to study the Scotia Arc region's geology. We also are grateful to the crew of R/V *Hero,* and to the masters and crews of USCGC *Glacier,* USCGC *Edisto,* RRS *Bransfield,* HMS *Endurance,* and the Chilean cutters *Ivan, Viking, Milo, Roca,* and *21 de Mayo.*

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Field activities in the Scotia Arc tectonics project

The following is a resume of geologic field work in the Scotia Arc tectonics project from January 1969 to July 1975 (locations are shown in figure 2):

January-March 1969. Eastern Livingston Island (Hurd Peninsula and False Bay), South Shetland Islands; supported by R/V *Hero* and USCGC *Edisto;* participants from Lamont-Doherty Geological Observatory.

November-December 1969. Northwest Strait of Magellan region, Chile; supported by R/V *Hero;* participants from University of Texas at Dallas, Lamont-Doherty Geological Observatory, Empresa Nacional del Petroleo, Universidad de Chile, and Instituto de Investigaciones Geologicas.

January 1970. Elephant Island and Gibbs Island, South Shetland Islands, and Hope Bay (Antarctic Peninsula); supported by USGC *Glacier;* participants from Lamont-Doherty Geological Observatory.

February 1970. Western Livingston Island, South Shetland Islands; supported by R/V *Hero* and *Piloto Pardo;* participants from Lamont-Doherty Geological Observatory and Universidad de Chile.

July 1970. Cordillera Darwin, Tierra del Fuego, Chile; supported by cutter *Ivan;* participants from Lamont-Doherty Geological Observatory and Empresa Nacional del Petróleo.

January-March 1971. South Orkney Islands; supported by R/V *Hero;* participants from Lamont-Doherty Geological Observatory.

February-April 1972. Tierra del Fuego, Chile; supported by cutters *Ivan* and *Viking;* participants from Lamont-Doherty Geological Observatory and Empresa Nacional del Petróleo.

April-May 1972. Isla de los Estados, Tierra del Fuego, Argentina; supported by R/V *Hero;* participants from Lamont-Doherty Geological Observatory, Universidad de Buenos Aires, and Dirección Nacional de Geología y Minería.

January-March 1973. South Georgia Island; supported by RRS *Bransfield* and HMS *Endurance;* participants from Lamont-Doherty Geological Observatory and University of Wisconsin.

January-March 1973. Northwest Strait of Magellan area, Chile; supported by cutters *Ivan* and *Viking;* participants from Lamont-Doherty Geological Observatory and Empresa Nacional del Petróleo.

April-May 1973. Cordillera Darwin, Tierra del Fuego, Argentina; participants from Lamont-Doherty Geological Observatory and University of Wisconsin.

January-March 1974. Northwest Strait of Magellan area, and Cordillera Darwin, Chile; supported by cutters *Ivan, Rica,* and *21 de Mayo;* participants from Lamont-Doherty Geological Observatory and Empresa Nacional del Petróleo.

May-June 1974. Navarino Island-Cape Horn area, Chile; supported by R/V *Hero;* participants from University of Wisconsin and Lamont-Doherty Geological Observatory.

January-March 1975. Cordillera Darwin, Tierra del Fuego, Argentina and Chile; supported by Chilean navy; participants from Lamont-Doherty Geological Observatory.

January-February 1975. Northwest Strait of Magellan area, Chile; supported by cutters *Roca* and *21 de Mayo;* participants from Lamont-Doherty Geological Observatory, Universidad de Chile, and Empresa Nacional del Petróleo.

February 1975. Tierra del Fuego, Chile; participants from Lamont-Doherty Geological Observatory.

January-March 1975. South Shetland Islands (Gibbs Island and Western Livingston Island), Antarctic Peninsula and offshore islands; supported by R/V *Hero;* participants from Lamont-Doherty Geological Observatory.

June-July 1975. A cruise is being planned for the Chilean coastal cordillera (Punta Arenas-Puerto Montt); supported by R/V *Hero;* participants from Lamont-Doherty Geological Observatory, Universidad de Chile, Empresa Nacional del Petróleo, and Instituto de Investigaciones Geologicas. Also, R/V *Robert D. Conrad* is presently involved in geophysical research in the southeastern Pacific related to the Scotia Arc tectonics project.

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Vegetation of Isla de Los Estados, Argentina

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The primary mission of R/V *Hero* cruise 71-5 was a botanical expedition to Isla de los Estados, Argentina, which is off the eastern tip of Tierra del Fuego and is separated from it by LeMaire Strait. This rugged, mountainous island is about 60 kilometers long, with its long axis running east-west. Both the north and south coasts are much dissected by numerous bays and harbors, many fjord-like.

The itinerary of cruise 71-5 was designed to

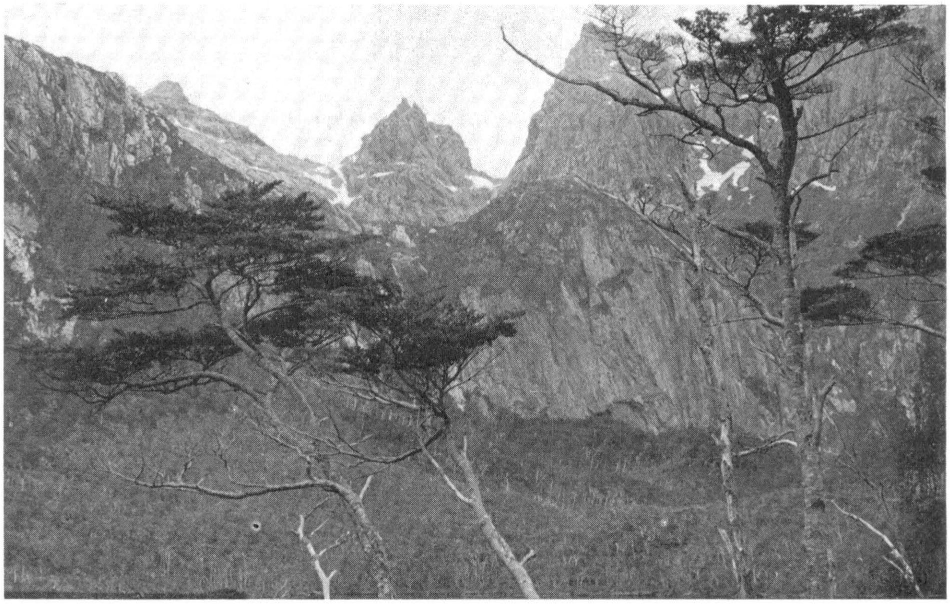

Figure 1. *Nothofagus betuloides-Drimys winteri* association. *N. betuloides* is in the foreground. Location: Puerto Celular.

Photos by author

Figure 2. Luxuriant growth of filmy ferns on forest floor. Location: Puerto Parry.

explore both the north and south coasts in an effort to survey the island's flora, including vascular plants, lichens, and bryophytes. Theodore R. Dudley, R. N. P. Goodall, and I dealt with the vascular plants. A full report of *Hero* cruise 71-5 was presented in Imshaug (1972).

The total vascular flora is strikingly impoverished with regard to the number of species comprising

Figure 3. *Nothofagus antarctica* association. Location: Puerto San Juan del Salvamento.

it. About 140 taxa are now known from Isla de los Estados and its adjacent islands. On this expedition 1,413 collections of vascular plants (about 4,000 specimens, including duplicates) were made. Seasonal ephemerals of late spring, summer, and fall were probably not represented in our collections. Eight families of vascular cryptogams and 46 families of angiosperms are represented in the flora. No gymnosperms are known to occur on the island.

The following vegetation types occur on Isla de los Estados:

(1) Evergreen forest formation. *Nothofagus betuloides-Drimys winteri* association. The evergreen forest of Isla de los Estados is dominated by *Nothofagus betuloides* and by *Drimys winteri* (figure 1). On the northwestern portion of the island, particularly to the west of the Spegazzini Mountains, the evergreen forest is characteristic of the Magellanic evergreen (mesic) transitional forest as described by Young (1973). Considerable litter occurs on the forest floor and there is a marked sparseness of bryophytes and filmy ferns. In contrast, the forest to the south and east of the island is much wetter and the forest floor consists of a luxuriant growth of bryophytes and filmy ferns, particularly *Hymenophyllum tortuosum* (figure 2). The creeping shrub *Prionotes myrsinites* becomes well developed, often forming a dense growth on the forest floor, and frequently occurs climbing up the bases of trunks and rotting stumps. Epiphytic ferns and bryophytes are also frequent and the ground-dwelling fern, *Blechnum magellanicum,* is often encountered. The forest of this portion of the island is more characteristic of the true Magellanic evergreen rain forest occurring along coastal southwestern Chile (Young, 1973).

The forest of Isla de los Estados, especially at Cabo San Juan de Salvamente, at the eastern tip of the island, was an important source of wood for early sealing expeditions as this was the last opportunity to take on wood before heading south to the "barren" islands of the southern oceans (Mitterling, 1959).

(2) Scrub formation. *(a) Nothofagus antarctica* association. The summer green (deciduous forest of the Magellanic region is represented by the upper-elevation *Nothofagus antarctica* zone (Skottsberg, 1910). It is restricted to a narrow belt of dwarfed, gnarled, scrub vegetation occurring above the evergreen forest at the upper elevations of the mountains, and just below the alpine zone (figure 3). *Nothofagus antarctica* forms nearly a pure stand of scrub with little undergrowth present. This stunted, thick, crooked, flat-topped vegetation reaches a height of 1 to 1.5 meters and is nearly impenetrable. Frequently, it was found more profitable to struggle over the flat-topped surface than through it. *Nothofagus pumilio* is entirely absent from the island.

(b) Nothofagus betuloides-Marsippospermum grandiflorum association. This vegetation type is best developed on the slopes of the rounded hills at Bahía Crossley at the northwestern end of the island. *Nothofagus betuloides* is the important woody constituent, shrubby in habit, and forming a dense growth that is sometimes almost impenetrable. The rush, *Marsippospermum grandiflorum,* is the dominant ground cover (figure 4).

(3) Magellanic moorland formation. The plant communities of the moorland are perhaps the most difficult to define since the formation consists of a mosaic of subunits that may be quite small or may be very extensive, as is sometimes the case of *Astelia* mats. The moorland is largely dominated by *Empetrum rubrum, Pernettya mucronata,* and *Marsippospermum grandiflorum* (figure 5). *Sphagnum* moss is often present as well. At higher elevations, extensive low, flat mats of *Astelia pumila* and large, flat patches of *Caltha dioneifolia* are frequently encountered. Nowhere on the island were true sphagnum bogs encountered.

(4) Alpine formation. Generally alpine sites occur above 450 meters, with the lower limits modified locally by exposure and edaphic factors. Most alpine sites consist of fellfield. The vegetation typically consists of cushion plants creeping along the ground. *Nothofagus antarctica* and *Empetrum rubrum* are generally present, but are greatly dwarfed and grow prostrate to the soil surface (figure 6).

(5) Meadow formation. *Marsippospermum grandiflorum* association. This community is generally associated with valleys and other sites of level terrain. The dense growth of *Marsippospermum grandiflorum* gives the appearance of a grass meadow. Woody species attain only a small shrubby form and occur scattered throughout (figure 7).

(6) Littoral vegetation. Plants along the rocky shoreline occur rooted in cracks and shallow soil pockets and are mostly cushion plants or tufted plants. *Colobanthus subulatus, Crassula moschata, Plantago barbata,* and *Poa darwiniana* commonly occur in this habitat.

Sandy beaches are infrequent on this island but where they do occur the most common plants just above the high tide mark are *Senecio candicans, Apium australe, Caltha sagittata, Acaena magellanica,* and bunch grasses. Only two beaches, at Puerto Roca and at Bahía Colnett, are of sufficient length to land a small plane.

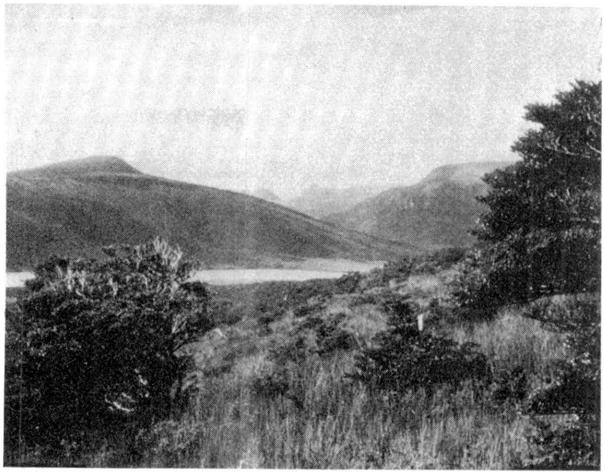

Figure 4. *Nothofagus grandiflora-Marsipposperum grandiflorum* association. Location: Bahía Crossley.

(7) Maritime tussock formation. *(a) Poa flabellata* association. Out on the headlands and high bluffs facing the ocean there is generally a zone dominated by the tussock grass, *Poa flabellata.* The greatest development of the tussock grass formation was seen on Isla Alfredo Goffré, an island off the north coast (figures 8 and 9). Here the Magellanic penguin finds the tussock grass bases ideal for its burrows.

A site of especial interest is Cabo San Bartolomé, at the southwestern end of the island. Here *Nothofagus betuloides* and *Drimys winteri* are dwarfed by the strong westerly and southwesterly winds and are restricted to draws. Tussock grass is well established on the windward slopes and numerous large

Figure 5. Magellanic moorland. Location: Bahía Flinders.

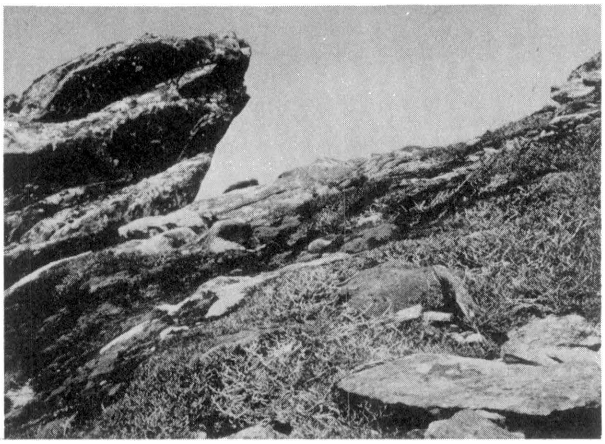

Figure 6. Alpine. Location: mountain peak between Bahía Alexander and Bahía Capitan Cánepa.

cushions (1 to 1.5 meters in diameter) of *Bolax gummifera* are conspicuous in the extensive *Marsippospermum grandiflorum* meadow on top of the cape. This locality is the only site where the giant petrel *(Macronectes giganteus)* was seen nesting. This section of Isla de los Estados is floristically reminiscent of sites in the Falkland Islands (Islas Malvinas) (Imshaug, personal communication).

Of particular interest is the near absence of introduced species on Isla de los Estados. Field mouse-ear chickweed *(Cerastium arvense)* is present, but is infrequent and restricted to coastal sites. Similarly, only single occurrences of common mouse-ear chickweed *(Stellaria media)* were noted. Only one specimen of dandelion *(Taraxacum officinale)* was found, a plant that occurs abundantly in disturbed sites on Isla Grande, Tierra del Fuego.

Sagina procumbens, an introduced Eurasian species that occurs widely in disturbed habitats on Isla Grande, Tierra del Fuego, and in fact widely throughout the subantarctic, is entirely absent from Isla de los Estados (Crow, 1974). The near absence of weeds is especially noteworthy since Puerto Cook was the site of a prison operated by the Argentine government at the turn of the century (Bridges, 1948; Skottsberg, 1909). Skottsberg makes brief reference to some occurrence of weeds at this site; however, now no evidence of habitation can be observed except for crosses marking gravesites. The relative absence of weed species on the island can most probably be attributed to a scarcity of sites with a mineral soil rather than peat, as weeds are generally colonizers of disturbed sites with a mineral soil. The very wet, cold climate favors peat formation and the peat accumulations would tend to exclude weedy species, even in somewhat disturbed sites.

In addition to plant specimens, peat cores were taken from three sites (Puerto Vancouver, Puerto

Figure 7. *Marsipposperum grandiflorum* association in foreground. Hillside in background is covered with *Nothofagus betuloides-Marsipposperum grandiflorum* association. *Nothofagus antarctica* association appears as "bare" patches on the upper slopes and the summit.

Figure 8. Maritime tussock formation. *Poa flabellata.* Location: Isla Alfredo Goffré.

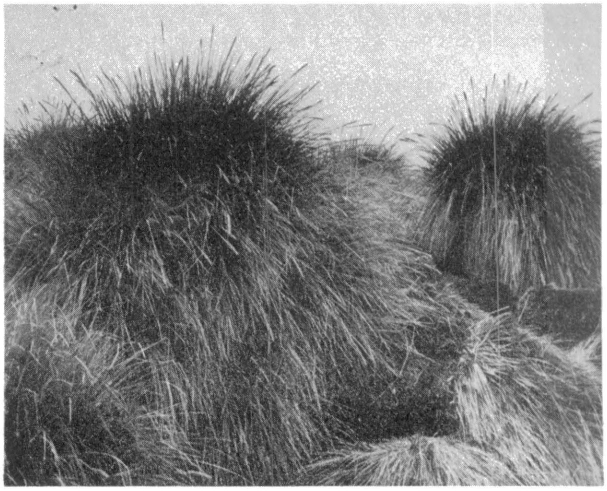

Figure 9. Tussocks of *Poa flabellata.* Location: Isla Alfredo Goffré.

Celular, and Bahía Crossley) with the greatest depth reached being 9.5 meters at Bahía Crossley. A pollen analysis is being carried out by Ralph Taggart, Michigan State University, which will hopefully shed new light on the post-Pleistocene climatic and vegetational history of the Fuegian region. A paper on the vegetation of Isla de los Estados, past and present, is in preparation by Dr. Taggart and me.

The success of *Hero* cruise 71-5 is due in no small part to the dedicated support of Captain Liberty and his crew. Gratitude also is expressed to Dr. H. A. Imshaug, chief scientist of the expedition. I thank Drs. D. M. Moore, Imshaug, and Dudley, and Mrs. Goodall for their critical review of my manuscript.

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Encounters with leopard seals *(Hydruga leptonyx)* along the Antarctic Peninsula

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The leopard seal, *Hydruga leptonyx,* is a major large carnivore in antarctic waters that frequently consumes warm-blooded prey. It is commonly abundant in nearshore areas or along edges of pack ice where it feeds chiefly on krill, penguins, and sometimes other pinnipeds. It has a rather sinister reputation among some antarctic explorers, probably because of its reptilian appearance, toothy maw, and predatory behavior. Known attacks or possible aggression toward humans, however, are few and are anecdotal in nature. This seal nevertheless is potentially dangerous because of its large size, mobility, and feeding habits.

For the past 4 years our group has engaged in scuba diving and small boat operations chiefly at Palmer Station (Anvers Island), as well as at numerous other locations along the Antarctic Peninsula. Well over 1,200 dives and hundreds of hours of small boat operations have been completed, during which there have been several encounters with leopard seals that have caused us concern. We have documented our experiences and observations because they appear to be largely unrecorded and unique, and because these seals must be regarded as dangerous to humans in or near the water. In addition to summarizing our encounters, this paper presents the procedures that we have developed to avoid or to reduce the hazards of coping with leopard seals.

"Although krill are commonly taken, leopard seals consume larger prey as well. . ."

Predatory behavior

Previous observations of leopard seal predatory behavior primarily have been made near penguin rookeries and around floating ice (Hofman, in press; Müller-Schwarze, 1971; Penney and Lowry, 1967; Ray, 1966). The type of food taken and the behavior required to capture it are dictated by the food's availability and by shifts in emphases of food preference that occur as the seal ages (Hofman, in press). Although krill are commonly taken, leopard seals consume larger prey as well: for example, penguin adults and chicks as they enter or leave the water (Müller-Schwarze, 1971; Penney and Lowry, 1967; Peterson, 1965), fish (Ray, 1966; Hamilton, 1934), platypus (Scheffer, 1958), and other species of seals (Hofman, in press) including an adult sea lion (Hamilton, 1934). Leopard seals normally do not hunt on land or ice; prospective victims therefore are relatively safe there. We have seen penguins being pursued by leopard seals, and commonly the penguins get out of the water as fast as possible. Apparently penguins and perhaps smaller seals can outmaneuver leopard seals in open water. But near shore, where maneuverability is restricted and there is some element of surprise, leopard seals can more easily capture their prey.

". . . suddenly the seal reversed itself, reentered the water, swam under the floe, and appeared again . . . in Orde-Lees' path."

Leopard seals and humans

Leopard seals occasionally have confronted humans. As far as we know, however, there have been no injuries. These seals have been known to lunge or chase after people standing on beaches or ice. According to A. Lansing's (1959) account of Shakleton's ordeal when *Endurance* was beset in the Weddell Sea, a leopard seal leaped from between ice floes and began to chase the storekeeper, T. H. Orde-Lees. Orde-Lees fled across the floe with the seal in pursuit when suddenly the seal reversed itself, reentered the water, swam under the floe, and appeared again from between floes in Orde-Lees' path. The animal then lunged for the man with its mouth open. The episode ended when the second in command, F. Wild, approached the scene with a gun, and the seal began to move toward him. Wild killed the seal with several shots.

Zimmerman (1965) also reported several encounters with leopard seals during his stay on the Melchior Islands (immediately north of Anvers Island). In one of these encounters a colleague was examining intertidal organisms on a rocky area that was flanked by high ice and snow banks. A leopard seal appeared, cutting off his colleague's retreat and forcing him to keep the animal at bay by throwing chunks of ice. The animal was eventually discouraged and escape was accomplished.

W. Curtsinger, while diving along the Antarctic Peninsula in 1970, was approached closely underwater by a leopard seal. Curtsinger managed to photograph the seal at very close range (Matthews and Curtsinger, 1971) before he left the water. Bellisio and Tomo (1974, page 159) reported that Argentine divers also have seen leopard seals underwater, and that their divers have always left the water without incident.

Although some of these accounts may be partially fanciful or incomplete, it is this kind of information—as well as the leopard seal's physical appearance—on which the animal's threat to humans is based.

Documented confrontations, 1971-1975

Members of our research group, working on the Antarctic Peninsula where leopard seals are common, have observed or participated in many surface and underwater encounters with these seals. Since December 1971 we have documented these events to assess the dangers posed by leopard seals. Our findings are summarized below.

(1) On numerous occasions we and others in motorized rubber boats have approached leopard seals on ice floes or bergs. In most of these cases, after eying the boats and their occupants, the animals have slipped into the water and disappeared. Other animals simply have reared and opened their mouths while remaining on the ice. R. Hofman and assistants have approached, anesthetized, and tagged many leopard seals resting or sleeping on floating ice in the Arthur Harbor vicinity without serious incident. Leopard seals seem unaggressive when surprised on ice.

(2) In January 1972 P. Jacobs and A. Owens were crossing Arthur Harbor, adjacent to Palmer Station, in a small, motorized whaleboat, when a penguin with blood oozing from several puncture wounds in its breast leaped from the water into the boat. A leopard seal immediately surfaced and

swam in circles around the boat, coming next to the boat and lifting its head high to see inside. Messrs. Jacobs and Owens drove the boat away as fast as possible because they believed their lives would be in danger if the seal decided to enter or attack the boat. The seal in this case seemed more interested in completing its capture of the penguin.

". . . a penguin with blood oozing from several puncture wounds in its breast leaped . . . into the boat."

(3) The only encounter involving physical contact occurred underwater in January 1972. Mr. DeLaca was bumped hard by a large seal while he was diving at 10 meters under some kelp in Arthur Harbor. The animal struck a glancing blow to Mr. DeLaca's scuba tanks, spinning him around. The dive, however, continued for several more minutes without further incident. Upon surfacing, a leopard seal was seen circling the dive boat, and the tender reported that the animal had been in the area for 10 minutes or so. Mr. DeLaca concluded he had been hit by that animal, although he did not actually see the seal strike him.

(4) In January 1973 Mr. DeLaca and A. Gianinni were ascending from a 30-meter dive at Sail Rock, near Deception Island, when they saw a leopard seal capture a penguin just above them. The penguin was grabbed quickly by the seal and taken out of view, leaving only blood and feathers in the water. The divers terminated their dive, boarded the boat, and motored away without incident. Again the seal appeared to be interested only in the penguin.

(5) Later that same month, Messrs. DeLaca and Giannini were diving in the channel next to Palmer Station. W. Stockton, the boat tender, saw a leopard seal approaching and notified the divers by underwater communication gear to terminate their dive. Seconds afterwards, the divers observed a large seal flash by in the murky water; the divers entered the boat rapidly. The seal remained nearby for the brief time it took to start the boat. As the boat moved away the seal followed for over 100 meters (all the way to the Palmer Station dock), rearing its head out of the water and lunging to within a meter of the boat's transome. At the dock the men scrambled up a ladder while the seal swam vigorously back and forth near the dock, rearing out of the water in what was interpreted at the time as an aggressive display.

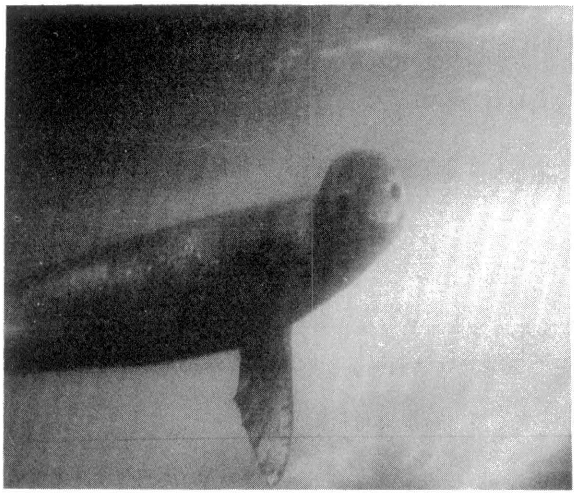
(6) In October 1973 Mr. Gianinni and P. Haley were swimming along a transect line at 12 meters after collecting samples near Palmer Station. A leopard seal appeared. It swam in circles around Mr. Gianinni for several minutes. Mr. Gianinni used his bulky camera housing for protection as the animal approached, and he worked his way to the Palmer Station dock. The leopard seal seemed to lose interest as the divers left the water. The divers' interpretation was that the animal was only curious.

(7) In January 1974 R. Moe and N. Temnikow traveled to Sail Rock in a 3.5-meter, motorized inflatable boat. Before they entered the water for a planned scuba dive, a large leopard seal rapidly approached the boat, circling and lying in the water near it. Abandoning their diving plans, the men left in the boat. The seal followed them closely for over 100 meters, occasionally lifting its head clear of the water. This animal also seemed to be attracted only to the boat and motor.

(8) On several occasions divers have been approached by leopard seals underwater when they were unaware of it. For example, in January 1974 Messrs. Gianinni, Lipps, and Temnikow were diving in shallow, low-visibility water adjacent to Palmer Station when a leopard seal approached and swam near the divers but was not seen by them. People gathered on shore and reported that the seal swam among the divers. No contact was made with the seal who again seemed merely curious.

". . . the seal had followed them and was lying in the water under the boat."

(9) During that same season, Messrs. Moe and Temnikow were preparing to dive adjacent to the Joubin Islands, near Arthur Harbor, when they noticed a leopard seal close to the boat. They decided to avoid the animal and moved the boat approximately 400 meters to an alternate dive site. As they prepared to enter the water they discovered that the leopard seal had followed them



Photos by T. E. DeLaca

Figure 1. The leopard seal commonly positioned itself between the retreating divers and their only place of escape—the shore.

and was lying in the water under the boat. Although the seal did not again follow the boat when it left this last station, it apparently was curious about it when it first arrived.

(10) A more serious encounter occurred on February 2, 1974, between Messrs. DeLaca and Zumwalt and three leopard seals. The divers were descending a submarine cliff off Janus Island in Arthur Harbor when, at a depth of 22 meters, a large leopard seal (approximately 4 meters in length) approached from shallower water to within 4 meters of the men. The seal only appeared to be curious so the dive was continued. At 32 meters, after they began to collect specimens, two more large leopard seals appeared and the original seal became more aggressive. It became obvious that the situation had become serious and that the dive should be terminated. Leaving their collecting apparatus and only carrying camera gear they moved up the cliff with the original seal still following at a distance of 7 to 10 meters. The other two seals disappeared.

At a break in the vertical cliff face at 21 meters in depth the behavior of the leopard seal changed markedly: it began to approach more closely. Until about 10 meters in depth the divers were forced to slow their ascent because of the repeated and close approaches of the seal. The seal appeared more agitated as the divers approached shore, spending more time at increasingly closer inspections. At approximately 7 meters the divers found meter-long pieces of angle iron, which they held between themselves and the seal as they continued their ascent. At 5 meters they were trapped in a rock alcove for 30 minutes (figure 1). Further progress toward shore was prevented by the now constant presence of the seal. The seal breathed at the surface immediately above the divers (figure 2) and

"The seal . . . shook its head vigorously from side to side and blew bubbles into the water."

then returned to within a meter of them, hovering in the water with its nose about 0.3 meter from the end of the angle iron and repeatedly striking at the end of the angle iron. When striking, the seal would bend its neck into an "S" or coil it (figures 3 and 4). It seemed more aggressive for it increased its swimming rate and frequency of striking as time passed. The seal never opened its mouth, although it shook its head vigorously from side to side and blew bubbles into the water. When the animal returned to the surface for prolonged breathing periods, it frequently positioned itself between the divers and the only shoreward escape route possible. It also positioned itself in the sun. The divers were thus forced to look into the sun to keep the seal in sight. The seal's movements were difficult to follow because after leaving the bright surface it approached from unexpected directions of subdued lighting (figure 5).

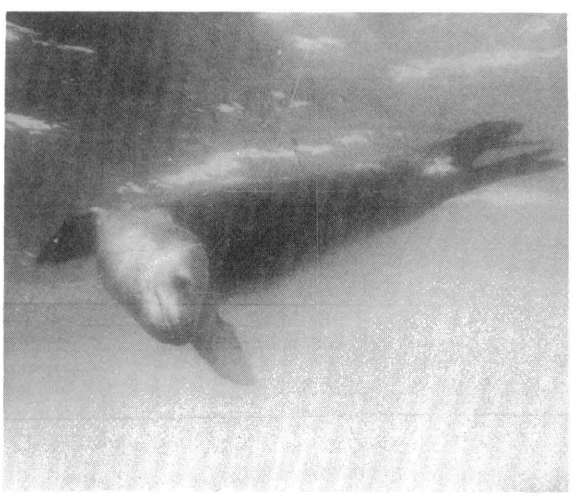
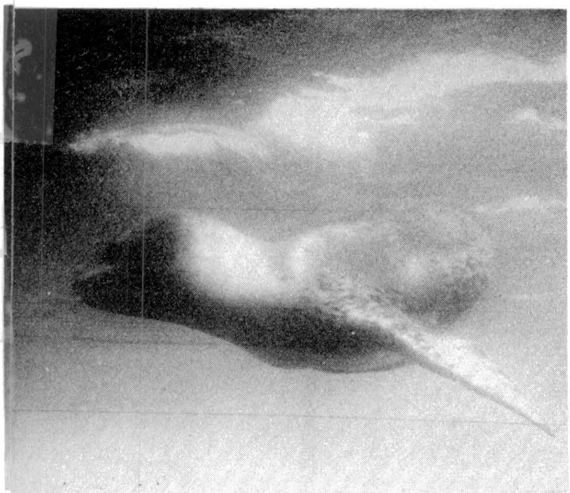


Figure 2. The leopard seal made further progress impossible by its constant presence.

This sequence of events averaged 15 to 20



Figures 3 and 4. While hovering, the leopard seal would "S" curve its neck prior to striking. When it struck, its muzzle moved approximately 0.3 meter with surprising quickness and force.

seconds. Finally a break in the sequence occurred when the boat tender succeeded in distracting the seal, thereby allowing Messrs. DeLaca and Zumwalt to swim up a tide channel and leave the water. This whole confrontation lasted for approximately 45 minutes.

(11) Messrs. DeLaca and Zumwalt encountered another smaller leopard seal (2.5 meters in length) (figure 6) underwater on February 5, 1974, in the channel next to Palmer Station. Because of their previous experience they carried a meter-long staff with them. At 13 meters the seal approached and positioned itself between the divers and the shore. The divers were forced to wait as the seal continued to swim closer. Unlike their first encounter, where the divers only used the angle iron defensively, Mr. DeLaca several times swam at the seal for 1 to 2 meters with the staff extended. This younger animal performed the same striking behavior as the previous seal, but when charged it back away and there was no contact. After 20 minutes the divers reached a depth of 7 meters and a place that offered a favorable exit. While the seal was momentarily distracted they escaped to shore. The seal swam around in the immediate area for several minutes and then remained in the general area for some time thereafter.

(12) On January 21, 1975, Mr. DeLaca and W. Showers were scuba diving near Palmer Station when, at 23 meters, a small leopard seal appeared. The divers stopped sampling and moved along the bottom toward shallower water and shore with intermittent interruption by the seal. Their progress was reduced as they neared shore by the

Figure 5. The animal's extreme speed and maneuverability, and abrupt changes in light intensity from the bright surface to the murky depths, made it difficult for the divers to follow the seal's movements.

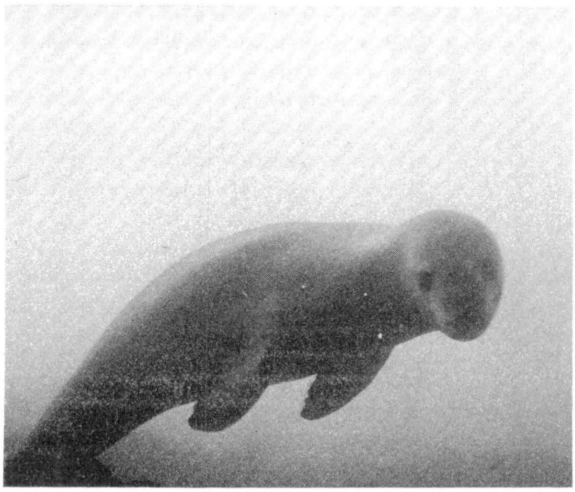


Figure 6. The younger and smaller seal that approached the divers on February 5, 1974.

constant presence of the leopard seal, which by this time had approached to within a meter. The animal seemed to be playful and only curious; the divers moved past it to shore. The leopard seal lost interest and left as the divers climbed out of the water.

(13) On January 25, 1975, D. Parmelee and two assistants in a zodiac boat were attacked by a very large leopard seal as they approached Breaker Island, Wylie Bay. The seal swam with rapid movements under their boat and with its mouth open struck the bottom of the boat. On several occasions during this confrontation the seal surfaced and bit at the pontoons that formed the sides of their inflatable motor boat. This encounter lasted more than 10 minutes. The seal eventually lost interest and moved on.

Dr. Parmelee reported that apparently the same leopard seal had approached his party on previous excursions to Breaker Island and that it had become progressively more aggressive with each successive encounter. Until this incident, however, it had never made physical contact with the zodiac.

(14) A potentially dangerous situation developed in February 1975 when D. Laine entered the water from a moored zodiac in the channel adjacent to Palmer Station. After Messrs. Laine and Temnikow completed predive preparations, Mr. Laine entered the murky water. He began swimming just below the water's surface toward what appeared to be the moving silhouette of his diving partner. As he drew nearer he realized that the silhouette was that of a leopard seal that was swimming, open-mouthed, toward the zodiac. At that moment Mr. Laine's presence distracted the seal, which then turned to confront him. Mr. Laine quickly reentered the zodiac. Mr. Temnikow, who was sitting on a submerged rock platform alongside the zodiac, felt the leopard seal as it brushed by him. The seal left and did not return.

Conclusions

Leopard seals are sophisticated top-level carnivores. They, like many high-latitude organisms, are extremely generalized and opportunistic in their feeding habits. Their behavior undoubtedly is quite complicated. Based on our field observations we nevertheless have drawn the following generalizations concerning their interactions with humans:

(1) Leopard seals on ice floes are not especially dangerous when surprised by boats or people. They usually flee or remain stationary. In most cases they merely seem to want to escape (unless they feel cornered). They may charge, but then probably only to an avenue of escape.

(2) While active in the water, leopard seals are attracted to unusual noises or vibrations; for example, small boat motors and propellers and the sounds that scuba divers make. M. G. White, British Antarctic Survey, also concluded this from his experience at Signy Island, northeast of the Antarctic Peninsula (personal communication, 1974). We think these animals are just curious.

(3) When hunting, leopard seals can be dangerous if people somehow interfere in the chase. Once their prey is taken, however, the danger subsides.

(4) After a period of time, leopard seals confronting submerged scuba divers may become aggressive. This behavior may be interpreted as an attempt to flush prey, "playfulness," increasing curiosity, or some sort of prey-capture procedure. We exclude the prey-capture possibility because the seals never made an attempt to seize divers, even unsuspecting ones. Of the remaining possibilities, we interpret their behavior—especially the striking action—as an attempt to flush divers into flight. Had this occurred, the seals might possibly have attempted a capture (they ordinarily capture large animals swimming in open water). Our divers have always been close to rocky cliffs during encounters with leopard seals; these solid surfaces have been used for protection.

Since humans are not the normal prey of leopard seals, scarcity of food may enhance seal inquisitiveness. Field notes taken in the Arthur Harbor area during late January and early February 1974 indicate a decrease in local krill and an increase in leopard seals. Further, during this period leopard seals displayed a behavior similar to that described by Penney and Lowry (1966) for leopard seal predation on penguin chicks 1 to 2 weeks before most of the chicks actually entered the water. We think that these conditions may have indicated a food shortage and may have contributed to our encounters of February 2 and 5, 1974.

Precautions with leopard seals

Leopard seals obviously pose a potential danger to humans, if for no other reason than their large size and close approaches. We have formulated procedures to reduce these hazards when people must work in or near the water. Although they seem logical, based on our observations, these procedures have not been tested many times. We present them because we have seen people previously inexperienced with leopard seals panic and do inappropriate acts. Hopefully our procedures will encourage discussion and awareness in other groups working around leopard seals.

(1) The work site vicinity should be inspected

United States inspects four Peninsula stations

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The United States inspected four foreign research stations in the Antarctic Peninsula area during January 1975. This was the fourth such U.S. inspection conducted in accordance with Article VII of the Antarctic Treaty, which states in part: "All areas of Antarctica, including all stations, installations and equipment within those areas, and all ships and aircraft at points of discharging or embarking cargoes or personnel in Antarctica, shall be open at all times to inspection by any observers" (designated by parties to the treaty). Since the treaty entered into force in 1961, other U.S. inspections of foreign antarctic stations have been made during the austral summers of 1963-1964, 1966-1967, and 1970-1971. Argentina, Australia, New Zealand, and the United Kingdom also have conducted inspections of other nations' antarctic stations under the provisions of Article VII.

Antarctic Peninsula stations were chosen for the recent inspection because of their accessibility, relative particularly to those in East Antarctica, and because the U.S. had not inspected Peninsula stations since 1963-1964. However, as anyone familiar with logistics planning in the Antarctic is aware, flexibility is essential for any operation. The original plan was to introduce the inspection team into the treaty area from South America and to conduct the inspection from the National Science Foundation's R/V *Hero*. But this plan had to be abandoned when *Hero* was delayed by mechanical difficulties en route to South America. Instead the team flew to McMurdo Station to board the U.S. Coast Guard icebreaker *Glacier* for the 4,200-kilometer voyage to the peninsula.

Mr. Yoder, a State Department consultant on antarctic affairs, served as antarctic "desk officer" at the Department of State from 1970 until his retirement in March 1974. In addition to Mr. Yoder, the 1975 U.S. inspection team was comprised of U.S. Navy Commander Kelsey B. Goodman, Department of Defense, U.S. Navy Lieutenant Commander Thomas P. Jones, Jr., Arms Control and Disarmament Agency, Frank C. Mahncke, Department of Defense, and Jon Glassman, Arms Control and Disarmament Agency. The Secretary of State chose these individuals from a list of U.S. observers.

Five nations maintain one or more scientific research stations—including the United States' Palmer Station—in the Antarctic Peninsula area. The observers visited the following foreign stations: Argentine Islands (United Kingdom), January 24; Almirante Brown (Argentina), January 25; Bellingshausen (Soviet Union), January 27; and Presidente Frei (Chile), January 28.

The purpose of these inspections was to promote the objectives of the Antarctic Treaty and to observe compliance with its provisions. Hopefully the inspections also served to enhance the spirit of friendly cooperation that has characterized international relations in the Antarctic. Each station was toured comprehensively and the observed activities were compared with the information furnished by each nation under Article VII(5) of the Antarctic Treaty and under certain recommendations of treaty consultative meetings. Facilities, equipment, and instruments were examined to determine their general utility and intended purpose. On-site observations were supplemented by aerial observations of each station and its surrounding area.

Scientists and support personnel at the visited stations extended warm welcomes to our team and graciously offered full cooperation and hospitality. Small token gifts were exchanged, the team having been provided with a number of special shoulder patches for that purpose. In each station the station leader and others described their station and its programs in detail and answered questions with apparent candor. Without reservation they made all buildings and equipment available for inspection. At the conclusion of each visit, the team reciprocated the host station's hospitality by extending an invitation, on behalf of U.S. Coast Guard Captain C. R. Gillette, to visit *Glacier* for dinner.

The science program at Argentine Islands is devoted primarily to the collection of physical science data with emphasis on meteorology, geomagnetism, and upper atmosphere physics. A new experimental summer operation designed to measure the amplitude, velocity, and direction of propagation of ionospheric disturbances began in January 1975. The station makes standard synoptic for leopard seals prior to beginning work. No work should be attempted when active leopard seals are seen within about 400 meters. Personnel should not remain in the area when active leopard seals are present.

(2) An assistant should maintain a watch for leopard seal activity while the work is in progress. If seals are sighted, the assistant should signal the workers to abort their activities and should also alert the base station or ship by radio, if possible, that assistance may be necessary.

Diving in Antarctica presents special problems with regard to leopard seals. We have used the following procedures:

(1) While in the water, one diver is specifically charged with keeping watch for seals.

(2) Divers carry sturdy poles or rods of at least 1.5 meters in length to ward off seals.

(3) If an underwater encounter with a leopard seal occurs, a diver should observe the following procedures:

(a) Notify the partner that a seal has been sighted. Both divers should stay together with rods pointed at the seal and their backs against the rocks. If they are on a flat bottom, the divers should drop to the bottom. In open water, the divers should back together. As soon as possible, the divers should make their way *slowly* to the surface, keeping next to cliffs if possible. They should not rush to the surface or make a quick break in open water.

(b) Should one diver have trouble (runs out of air, drops a fin, mask, *etc.*) the other diver should distract the seal and protect his or her partner.

(c) Upon approaching the surface, the divers should exit the water on land and *not* into a boat. Both divers may be able to exit onto shore easily, whereas the diver exiting into the boat may jeopardize the diver remaining in the water and/or the boat tender.

(d) The boat tender should try to distract the seal(s) by waving arms and slapping the water or the seal with an oar. The tender should not start the motor until the divers are ashore.

(e) If the station's or ship's crew has come to assist, the boat tender should direct them to go ashore to assist the divers' exit from the water by distracting the seal and helping in any other way possible.

(f) When the divers are ashore, the boat tender should start the motor and move away from the scene while at the same time trying to get the seal to follow as the divers climb higher on shore. The divers should be picked up later or at a different and safe spot along the shore, unless circumstances warrant otherwise.

We have considered other methods of protecting ourselves from leopard seals; for example, some sort of electric prod, "shark darts" that discharge carbon dioxide through a hypodermic-style tip, shark "bang sticks" that fire a cartridge upon contact, shooting the seals as they surface, or using "seal bombs" (firecracker-sized explosives) at the site prior to making dives. At present, these alter-

"Avoidance is of course the best solution."

natives seem ineffective and even more hazardous to the divers than to the seals. We prefer a more passive, slow retreat to other methods that may antagonize the seals. Avoidance is of course the best solution.

We thank all the members of our diving team who, despite some terrifying experiences, remained composed and clearly reported their encounters: T. Brand, R. Daniels, M. Erskian, T. Kauffman, W. Krebs, and Messrs. Giannini, Haley, Laine, Moe, Showers, Stockton, and Temnikow. Drs. Parmelee, Hofman, and Owens discussed their experiences with us. Our project to study the biology and ecology of benthic foraminifera is supported by National Science Foundation grants GV-31162 and 74-12139.

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meteorological observations, including a daily radiosonde balloon launch.

The major science programs at Almirante Brown are in chemical oceanography, marine biology, and meteorology. Quantitative and qualitative chemical analyses of seawater and plankton support an effort to determine the productivity of the contiguous waters. Standard surface synoptic meteorological observations generate continuous pressure, temperature, and humidity records. Situated in a dramatically scenic setting, the station looks out at a glacier-capped rugged mountain across a placid bay. Such striking beauty had attracted some 2,000 tourists this season by the time of our visit.

Science programs at Bellingshausen were principally in meteorology, satellite tracking photography, biology, and medicine. Two new programs in radiometrics and radioactive atmospherics are being established this year. Synoptic meteorological observations are sent to the Soviet antarctic weather center at Molodezhnaya. There are plans to move the balloon launching hut to a hill on the east side of the base. In its present location, the adjacent Chilean antenna farm presents a hazard in which balloons occasionally become entangled. The biology program, which included the taking of a few birds and mammals for research, terminates with the departure of the 1974-1975 winter personnel.

Frei is the meteorological and communications center for the Chilean antarctic program, and provides weather forecasting services based on standard observations and analyses. The station chief said that Chile is considering relocating this meteorological center, possibly to Adelaide Island or elsewhere in the Marguerite Bay vicinity.

The team concluded that all scientific programs and support operations at the visited stations appeared to be for peaceful purposes only. There was no evidence of any treaty-prohibited activity. The team also found no evidence that Antarctica had been used for nuclear explosions or for the disposal of radioactive wastes. The only weapons seen were a few small arms used for signaling purposes or to obtain animal specimens principally for biological programs. Sound practices for preserving and conserving living resources were being observed. The locations of the stations visited and the activities conducted at each do not appear to have an adverse effect upon the environment.

Emperor penguins nesting on Inaccessible Island

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Emperor penguins *(Aptenodytes forsteri)* nest in possibly 29 coastal rookeries around Antarctica and are estimated to number a million individuals (Korotkevich, 1964). During the austral winter they nest on ice attached to either the continent or adjacent islands. The first egg is laid in early May and the emperors abandon their breeding grounds in early January (Pryor, 1962).

During the 1973 winter, emperor penguins nested on Inaccessible Island. This small island (77°40′S. 166°22′E.) in McMurdo Sound is north of McMurdo Station and west of Ross Island. These emperor penguins were seen by a number of persons from McMurdo Station and Scott Base (New Zealand). Among these persons, on August 25, 1973, R. W. Reeves (personal communication, 1974) saw four emperor penguins sitting on eggs in a natural ice shelter created by a pressure ridge on the island's eastern tip. He also walked to the island's north side but saw no other signs of life. The penguins seemed agitated by his presence so the visit lasted only long enough to take photographs. Mr. Reeves' group was the second Scott Base party to visit the nesting penguins, the first dog sled party having sighted six penguins 2 weeks earlier. At that time four seemed to be sitting on eggs or chicks. In late September 1973 a Scott Base party again visited the area by dog sled and reported seeing 24 penguins (Prill, 1974, personal communication). This nesting of emperors un-

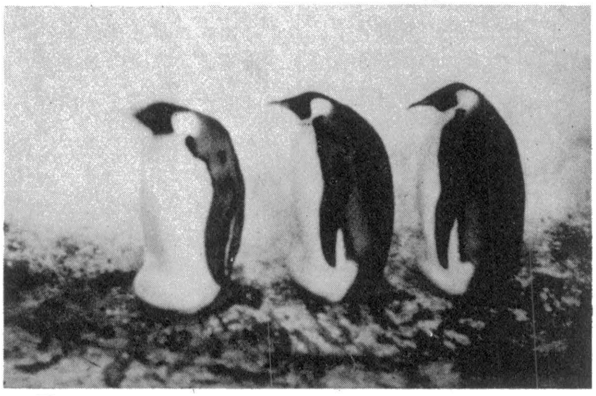

Figure 1. Emperor penguins on Inaccessible Island.

fortunately became a local attraction and various persons wintering at McMurdo Station and Scott Base visited them. Immediate isolation of the new colony from humans might have been appropriate since this nesting attempt was not very successful. On September 26, 1974, J. A. Raymond of McMurdo Station (personal communication, 1974) visited the site and later reported that one emperor and one chick remained; he also found one egg and a frozen chick, which were taken to Eklund Biological Laboratory (figures 1 through 3).

This is the southernmost nesting of emperor penguins thus far recorded; it also could be the

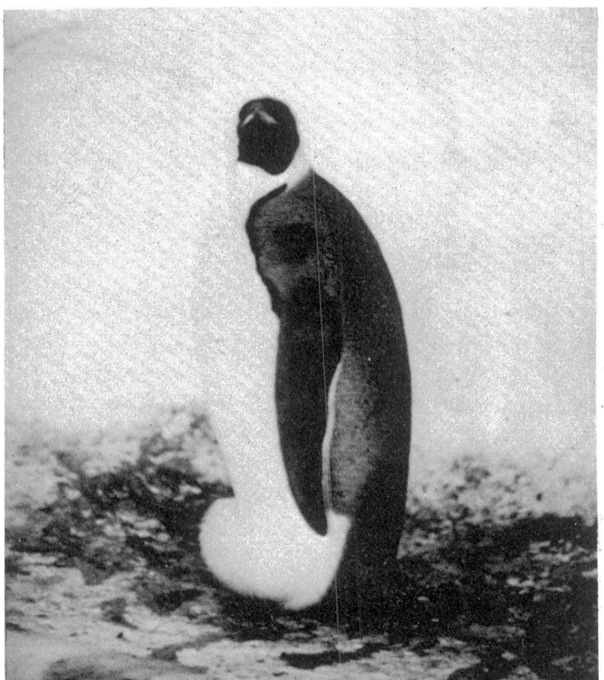

Figure 2. Incubating emperor penguin on Inaccessible Island.

first record of emperors attempting to start a new rookery. This site, however, may have been used by emperors in the past. When Scott camped at Cape Evans, Ross Island, in 1910 and 1911 (Scott, 1923), his party killed an emperor penguin on May 22, 1911, in the bay beyond Cape Barne.

H. Jones of Scott Base (personal communication, 1974) reported a sighting of one adult emperor penguin at the margin between fast sea ice and open water at 77°50′S. 165°30′E. on August 24, 1974. An unusual ice breakout at about that time, however, prevented reaching Inaccessible Island to check on the rookery.

The closest reported nesting of emperor penguins to Inaccessible Island is on the Ross Ice Shelf east of Cape Crozier, Ross Island. Emperor penguins have frequented that rookery for many years, possibly every year since Scott first saw them there in 1902 and when Wilson visited them in the winter of 1911 when Scott's expedition camped at Cape Evans. Captain J. Cadwallader, U. S. Naval Support Force, Antarctica, informed H. J. Harrington (Harrington, 1959) that in earlier seasons he had noticed groups of a dozen or more emperor penguins in the vicinity of Marble Point in McMurdo Sound, which suggested that there might be other small emperor penguin rookeries along the Victoria Land coast. In the 1957-1958 season Captain Cadwallader had also noticed an emperor chick, still partly in down, on an ice floe in McMurdo Sound, and he doubted that it could have drifted from either Cape Crozier or Coulman Island. Except for the chick these emperors were probably in molt.

In late January 1974, while en route to New Harbor by helicopter from McMurdo Station, Dr. Llano sighted small groups of a dozen or more emperor penguins moving over fast ice from open water apparently toward the coast. Observations over several days established that although the penguins, which altogether totaled several hundred, moved from one place to another, they did not approach the land. The helicopter landed close to some of the groups, which were found to consist of adult emperor penguins in various stages of molt.

Since the ice at the Cape Crozier emperor penguin rookery frequently breaks up and drifts out to sea late in the austral summer, there is no suitable permanent habitat at Cape Crozier for emperor penguin molting. Indeed, storms during some years have caused an early breakup of sea ice at the Cape Crozier emperor penguin rookery site and a consequent loss of young chicks. This condition is less evident in McMurdo Sound where fast ice generally remains more commonly in late austral summer. With the exception of the Inaccessible Island record, there is little evidence that

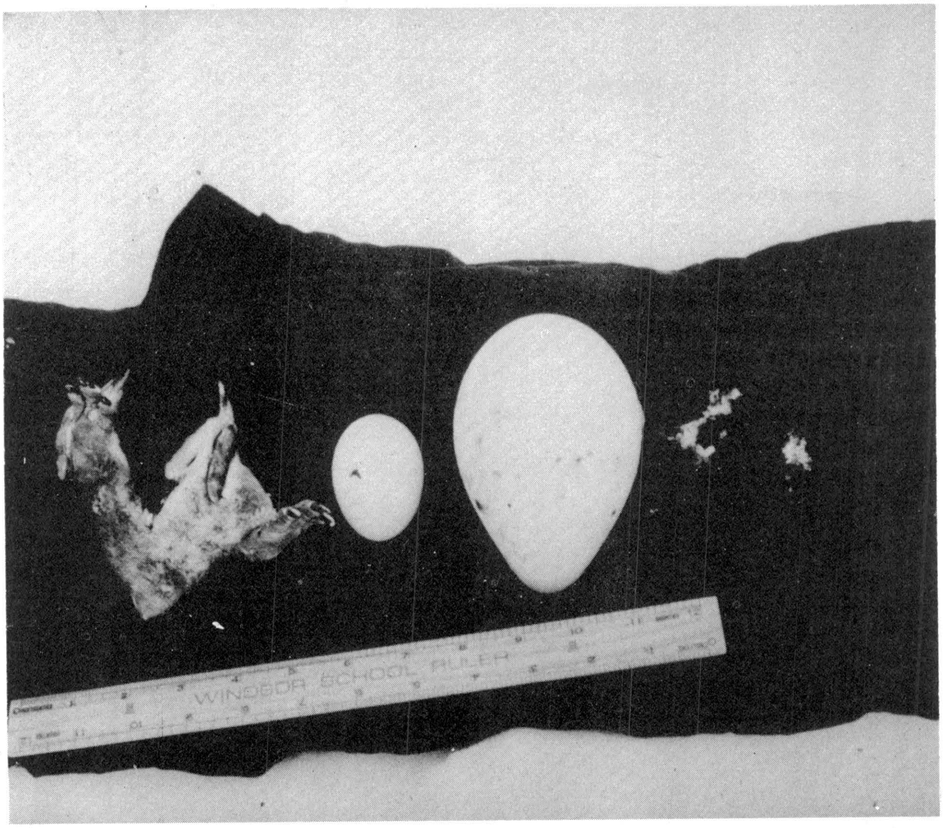

Figure 3. Abandoned egg and dead emperor chick found on Inaccessible Island.

emperor penguins breed in McMurdo Sound proper.

Emperor penguins apparently have nested on rare occasions in the Falkland Islands (Islas Malvinas) (Cawkell, 1954), where at least one young bird has been seen (Hamilton, 1954). They also wander onto the antarctic continent, as evidenced by a decapitated skeleton found in the westernmost corner of New Harbor in the dry valleys (Kohn *et al.*, 1971). An emperor also was found on Oreti Beach near Invercargill, New Zealand, on April 5, 1967 (Henderson, 1968).

Emperor penguins may renest in new locations near established rookeries. Cameron (1969) reported that an ice breakup at the Auster emperor penguin rookery, 50 kilometers from Mawson Station, caused many birds to leave the original colony and establish another rookery 5 kilometers away. Since emperor penguins nest on sea ice, unusual breakup of the rookery site may necessitate such moves.

For sharing their personal observations of this apparently first recorded attempt of penguins to start a new rookery, the authors express appreciation to Messrs. Reeves, Prill, Raymond, and Jones.

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Byrd Station: the first 2 years (1956-1958)

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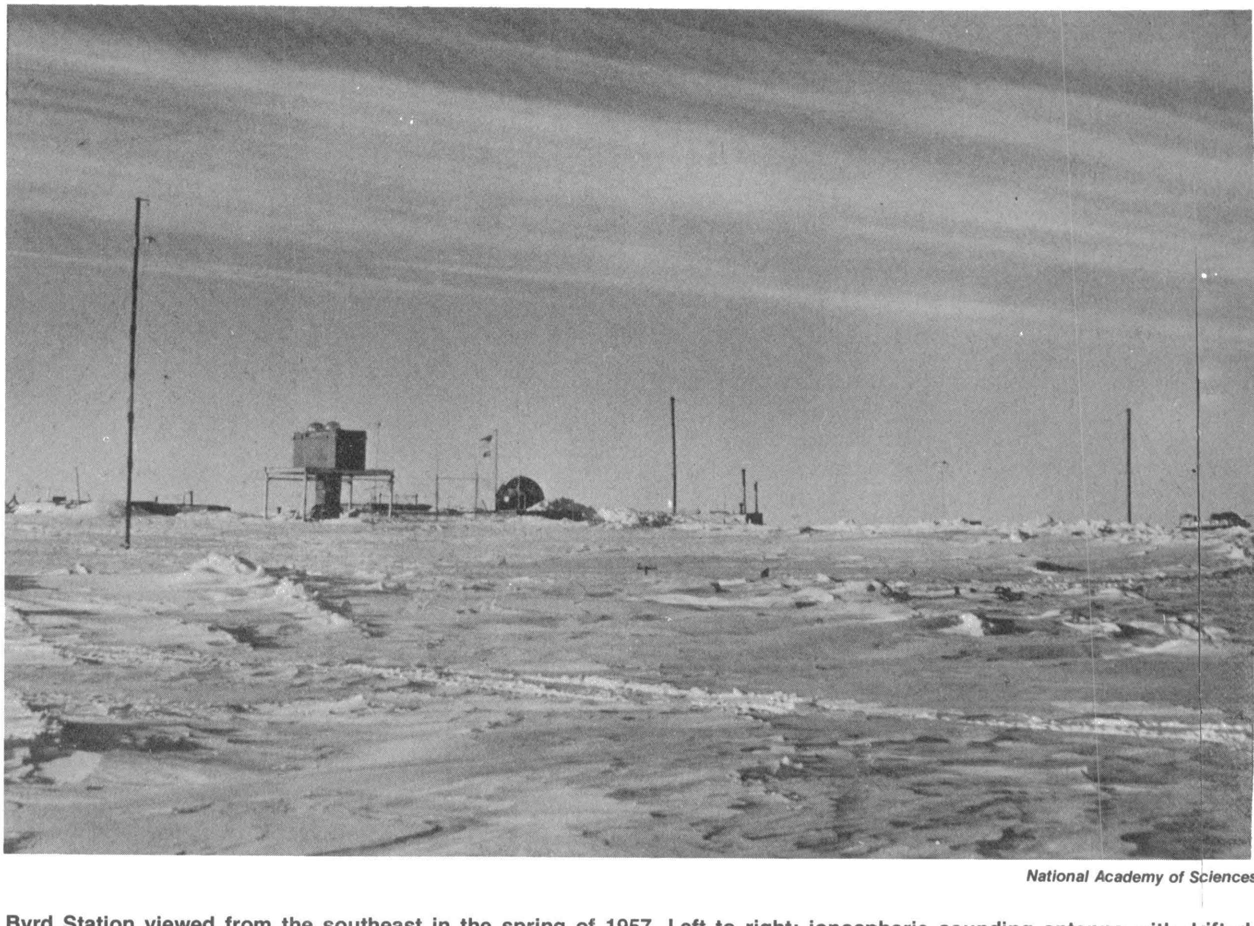
Byrd Station was one of three stations in the original U.S. antarctic program for the International Geophysical Year (IGY), 1957-1958. The other two were Little America V, on the Ross Ice Shelf, and South Pole Station (in 1961 named Amundsen-Scott South Pole Station).

A proposal to construct a scientific observatory at 80°S. 120°W. appeared in January 1954 as part of the mimeographed document, *International Geophysical Year Program and Budget* (generally referred to as the "blue book," a name derived from the color of its cover). The blue book was prepared by the U.S. National Committee for the IGY (USNC-IGY), which was established in March 1953 by the National Academy of Sciences, National Research Council. The blue book's purpose was to present the contemplated program to the National Science Board. Upon approval it would be submitted to the National Science Foundation, which in turn would ask Congress for the needed funds as part of the Foundation's appropriations for the support

This is the first segment of an uncompleted history of Byrd Station, Antarctica, which operated year-round from 1956 through 1971. Dr. Dater was historian of the U.S. Naval Support Force, Antarctica, from 1956 until his death in June 1974.



National Academy of Sciences

Byrd Station viewed from the southeast in the spring of 1957. Left to right: ionospheric sounding antenna with drifted-over buildings behind, aurora tower, and rawin dome. Radio antennas, flagpoles, and stovepipes are visible elsewhere.

of science. The request, however, did not include money for antarctic logistics support because it was assumed that these costs would be borne by the Department of Defense. Otherwise the antarctic portion of the total program for the IGY would have to be dropped.

There followed a period of bureaucratic maneuvering that ended on July 17, 1954, when President Eisenhower directed the Secretary of Defense to provide logistics support for the U.S. antarctic program during the IGY. The Secretary of Defense delegated this responsibility to the Navy as the service best qualified by its equipment and experience to do the job. The Navy moved ahead quickly, organizing a planning group headed by Captain (later Rear Admiral) George J. Dufek.

Early plans

When Admiral Dufek reported for duty in late August 1954, he found that the science community had developed detailed plans based on the blue book. Ready for his consideration was a document, *The USNC-IGY Antarctic Program,* which called for a main base on the Ross Ice Shelf and two satellite stations: one at the geographic South Pole and the other in Marie Byrd Land at 80°S. 120°W. The latter site was chosen primarily because research by Sir George S. Simpson during the British Antarctic Expedition (1910 to 1913) had indicated that pressure waves or "surges" spreading out from this area greatly affected antarctic weather. Secondly, part of the global IGY program provided for observatories along meridional lines from Pole to Pole. One of these lines started in the Northern Hemisphere along longitude 80°W. In the Southern Hemisphere it was to be displaced eastward to 70°W. in order to have stations in South America. The USNC-IGY agreed that an observatory placed at 120°W. would introduce a "slight dog-leg" in this meridional line. Part of their justification was that 50 degrees of longitude (which equals about 5,000 kilometers at the equator) amounts to only a little over 800 kilometers at latitude 80°S.

U.S. and foreign scientists from the start recognized the magnitude of the logistics effort and the cost required to establish antarctic stations. It was also felt that once shelter and support personnel were provided, additional geophysical studies could be undertaken with relatively minor cost increases. Antarctic installations should therefore be established as multiple observatories. In the U.S. program this meant that the stations should be equipped to carry out studies in all or most of the following: meteorology, glaciology, ionospheric physics, aurora, geomagnetism, and cosmic rays. Scientific equipment and supplies actually amounted to about one-sixth of the tonnage that the committee estimated would have to be transported inland from the coast.

In his book, *Operation Deepfreeze,* Admiral Dufek states that one thing worried him: how to move about 450 metric tons of cargo to each site on the polar plateau. In presenting their program, the scientists had remained silent on this point. In the minutes of their meeting, however, they seem to have assumed that the station in Marie Byrd Land would be established and resupplied by tractor train from Little America and that the station at the South Pole would be supported by airplanes. Admiral Dufek accepted these approaches and laid his plans accordingly.

"... part of the global IGY program provided for observatories along meridional lines from Pole to Pole."

As a first step, the Navy sent the icebreaker USS *Atka* to reconnoiter possible base sites. The ship sailed from Boston on December 1, 1954, and returned on April 12, 1955. One finding of this reconnaissance was that the Bay of Whales, site of four previous Little Americas, had gone to sea after a gigantic calving of the ice shelf. The break ran right through the middle of Little America IV, and six Dakotas (C-47s) left there in 1947 at the end of *Operation Highjump* had been carried out to sea. But Kainan Bay, 50 kilometers to the east, did seem usable for the main coastal station, although it appeared doubtful that a snow-compacted airstrip capable of handling the heavy cargo planes required to support the South Pole station could be built on the Ross Ice Shelf.

With *Atka* still in antarctic waters, on February 1, 1955, the Naval Support Force, Antarctica, was created with Admiral Dufek in command and the members of his planning group as the nucleus of a staff. On the basis of information arriving from *Atka,* it was decided to separate the support base for the South Pole from that for the Marie Byrd Land station. The former would be moved to McMurdo Sound where, after a site survey, it was decided that an air operating facility could be established. The latter would be retained, as planned, on the Ross Ice Shelf at Kainan Bay, where a fifth Little America would be erected. It would be necessary to have a logistics base near the eastern edge of the ice shelf for surface vehicle support of the station on the Marie Byrd Land plateau. Meteorologists also were interested in this location because it was one of the few in the Antarctic for which past weather data were available, in this case going back to the Norwegian, Roald Amundsen, in 1911-1912, and continuing through four later U.S. expeditions.

"One finding of this reconnaissance was that the Bay of Whales, site of four previous Little Americas, had gone to sea..."

With the basic decisions made, detailed planning could go forward. The plan for *Operation Deep Freeze I* was dated July 1, 1955. A revised version of the USNC-IGY program appeared in August. These documents provided the basis for the first year's operations. In December an icebreaker would land site survey and trail reconnaissance parties at Kainan Bay. While the first selected a site for Little America V, the other would commence the search for a route inland. The next month cargo ships and icebreakers would bring in a Naval Construction Battalion (Seabee) detachment and supplies for the building and maintenance of Little America, and also the vehicles, materials, and supplies for the Marie Byrd Land station, referred to in the plan simply as Byrd. Seabees would remain over the winter and, early the following season, would set out for Marie Byrd Land with their equipment and supplies. To prepare for this traverse, and if the trail reconnaissance party was successful, it was hoped that the heavy vehicles of the tractor train could lay out food and fuel caches in February and March 1956.

If all went according to schedule, construction would be finished by January 1, 1957. A caretaker party of military personnel would remain at the site until relieved by an all-civilian team of scientists and support specialists. A relief and resupply expedition would be carried out during 1957-1958 and, after the end of the IGY in early 1959, scientific instruments and other valuable equipment would be removed and the station abandoned.

In the complementary scientific plan, the USNC-IGY provided for projects in aurora and airglow, geomagnetism, glaciology, ionospheric physics, meteorology, and seismology. To carry out this program would require 12 scientists and 8 support personnel. During 1957-1958 a scientific traverse from Byrd Station would take gravity measurements and collect data in glaciology, meteorology, and seismology. The traverse route would be determined later by aerial reconnaissance. The Navy did not expect to use the station again, except possibly as a base for emergency aerial search and rescue.

Search for a route

Delays encountered early in the season prevented an icebreaker from putting the site survey and trail reconnaissance parties ashore at Kainan Bay in advance of the cargo vessels and construction crews. Everybody arrived at once on December 30, 1955. Site survey and unloading occurred simultaneously, and building Little America V began as soon as possible.

Amid the confusion, the trail reconnaissance party sought to get organized. In charge was Lieutenant Commander Jack Bursey, U.S. Coast Guard, whose antarctic experience went back to Richard E. Byrd's first expedition (1928 to 1931). On the Antarctic Service Expedition (1939 to 1941) he led a dogsled traverse from Little America III to the Flood Range in Marie Byrd Land, a roundtrip distance of over 1,900 kilometers. In so doing, he had crossed the heavily crevassed area that separates the polar plateau from the Ross Ice Shelf, which would have to be transited again if Byrd Station was to be built. Commander Bursey thus was a natural choice to lay out the trail for the tractor trains.

"Admiral Dufek . . . was determined that the station would be established exactly where the scientists wanted it. . ."

On January 14, 1956, several weeks behind schedule, Commander Bursey and six others set out in a weasel and two Sno-Cats. Air support was provided by a single-engine Otter based at Little

America. After traveling 126 kilometers they encountered apparently impassable crevasses. Commander Bursey decided to backtrack and swing north toward Prestrud Inlet, with which he was familiar from a previous journey. They reached the plateau and set a course southeastward to Byrd Station's proposed site. Trail flags were placed to mark the route, and every 80 kilometers a cache was laid. On February 1 the trail party had reached 79°31'S. 134°W., 613 kilometers by air and 676 kilometers by surface from Little America and about 240 kilometers short of their goal. Another crevasse field was faced at this point, and the vehicles had begun to break down. Owing to the lateness of the season, U.S. Navy Commander Herbert Whitney, commanding officer of the Mobile Construction Battalion (Special) and officer-in-charge for antarctic stations, decided that the location reached by Commander Bursey's party would be satisfactory for Byrd Station. He ordered the remaining supplies cached and the vehicles left in the field. The men would return to Little America by air.

On February 3 an Otter evacuated four members of the trail party with their gear, leaving Commander Bursey and two others to be picked up on a second flight. When the airplane failed to arrive at Little America, Commander Bursey was ordered to search for the plane and survivors back along the trail with his ailing vehicles. About halfway he met another search party, led by U.S. Navy Chief Warrant Officer Victor Young, that had started out from Little America. Although the two parties had failed to find the downed airplane, it finally was sighted and the survivors were picked up by helicopter. Commander Bursey and Mr. Young then led the vehicles back to Little America for storage over the winter.

On February 27 Mr. Young again set out from Little America with D-8 tractors hauling heavy sleds. His objective was to position fuel caches so that the next season's tractor trains could carry a maximum of building equipment and supplies. At kilometer 177 he discovered crevasses that both he and Commander Bursey had unsuspectingly crossed and recrossed with lighter vehicles a month before. He decided to blast them open and fill them with snow. During this operation a D-8 tractor driven by Max Kiel slipped backward into another undetected crevasse. The cab was crushed, and the driver was killed instantly. This accident brought an end to trail operations for the year. Mr. Young cached the fuel at kilometer 160 and returned to Little America.

When Admiral Dufek learned of Mr. Young's experience, he knew the whole thing would have to be done over. He was determined that the station would be established exactly where scientists wanted it and detailed one of his best officers, Commander Paul W. Frazier, to devote himself to nothing else during *Operation Deep Freeze II*. In the directive making the Navy responsible for antarctic operations, the Secretary of Defense authorized the Navy to call upon the other military services for assistance. Admiral Dufek and Commander Frazier thus sought help from the U.S. Army's Transportation Corps, which had experience with sled train operations in Greenland. At their request, the Army's chief of transportation asked for volunteers; three officers and three enlisted men were selected from the many who applied. At Little America they would be joined by five Navy men. Major Merle Dawson, U.S. Army, was named officer-in-charge. They were given two D-8 tractors, two weasels, and a Sno-Cat from among those brought to Little America the previous year. These vehicles would haul four 20-ton Otaco and four one-ton trail sleds. Air reconnaissance and resupply would be furnished by ski-equipped Otters and Dakotas of Naval Air Development Squadron Six (vx-6).

Commander Frazier and the Army members of the trail party were among the early arrivals of *Deep Freeze II*. Before leaving Little America they did an extensive aerial reconnaissance of the route to be followed, especially the heavily-crevassed area where the ice shelf meets the plateau. They discarded the northern route pioneered by Commander Bursey and chose to travel from Little America on a great circle course for 80°S. 120°W.

Designated the Army-Navy Trail Reconnaissance Party, Major Dawson and his colleagues set out on November 5, 1956. They followed the planned course to about 260 kilometers southeast of Little America, where they encountered crevasses that they were able to skirt until they reached kilometer 295.5. There a heavily disturbed area, which could not be avoided, lay across their path. From November 19 to December 3 the party crept along, running parallel to the crevasse systems and, where necessary, blasting open and filling those that had to be crossed. After reaching the Rockefeller Plateau at kilometer 307.2, the worst was over. Once on the plateau, they could detour around any crevassed areas encountered. On December 18 they arrived at 80°S. 120°W.; their mission was accomplished. This marked route, 1,041 kilometers long, was named the Army-Navy Trail. The tortuous portion where the trail ascended from the ice shelf to the plateau was called Fashion Lane from the numerous multicolored flags, beacons, and other markers that outlined its winding course.

No time could be lost if Byrd Station was to be built that season. As soon as word was received at Little America that the plateau had been attained, a waiting heavy tractor swing prepared to leave. With Mr. Young in charge, on December 5 it set out in six D-8 tractors and one weasel. The 19 Navy men assigned to the swing were not only to deliver materials and supplies over the Army-Navy Trail but also were to remain at the site and build the station. When they reached Fashion Lane, Commander Frazier and Army Lieutenant Philip M. Smith were there to guide them through the crevasses. Once across, they pushed on as rapidly as possible and arrived at the site on December 23, a mere 5 days behind Major Dawson and his Army-Navy Trail Party. With Mr. Young at the scene, construction began.

Construction at Byrd Station

Work commenced at once. Before his departure, Major Dawson had selected a site for the station (79°59′S. 120°01′W.) and indicated where the buildings should be built. Within a few hours, 10 more construction workers arrived by airplane to join Mr. Young and his party. At midnight on the first day, the first building's shell was completed and immediately was used for berthing spaces. Construction of the mess hall began on December 24 and Christmas was celebrated by laying the floor of the combined garage and powerhouse. Almost simultaneously equipment was moved into the buildings; the generators were in place on December 26, and the following day the galley began serving hot meals. With that auspicious event, Mr. Young and his tractor train began the long treck back to Little America, leaving a skeleton crew to finish the construction. On New Year's Day, 1957, the station was in full operation, and the last of the four buildings that had arrived with the tractors was completed 3 days later. Byrd Station now consisted of four structures: mess hall, garage-powerhouse, meteorology-glaciology building, and latrine.

". . . Christmas was celebrated by laying the floor of the combined garage and powerhouse."

The remaining personnel worked on erecting antennas, caching food and supplies, laying out a runway, and unloading arriving airplanes. The airplanes also brought personnel assigned to winter at the new station; these new arrivals gradually replaced the original construction crew. On January 29 the station was turned over to those who would live and work there during the coming austral winter. Between *Deep Freeze I* and *Deep Freeze II* a change occurred in operations. The Navy, rather than completely turning over the stations to the scientists, agreed to furnish the necessary maintenance and support personnel, including physicians, cooks, utilities and radio operators, vehicle drivers, and electricians. The scientists would thus have more time to work on their projects.

For the first couple of months at Byrd Station, this division of labor meant little in actual practice. Before scientific projects could be started, there remained much to be done in the way of finishing and arranging the building interiors and preparing the station to withstand the rigors of winter. For a time it appeared that plans to winter over might have to be abandoned. Laurence M. Gould, director of the USNC-IGY antarctic program, Harry Wexler, chief scientist, Albert P. Crary, deputy chief scientist and science leader at Little America, and Admiral Dufek, Support Force commander, decided to gamble on getting another tractor train through with additional buildings and supplies. They also arranged for an airdrop of fuel and food by U.S. Air Force C-124 Globemasters flying from McMurdo Sound. With the February 12 arrival of the tractors and sleds, all hands worked to erect additional buildings, some of which required considerable modification because not all the parts had been delivered. With "inexperience but ingenuity," as the Navy officer-in-charge reported, station personnel put up a science building, an inflation shelter, two huts for geomagnetism, a rawin dome, and an aurora tower before winter set in. Tunnels connecting the structures had to be improvised from available materials such as scrap lumber, fuel drums, pieces of pipe, and parachutes. The only standard item of tunnel construction to reach Byrd Station was chicken wire. A barracks building with accommodations for 12 remained behind at Little America, as did many other supplies. Between February 18 and 25, the Air Force helped with fuel and food. Not all parachutes opened and fuel drums broke on impact or landed so far from the station that they were impractical to recover. The parachute release on a crate of needed clothing failed to work, and in a 15-meter-per-second wind both parachute and box disappeared over the horizon.

What the station probably did not need at this point was additional inhabitants. On February 27, however, three Sno-Cats arrived with five people and their gear. They were members of a glaciological traverse party that was scheduled to operate from Byrd Station during the 1957-1958 austral summer. To get an early start they had made the journey from Little America along the Army-Navy Trail during February, taking glaciological observations as they went. Their presence raised the station population to 23; 13 civilians and 10 military. The station science leader was George R. Toney, U.S. Weather Bureau, and U.S. Navy Lieutenant Brian C. Dalton, MC, was the officer-in-charge and also the medical officer.

The last airplane, a Dakota (C-47/R4D) from Little America, called briefly on March 8. From then on, the station party was entirely on its own. Outside work continued through March and April, as long as there was sufficient light. The scientists concentrated on their own spaces and the installation of their equipment, with help from Navy builders and utilities personnel. Two domes, one for radiosonde tracking and the other for aurora and airglow observations, caused some difficulties. The scientists adapted the legs designed for the rawin dome to support the aurora tower and placed the former on top of one of the buildings. Such improvisions were typical in the construction of Byrd Station.

The IGY was scheduled to begin on July 1, 1957. By that date the scientists and technicians were ready to start their observations in aurora and airglow, geomagnetism, seismology, meteorology, ionospheric physics, gravity, geomagnetism, and glaciology. The entire station complement had five buildings in which to live and do their work. The first, a meteorology-radio communications building, also contained the geomagnetism-seismology office, the station seismographs, and 12 bunks. Next came the mess hall, which in addition to dining space included a kitchen, an amateur radio room, a store, a dispensary, and a doctor's office where he also slept and conducted his business as officer-in-charge. The powerhouse-garage had little space left except for a workbench and some power tools, while showers and a photographic darkroom were crowded into the latrine. What was called the science building on the plot plan had spaces for glaciology and the traverse party, the ionospheric physics laboratory, the science library, the station science leader's office, and nine bunks. The auroral observer slept in the aurora tower, which adjoined the science building. Separated from the main station complex were an inflation shelter for weather balloons (highly flammable because of the hydrogen with which the balloons were filled) and two geomagnetic huts that had to be relatively free from outside magnetic influence. Radio communications antennas were located north of the station, while those for ionospheric soundings were to the south to reduce interference between the two.

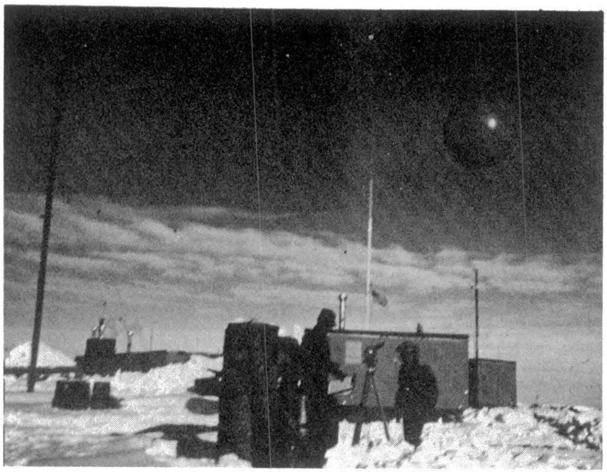
The first winter

On Easter Sunday, April 21, the sun set for the last time that year. Shortly thereafter, all but the most necessary outside work ceased. It could not be avoided altogether, however. Buildings were heated by oil-fired furnaces and the same diesel fuel was used to generate electricity and to run the cook stove. With a station fuel consumption of 270 to 340 liters a day, the small quantity that could be stored in the tunnel had to be renewed frequently. This required a work detail to visit the cache where the fuel had originally been placed. Unfortunately, the spot chosen for the cache was one of heavy snow drifting. Frequently, the detail had to remove up to 4 meters of drift to get at the drums. When it was operational, the D-8 tractor could be used to remove the snow and drag the fuel to the tunnel entrance. Too often, though, only human power was available for the task.

"The parachute release on a crate of needed clothing failed to work, and . . . both parachute and box disappeared over the horizon."

As snow drifted higher on the sides of the buildings and finally covered the roofs, it provided insulation that reduced fuel consumption. It also helped to reduce the marked difference in temperature between floor and ceiling. But the snow's weight put a considerable strain on the makeshift tunnel, which in places had to be shored.

Another periodic outside chore was the removal of garbage and trash, which were collected in the tunnel. When enough had accumulated, it was hauled away on a hand-drawn "banana" sled. Once in the disposal area, it was burned using old oil from vehicle and generator engines. This technique had the dual advantage of reducing the volume and causing the remainder to sink into the snow. An



National Academy of Sciences

The first weather balloon at Byrd Station is launched in January 1957.

original trash pile, which accumulated before burning was adopted, drifted over and created a small white hill on an otherwise featureless plain.

A deep pit below the latrine provided for the disposal of human waste. A temperature of −30°C. in the pit and a forced downdraft past the toilet seats kept offensive odors from seeping into the building that also housed bathing showers, washing machine, and photographic darkroom. The pit, however, filled faster than expected and by midwinter corrective action became necessary. After much discussion as to the relative merits of explosives, steam, and hot water for reducing the level, the last was chosen and proved successful.

Water for the latrine came from the adjacent garage-powerhouse where snow was melted by running the exhausts from the generators through a tank. After taking a shower or using the washing machine, an individual was expected to refill the tank with snow. This system worked satisfactorily except that overenthusiastic shoveling resulted in water seeping onto the floor where, combined with the weight and vibration of the generators, it caused the building to settle. Water for the galley and for drinking was obtained from a tank above the stove through which hot water was circulated. At first, snow had to be hauled for some distance to the snow melters. As outside activity diminished and winter storms drifted the buildings over, a constantly renewed supply of fresh snow was available beside the tanks. Although filling them was a cold, difficult job, only once—during a prolonged storm—was the use of water curtailed.

Scarcity of water, even when there is enough for personal needs, has always been an antarctic problem. If fire breaks out, this problem may lead to disaster. Byrd Station had drypowder fire extinguishers, and all hands were briefed in their use. Because early detection is vital to successful firefighting, a regular watch was maintained. Snow walls between buildings would help to check the spread of a possible conflagration. The effectiveness of these measures fortunately was never put to the test.

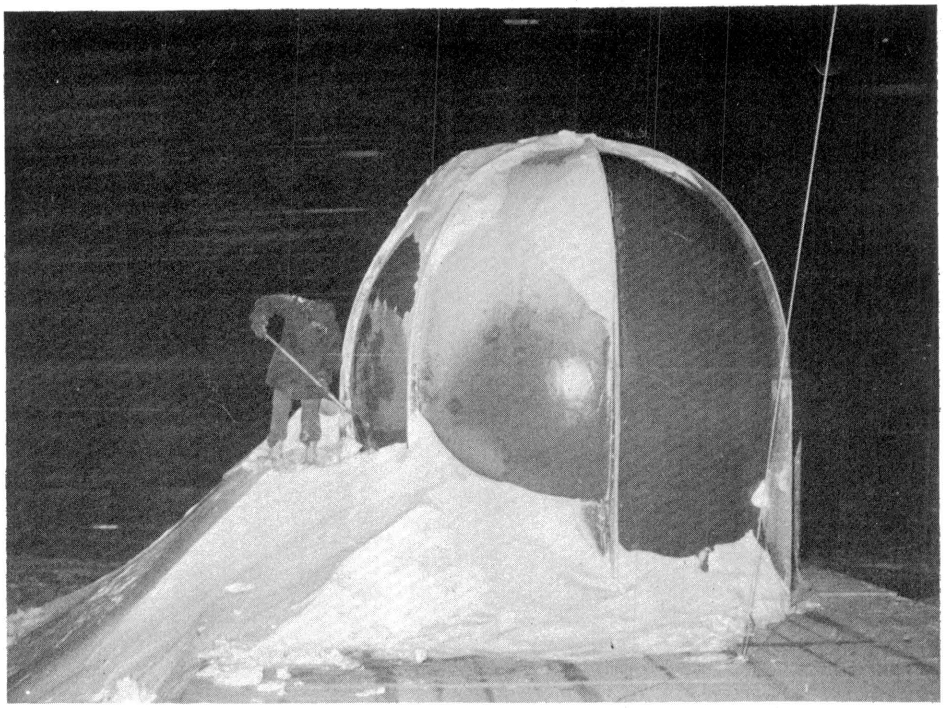
The plan for U.S. stations called for an emergency shelter stocked for survival and sufficiently remote from other buildings so that fire would not spread to it. At Byrd, of course, neither materials nor time existed to erect such a structure. Fuel caches, however, were far enough from the station to prevent ignition. Food and spare clothing were stored in the three Sno-Cats of the traverse party. When these vehicles were brought inside for maintenance, the emergency supplies were piled on a sled that was allowed to drift over.

Although enough food was delivered in the rush to get Byrd Station built and supplied, many important items either failed to arrive or were in short supply. Among these were canned tomatoes, catsup, spices, garlic, vinegar, olive oil, corn starch, shrimp, and cheese. The cook, however, displayed considerable ingenuity in using what he had; the proof of his success was a noticeable gain in weight by most of the personnel, even though, with the end of outside work, the number of daily meals was reduced from three to two. Breakfast

"Scarcity of water, even when there is enough for personal needs, has always been an antarctic problem."

was served between 9:30 and 10:00 a.m., and dinner at 4:30 p.m. Coffee, tea, and hot chocolate were available at all hours, and an informal but usually well-attended coffee break occurred each day at 1:00 p.m. At these breaks the cook set out cookies, coffeecake, or doughnuts that were long remembered by all hands. Not even the cook's skill, however, could keep the diet from becoming monotonous. As the choicer items ran out, the station subsisted principally on meat and potatoes served up in as many different forms as the cook could think of.

During the construction period, the task of assisting the cook was rotated among all hands, but during the winter three Navy workers volunteered in succession for the job. When outside work resumed, the rotation system was restored. The sta-



Clearing snowdrifts around the rawin dome at Byrd Station during the 1957 austral winter. The streaks are wind-driven snow.

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ion science leader found it required his "utmost persuasion and diplomacy" to convince some individuals of the need for their help in the mess hall.

Dr. Dalton described the winter as a period of "quiet routine." Although there was work to be done, there also was time for recreation, reading, and study. The station had a movie projector and 178 films for nightly showing in the mess hall. Hobby materials and games also were available (including fishing gear, which Dr. Dalton pointed out could not be used because of the climate). Except for a few weeks when there was space in the garage, it was impossible to set up a ping-pong or pool table or to play basketball.

Jigsaw puzzles, model kits, leathercraft, and painting sets were among the popular recreational equipment at Byrd Station. Some enjoyed card games, especially cribbage and rummy, and poker had a period of popularity, perhaps encouraged by a lack of money, which made it difficult to lose. There was a record player with 400 recordings (generally classical). For general reading, the station library had 40 adventure books and a handful of paperback novels donated by individuals. Most of the books purchased for the station did not arrive until October 1957. A certain number of scientific and technical works also were available, as were textbooks for Naval and U.S. Armed Forces Institute courses. The latter were frequently consulted for general reading or for reference purposes. A number of people also worked on courses or prepared for rating examinations. The selection of Navy courses was inadequate in some rates, however, and one person, who three times became eligible to take the test for second class petty officer, was unable to do so.

Such experiences were frustrating and lowered morale. Difficulties with the official amateur radio set up at Byrd did not help matters. Voice contact

". . . the entire winter ration of beer was 10 cans per person. The remainder . . . consisted of bourbon and medicinal alcohol."

was so poor that despite efforts to improve the antenna system only 65 phone patches were completed during the year. Because of propagation conditions, these tended to concentrate only in certain areas of the States; some personnel thus were able to talk to their families more than once while others were unable to do so at all. This led to recriminations and accusations of favoritism. Morse code, however, proved easier to transmit and an almost unlimited number of "hamgrams" were sent (these messages were transmitted in code and translated by an operator in the States before being mailed to the addressee). This situation was greatly aided by a meteorologist who had brought his own equipment and actually sent over 700 of the 1,050 hamgrams that were transmitted. Gratifying as this service was, however, it did not exactly compensate for the sound of a voice.

Parties were held occasionally, but their number was limited by a shortage of alcohol. Not nearly the quantity or variety programmed for the station had arrived. For example, the entire winter ration of beer was 10 cans per person. The remainder of the liquor supply consisted of bourbon and medicinal alcohol. The physician/officer-in-charge controlled the dispensing of spirits, which he did sparingly. An exception was Midwinter's Day (June 21) when, following a well-established antarctic custom, a holiday was declared and a morale-boosting party was held with dress competition, bingo game, and special menu.

Both Dr. Dalton's and Mr. Toney's diaries allude to psychological tensions during the winter and to a small group of malcontents, but neither is specific. In a dispatch from Byrd Station dated December 14, 1957, a *New York Times* reporter discussed the matter briefly and quoted Dr. Dalton as saying that, although there were some tense moments, no violence occurred. Such frictions are common at small stations and indeed wherever a group of people are confined for long periods to close quarters. At Byrd, they may have been exacerbated by overcrowding, lack of full recreational opportunities, and monotonous diet, but there is no solid evidence of this. Considering the conditions at Byrd Station that first winter, Admiral Dufek commented, "They did a remarkable job just living through the winter."

The second year at Byrd Station

Admiral Dufek was determined that there should not be a second winter like the first. As far as possible living conditions would be ameliorated and mistakes indicated by experience rectified. For example, new fuel supplies would be cached in a spot less susceptible to drifting. In emptying the old cache, the station crew was providentially aided by the chance discovery of a portable fuel pump buried in the snow behind one of the buildings. Much of the fuel in the old cache was pumped into barrels lined along the sides of the tunnels. The remainder was used to refuel the first tractor train, which arrived on October 22 and departed 4 days later.

Among the items received were the long-sought barracks building, a hut for radio noise investigations, and the proper materials for making tunnels. All hands helped to erect the barracks building as quickly as possible to relieve overcrowding in the science areas. Although the finishing touches were not applied for several months, it was soon habitable. The occasion called for a party that was enlivened by a fresh supply of beer thoughtfully brought along on the tractor train.

Plans for *Deep Freeze III* called for an increased air role for Byrd Station. No aviation fuel had been stored there the previous season, however, and all airplanes arriving from Little America had to carry enough fuel for the return flight. The Marie Byrd Land science traverse would be based at the station and would be supported by reconnaissance and logistics flights. An earlier mistake that needed rectification was the airstrip's orientation. In the haste and ignorance of the first year, it had been laid at right angles to the prevailing wind. Starting in mid-September, a new 1,700-meter strip was flagged. Whenever a flight was expected, the D-8 tractor smoothed the airstrip's sastrugi. Although primitive, this technique proved adequate.

"'They did a remarkable job just living through the winter.'"

Even before the arrival of the tractor train, Air Force Globemasters began dropping both aviation and diesel fuel, along with mail and other items. Between October 18 and December 4, 32 drops were made and 388.8 metric tons of cargo were delivered. Both those in the air and on the ground had learned from the experience of the previous year. Cargo was more carefully packaged, parachutes worked better, and the drops were more accurate. A recovery team on the ground, using a D-8 tractor with an attached boom, could pick up and move to the camp 64 drums of fuel in 4 hours. In all, 99.8 percent of the cargo was recovered.

The first airplane from Little America, an R4D (LC-47), landed on the improved skiway on November 7. Aboard was the new science team led by Mr. Stephen S. Barnes, U.S. Weather Bureau. Navy personnel also began arriving during November, with Lieutenant Peter P. Ruseski, MC, as the new officer-in-charge, reaching Byrd on December 7. Those who had wintered gradually departed after indoctrinating their successors. On December 9, Dr. Ruseski relieved Dr. Dalton. Neither Messrs. Toney nor Barnes recorded the date on which the science leadership changed; presumably it was at about this time.

Summer science projects included the traverse into Marie Byrd Land and ice core drilling at Byrd. The traverse personnel had arrived in March 1957, driving their vehicles overland from Little America. They were fully assimulated into station activities and had contributed greatly to the success of that first trying winter. With the approach of spring, they overhauled their three Sno-Cats and prepared their equipment and supplies. As the days passed they became impatient to get started. They had to wait, however, for the stocking of aviation fuel and the resumption of air support operations. Finally they got under way on November 19; five people in three vehicles headed north and slightly east toward a mountain, which they named Takahe. This was the first leg of their journey aimed at a study of the great ice sheet. Along the way, geological and biological observations also were made and specimens were collected. Before it returned to Byrd Station, on February 20, 1958, the party would cover 1,902 kilometers along a roughly rectangular route. From Mount Takahe, the traverse turned east to the Sentinel Mountains and then south to the Mount Woollard vicinity. The last leg ran almost directly west to Byrd Station.

The core drilling projects used about 36 metric tons of material and required the services of four civilians and five army enlisted specialists. The first 24 metric tons had been shipped to Little America during *Deep Freeze II* and arrived at Byrd Station with the first tractor train. The remaining 14 metric tons were delivered generally by airdrop between December 1 and 4, with about 2,000 kilograms being brought in on Navy ski-equipped Dakotas. The drill team reached Byrd by air on November 7, and began to assemble the drill rig. The engineer temporarily remained at McMurdo Station to expedite airshipments. Drilling began on December 16 and was well under way on Christmas Day when the two glaciologists attached to the project finally arrived. On January 26 work was terminated when the borehole had been drilled to 309 meters below the surface. Preliminary examination indicated the success of the project. For further analysis, cores were shipped to the United States aboard USS *Glacier*.

For those expecting to make Byrd their home for the winter, summer was a busy time. The station science leader accurately described the period as "hectic." Many of the projects undertaken were basically ones that could have been accomplished the previous season or over the winter if the materials had been available. Tile and linoleum for the mess hall, sick bay, and latrine floors was one example. The new barracks and the radio noise hut were others; these were erected with help from the tractor train party, but they still had to be finished and wired; the last was a particularly arduous task, especially in the case of the radio noise hut, which was over 300 meters from the nearest power source. A remote heater was installed at a safe distance from the inflation shelter and its dangerous hydrogen-generating equipment; this also gave the meteorologists a convenient heat source for snow melting, rather than having to lug water over a considerable distance. Storage areas were reorganized and, where possible, brought under shelter.

On January 31 the second tractor train of the season arrived. It brought 178 metric tons of cargo (including food and other supplies), a third electric generator, three 3,000-liter fuel tanks for placement in the tunnel and another of about 40,000 liters in capacity to be placed outside, and a Jamesway hut for a recreation hall. The 19 people on the tractor train not only unloaded the vehicles but also constituted a welcome addition to the labor force. During the 21 days that they were at the station, they helped place the fuel tanks, position the generator, and put up the Jamesway.

Because the season's last airplane departed from Byrd Station on February 5, the tractor train awaited the return of the science traverse party. The latter completed its successful journey on February 20, and the following day all but one of its members, Charles R. Bentley, left for Little America with the tractor party. To face the rigors of a second winter, 12 Navy personnel and 12 scientists, including Dr. Bentley, remained.

Conditions were much better the second winter than the first. Although the station population had increased by one person, the new barracks greatly relieved overcrowding. The Jamesway provided a new recreation area. Sheltered storage space was enlarged greatly and all kinds of supplies thus were more readily accessible. Sufficient varieties of food had been shipped to avoid the monotonous diet that was a common complaint during *Deep Freeze II,* and there was enough alcohol to permit occasional parties and celebrations. The new fuel system, from which the 3,000-liter tanks in the tunnels were gravity-fed from the 40,000-liter outside tank, allowed support personnel to wrestle fuel from the cache when the weather was favorable rather than battle the elements on a weekly schedule. To assist the officer-in-charge (again a physician rather than an engineer), the Navy assigned a senior chief petty officer to act as executive officer and to supervise the work of other support personnel. Further, a new antenna and more powerful transmitting equipment, some of it the personal property of a station member, greatly improved amateur radio communications and permitted frequent voice contact with home.

Scarcely had the tractor train disappeared over the horizon than Lieutenant Ruseski and Mr. Barnes called everyone at the station together. Mindful of the difficulties encountered the first year, they set forth the lines of authority for military and civilian groups, indicated the objectives for the year, and explained that, although the Navy was supporting the science program, this should not be construed that the support personnel were subordinate to or servants of the scientists. Each individual had an important role in the station's success. Finally, they recognized that, with so many people cooped up in a small place, occasional personality differences and frictions were bound to develop. They urged mutual tolerance and understanding. Mr. Barnes believed that this meeting started things off in the proper direction and provided a momentum that lasted all year. "Unquestionably," he wrote, "IGY and Navy men respected one another."

"Each individual had an important role in the station's success."

At about the same time, Dr. Ruseski called his crew together and discussed the work that had to be done. As so often happens, summer support personnel pushed projects as far as time allowed, and then departed, leaving the winter crew to finish the job. Typical was the installation of a third electric generator, which had not been wired or tested. Laying tile and linoleum were good indoor jobs during bad weather and darkness, as was interior painting. Although the recreation Jamesway had been erected, snowfall and high winds rendered a predictably short lifespan for such a flimsy structure. Station personnel decided to give it a protective roofing, which was improvised from available materials. Columns were made by welding fuel drums together across which were laid pieces of soil pipe to support a roofing of scrap lumber. Over the entire structure they spread parachutes to keep snow from drifting through. For a time, they rather unnecessarily kept topping-off the 40,000-liter fuel tank to obtain drums not only for the roof but also to strengthen the sides of the tunnel leading to the inflation shelter. Between April 15 and 20, a new hut was erected to house geomagnetic instruments. During this period the sun set and left their world in darkness.

Outside work had to be curtailed, but this hardly meant that the men were less busy. The scientists, of course, had observations to make and equipment to maintain. A number of improvisations had to be made, but no project failed to reach its objectives. One problem was interference between the upper-atmosphere research instruments and the station's radio communications gear, to the detriment of both. In one instance the station science leader noted that it had been minimized but not eliminated. Even those who wintered at Byrd so that they could get an early start on next season's traverse kept busy. Not satisfied with putting their vehicles in top condition, preparing equipment, and assembling supplies, they set up local projects in seismology and glaciology. One of the latter required a half-kilometer, twice-daily walk to check thermometers; another, a weekly ski trek of 15 kilometers to reach snow accummulation stakes. Working at outside temperatures as low as −60°C., as once occurred, helped to keep the participants in good condition for the hard summer's journey ahead.

Drifting snow caused difficulties for all. Principal reliance for clearing was upon a D-8 tractor that broke down frequently, and on April 5 suffered damage that defied all repair efforts. The D-4, even if it had not also suffered numerous casualties, was incapable of keeping ahead of the snow accumulation. Dr. Ruseski often wrote of digging out by hand. At times the scientists also pitched in to help, and they built a hatch over the main entrance. The most affected group were the meteorologists, who had to keep a hole open above the inflation shelter through which to launch their weather balloons. As the science leader plaintively remarked, the hole, which eventually reached a depth of nearly 5 meters, "didn't exactly grow there."

Neither, for that matter, did a 90-meter-long tunnel that Seabees dug to the proposed site of a radio transmitter building. Originally scheduled for the following summer, when the building would also go up, they decided to complete this much of the project in advance. Beginning on May 12, they burrowed away steadily until the goal was reached on August 22, just 3 days before the first sunrise and the resumption of more extensive outdoor activity. A helpful byproduct of this project was a convenient source of snow for the station's freshwater supply.

Not all was work, however. The officer-in-charge customarily placed Navy personnel on holiday routine from 1:00 p.m., Saturday, until Monday morning. The recreation hall had facilities for pool and ping-pong or listening to high-fidelity recordings. Birthdays and holidays were observed by special dinners, frequently featuring turkey with all the fixings. On July 4, a group led by the station science leader surreptitiously organized a kangaroo court that produced hilarious results. Tournaments were held and prizes awarded. The nightly movie, although usually a repeat, was appreciated as a distraction and a reminder of more familiar environments. Scientists held a well-attended seminar series, and the medical officer delivered several first-aid lectures directed especially to members of remote traverse parties. Despite the absence of a chaplain, well-attended religious services were regularly held using recorded tapes and accompanying explanatory texts.

With sunrise and the resumption of outdoor work, the station's pace of life increased. Knowing that the year of isolation was ending, attitudes rapidly became more optimistic. There was much preparation necessary for the resupply that would arrive by tractor train and airplane. Caches had to be dug out and cleaned up so that arriving cargo could be stored quickly, the air strip had to be prepared and marked, and a zone had to be established for airdrops. Because plans called for closing Little America in January 1959, after IGY was over, only one traverse was to be made to Byrd Station rather than the two of previous years. Most of the resupply would be delivered by Air Force Globemasters from McMurdo Station.

The tractor train departed Little America on September 25, 1958, but its progress was slowed by bad weather, an ill crew member, and equipment breakdowns. While it was crawling slowly over Army-Navy Drive, the Globemasters started the airdrops on October 7. Weather permitting, they continued almost daily until November 12. By this time 33 drops had been made to deliver 434 metric tons of cargo (not including drop gear). As in *Deep Freeze II,* however, many chutes failed to collapse upon landing and the prevalent high winds dragged the cargo considerable distances before retrieval (one electric generator was found 151 kilometers from the station). At one time, in fact, 51 pallets were known to be missing. In the end, however, over 90 percent of the cargo was recovered.

The task of retrieving, inventorying, and storing materials from airdrops placed another heavy burden on the few persons at Byrd Station. Some relief, however, was obtained on October 12: the tractors, with a 23-person crew, arrived from Little America. The tractor crews helped station personnel unload the 225 metric tons of general cargo that had arrived by surface transport, and they also helped stow materials from airdrops. The tractor crews moved the rawin tower and elevated it over 6 meters to lift it above the drifting snow. At first, the commander, Naval Support Force, Antarctica, directed that the tractor train remain at Byrd until airdrops were completed; but when he was assured by the officer-in-charge that station personnel were capable of retrieving all cargo, he permitted the train's departure on October 23.

On October 28 the first Dakota landed on the skiway with seven passengers. During this mission it also flew a reconnaissance over the route to be taken by the six-person science traverse in the Horlick Mountains. During these first months of the season, members of the party had been busy preparing their vehicles and putting their equipment and supplies in order. They departed on November 1 and did not return until January 21, 1959, after covering over 1,500 kilometers.

"Birthdays and holidays were observed by special dinners, frequently featuring turkey with all the fixings."

A second Dakota arrived on November 7 with the first increment of the relief party: seven Navy personnel and two scientists. The following day it departed with nine Navy winterers on the first leg of their homeward journey. The winter 1958 scientists and three other Navy personnel, including the officer-in-charge, remained. Their time was not long. On November 16 two more airplanes arrived with the rest of the relief personnel. On November 17, U.S. Navy Lieutenant Edward J. Galla, MC, relieved Dr. Ruseski as officer-in-charge and station physician. The latter, however, did not depart until November 21, when all remaining *Deep Freeze III* personnel left Byrd Station and the new crew took over. Mr. Barnes' replacement as station science leader, John Pirrit, a glaciologist, was en route overland from Ellsworth Station; until his arrival in January 1959, Bernard Weiss, U.S. Weather Bureau, was acting science leader.

As originally planned, IGY would have ended with the departure of science and support personnel at the end of 1958 or, at the latest, with the evacuation of the traverse party in January 1959. Byrd Station would have been abandoned to disappear beneath the drifting snow and fade from the memory of all but a few. The IGY had, however, proved enormously successful and greatly inconclusive. The data collected raised more new questions than answered old ones, and convinced the science community that further investigations were needed over a longer period both in Antarctica and elsewhere.

The 12 nations that had supported antarctic programs agreed to continue into the indefinite future.

"Byrd Station would have been abandoned to disappear beneath the drifting snow and fade from the memory of all but a few."

The United States, among other participants, wanted to reduce the scope of its activities and decided to close or transfer to other nations three of its seven stations. The remaining four—McMurdo, Hallett, Byrd, and South Pole—could all be supplied and maintained through a single supply line running from New Zealand through the Ross Sea. In addition to the savings gained by having three fewer stations to support, there would be savings in ships and personnel no longer necessary to resupply Wilkes Station, on the Knox Coast (some 3,200 kilometers west of Cape Adare), or Ellsworth Station, on the opposite side of the continent.

Support factors were not the only shaping forces behind the U.S. antarctic program's future pattern. Because of their dependence upon aerial resupply, the inland stations—South Pole and Byrd—were both difficult and expensive to maintain and presented a threat if for any reason heavy cargo airplanes were unable to operate from the McMurdo Sound sea ice. Politically and scientifically, however, good reasons existed for retaining them. Before the Antarctic Treaty in late 1959, there was a possibility that the United States might have to make a territorial claim to protect its interests. Byrd was in the center of the only large unclaimed territory in Antarctica, while the South Pole was on the spot where the pie-shaped sectors clained by other nations came together. Scientifically no stations had been established on the plateau prior to IGY, and even then their number was small. Information derived from these stations and from traverses staged from them was novel and important. Significant observations had been recorded in meteorology, geomagnetism, upper atmosphere physics, and glaciology. At Byrd, while the pressure waves or "surges" postulated by Sir George Simpson had proved nonexistent, the meteorological evidence was important in understanding the weather regimen of the interior; in glaciology, Byrd's position was unique. Situated far inland at over 1,500 meters above sea level, it was estimated to stand on some 2,400 meters of ice. Traverses during IGY confirmed the same general situation over much of the surrounding area and raised basic questions about West Antarctica's bedrock topography: was it continental in nature, or did it consist of archipelagos through which interconnecting channels ran between the Ross Sea, on the one hand, and the Bellingshausen and Weddell seas on the other? Byrd's location also made it especially suitable as a center from which parties could fan out in search of the answers to these basic questions. And with the addition of geology in post-IGY programs, other questions could be addressed regarding the obvious differences in origin between the mountains of Marie Byrd Land and those of East Antarctica. Thus, during the autumn of 1958 a new team arrived at Byrd Station to continue and expand the work of their predecessors.

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U.S. meteorology programs in the Antarctic: a status report

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Prior to the International Geophysical Year (IGY) (1957-1958), not much was known about meteorological conditions and processes of the polar atmosphere. In fact, major misconceptions about the nature of the general circulation were still widespread, such as Hobbs' theory of the polar anticyclone. With the establishment of research stations on the antarctic coast and, more importantly, in the interior, significant features of the thermal structure and circulation of the atmosphere over Antarctica and the surrounding ocean were revealed.

While on leave from the University of Alaska from May 1972 to June 1974, Dr. Weller was program associate for polar meteorology at the Office of Polar Programs. Dr. Kelley is currently on leave from the University of Alaska's Institute of Marine Science to be program associate for polar meteorology and oceanography at the Office of Polar Programs.

Many discoveries were surprising. For example, although it was known from earlier measurements that surface temperatures on the coast ceased their rapid fall after the sun had set for the winter, it was not suspected that this was also true for stations deep in the interior. Also unexpected was the great contrast during winter between tropospheric and stratospheric circulations: numerous moving cyclonic vortices ventilate most of the antarctic troposphere with marine air while at the same time the lower stratosphere is dominated by a single large cyclonic vortex generally centered somewhere over the polar plateau. During the dark season, the ozone concentration of the surface air at Little America increased, presumably as a result of increased winter transport of air from lower latitudes, inasmuch as natural ozone does not form locally in the absence of the sun. Also, very large year-to-year changes in temperature were observed; for example, Little America V was 11°C. warmer in

April 1958 than April 1957, and Byrd Station was 13°C. colder in August 1958 than August 1957. These changes indicated quite large year-to-year variations in the general circulation (Wexler and Rubin, 1960).

The IGY discoveries set the stage for further meteorological research. The following discussion will focus on some aspects of this research, primarily the meteorology and climatology of the high antarctic plateau and the lower layers of air above it.

The nature of the antarctic heat sink has been given particular attention over the years since the IGY. This radiative heat sink has a total annual loss of approximately 10^{21} calories. If there is to be a balanced energy budget over Antarctica, there must be a compensating flow of energy from other sources, principally by wind transport of heat and water vapor from lower latitudes. The study by Dalrymple *et al.* (1966) at South Pole Station was an early significant contribution to understanding the heat balance of the interior of the Antarctic.

Comprehensive summaries of the surface climatology of Antarctica were published later by Weyant (1967) and Wilson (1968), and of troposphere and lower stratosphere climatology by Weyant (1966). In studies of the dynamics of the low-level wind regime over the antarctic interior, Lettau *et al.* (1966, 1967, 1970, 1971) and Schwerdtfeger *et al.* (1967, 1968) related surface wind velocity to the strength of the inversion, geostrophic and thermal wind, and surface slope. Rubin (1966) brings together some of the studies of this meteorological phase.

The next important step in U.S. meteorology programs in the antarctic interior was the establishment of Plateau Station at 79°S. 40°E. (altitude: 3,600 meters), close to the Pole of Inaccessibility. This small station, which was primarily established for meteorology programs, was operated from 1966 to 1968 and recorded annual mean temperatures of −60°C. Papers on the energy and mass balance, boundary layer phenomena, and snow climatology resulting from research at this station are still emerging (Dingle *et al.*, 1967; Weller, 1969; Weller and Schwerdtfeger, 1970; Kuhn, 1970, 1974; Lettau and Dabberdt, 1970; Riordan and Wong, 1971) and will be published in the near future as a volme of the American Geophysical Union's *Antarctic Research Series*.

This introductory sketch of past U.S. research on the lower layers of the antarctic interior's atmosphere brings us to the present. What are the remaining problems? What can be done in Antarctica and why should we do it? The Committee on Polar Research, National Academy of Sciences, addressed these questions in their report, *Polar Research—A Survey* (National Academy of Sciences, 1970), which advocated further research into many aspects of antarctic meteorology, including tropospheric processes, energy balance, climatology, and other fields. Lettau (1971) makes a strong and eloquent case for using the antarctic atmosphere as a test tube for meteorological theories; specifically, mathematical models of thermodynamic and dynamic consequences of solar energy supplies at the snow-air interface. He argues that there are three important and principal factors favoring these studies: the exceptional uniformity of the physical structure of the antarctic snow surface, the large horizontal scale of the topographical gradients of the continental ice dome, and the relative paucity of short-time disturbances of the dominant long-period (seasonal) variation of isolation.

Then what are the scientific problems that might profitably be studied under such ideal boundary conditions? Again, the nature of the antarctic physical environment must be considered. The continental land mass lies poleward of around 60°S.; 98 percent of it is covered with snow and ice. With an average meridional radius of about 3,500 kilometers, this mass rises to more than 3,500 meters above the level of the surrounding sea, which is covered by fields and belts of floating ice. The ice dome is extraordinarily simple or uniform in topographical detail. Characteristic terrain slopes are 1:1,000, which is an intermediate value between the typical slope of the order of 1:10,000 for isobaric surfaces, and that of about 1:100 for temperature discontinuities in the free atmosphere (Lettau, 1971).

On the earth's surface, the primary source of energy is solar radiation. At the geographic South Pole the sun's elevation angle always equals the declination angle; 6 months with the sun above the horizon are therefore followed by 6 months of darkness.

During the relatively cloud-free, sunless winter period, strong longwave radiation losses out to space cool the snow surface and the air in contact with it. This sets up steep temperature inversions up to several hundred meters in depth. Air is set in motion by thermal and gravitational forces, the cold dense air in contact with the snow surface sliding down the inclined slopes of the continental ice dome. These so-called katabatic winds have velocities that are functions of the inversion strength and depth and the slope inclination. Airflow may occur at large angles across the slope, rather than directly downslope. This theory is quite well documented (Defant, 1933; Ball, 1956; Schwerdtfeger, 1967; Radok, 1974).

The inversion strength and depth depend on the energy balance at the surface, in which the longwave radiative components are the most important terms. Eddy, latent, and sensible heat compensate the radiative losses. The presence of clouds, par-

Meteorology programs at Amundsen-Scott South Pole Station.

Principal investigator	Institution	Program	Method
GROUP I: energy balance			
Carroll	U. Calif. (Davis)	Surface energy balance	Eddy correlation and profiles
Coulson	U. Calif. (Davis)	Atmospheric transmission	Polarimeter
M Kuhn	U. Innsbruck	Optical properties of snow	Pyranometers, pyrheliometers, *etc.*
GROUP II: ice crystals			
Ohtake	U. Alaska	Vertical distribution	Direct sampling from kitoons
Smiley/Warburton	U. Nevada	Vertical distribution	Lidar
Shaw	U. Alaska	Atmospheric transmission	Photometer
GROUP III: surface winds			
Schwerdtfeger	U. Wisconsin	Surface wind regime	Analysis
Hall	NOAA/ERL*	Remote sensing of boundary layer	Acoustic sounder
Sechrist	U. Wisconsin	Cyclones in high southern latitudes	Analysis
GROUP IV: atmospheric constituents			
Pack	NOAA/ERL*	Environmental benchmark station	CO, CO_2, O_3, and aerosol sampling
Zoller/Duce	U. Maryland	Trace metals and halogens	Neutron activation
	U. Rhode Island		Atomic absorption
Hofmann	U. Wyoming	Stratospheric aerosols	Balloon-borne photoelectric counters
Cobb	NOAA/ERL*	Atmospheric electricity	Electrical conductivity apparatus
Hogan	State U. New York	Aerosols	Direct sampling
Rasmussen	Washington State U.	Halocarbons and freons	Chromatography
GROUP V: weather observations			
NOAA**		Routine surface and upper-air observations	

*National Oceanic and Atmospheric Administration/Environmental Research Laboratories. **New Zealand Meteorological Service after December 1975.

ticles, and certain gases in the atmosphere affects the energy balance, and numerical relationships can be established between energy balance, inversion characteristics, and katabatic winds.

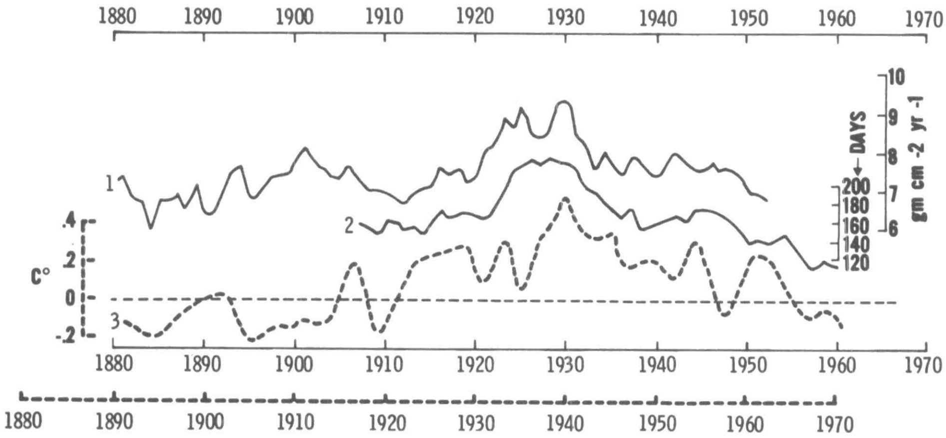
Over the interior antarctic plateau, the wind regime is somewhat more complex than the simple coastal katabatic regime. The main results of presently available theoretical and observational analyses can be summarized by stating that the equilibrium dynamics of the lower troposphere (including the inversion layer over the Antarctic) are controlled by air motions, which are generated by the large-scale ice dome surface inclination, and may be classified as "geostrophic thermal winds." These represent a topographic modification of the basic geostrophic thermal vortex system that exists around the South Pole and dominates the dynamics of the free troposphere (Lettau, 1971).

In antarctic coastal zones, katabatic winds blow fairly persistently and may reach high velocities (typically around 10 meters per second), carrying out to sea large quantities of drift snow, which in turn can affect the freezing processes (starting date and extent) of the sea ice.

To balance the outflow at the coast's surface, relatively warm and moist air flows into the interior of the continent at higher levels above the inversion. This air cools when moving inland; the moisture freezes, sinks, and results in the typical, almost continuous ice crystal precipitation observed under clear-sky conditions at all inland stations. The contribution of this clear-air precipitation to the annual snow accumulation is unknown, but it may be significant as indicated by the studies of Miller and Schwerdtfeger (1972). Since the ice crystals affect the radiation regimes over the continental interior, both long- and shortwave, they are important in the mass and energy balance of Antarctica. By systematically examining stratigraphic records of annual snow accumulation, it may be possible, through the chain of arguments presented above, to reconstruct simple numerical indices of past climates from the amount of snow accumulation.

The possibility of using snow accumulation on the antarctic plateau as an index of worldwide climate changes is demonstrated in the figure, which shows that snow accumulation at Amundsen-Scott South Pole Station bears a distinct resemblance to temperature variations in the Northern Hemisphere a decade later (Fletcher, 1969).

To examine these related phenomena a new meteorological program has begun at South Pole Station. The program's objectives in studying the conditions and processes of the atmosphere over the high polar plateau are to determine the following:



1: snow accumulation at South Pole Station. 2: iciness of the Weddell Sea. 3: annual mean temperature of Northern Hemisphere.

(1) The energy balance at the surface, its components and time variations.

(2) The effects of clouds, aerosols, ozone, and other atmospheric constituents and synoptic processes on energy balance.

(3) The relationship between energy balance and low-level tropospheric circulation.

(4) The effects of tropospheric circulation on crystal precipitation, accumulation, mass balance, and, through feedback, on energy balance.

(5) The effect of katabatic circulation on outflow of cold air from the continent, snowdrift transport, and freezing of the sea.

(6) The possibility of extracting paleometeorological and paleoclimatic data from the stratigraphic snow accumulation record, particularly if carried out in conjunction with similar studies at other locations on the high antarctic plateau (for example, Vostok, Plateau, domes A, B, and C.).

The polar regions provide key areas of research by offering opportunities to study their relatively clean background levels of gaseous and particulate atmospheric constituents and to allow comparison with global atmospheric properties. The current objectives in atmospheric chemistry are related to whether artificial emissions perturb the stratospheric ozone layer.

The extent and magnitude of the Antarctic as a global sink for the removal of trace gases and particulate matter must be defined. Another concern is to know whether the earth's climate is changing and, if so, whether these changes are related to human alterations of atmospheric chemistry.

Precipitation processes are studied to understand how chemical constituents are removed from the air. By identifying and quantifying the removal processes for gaseous and particulate matter in the polar atmosphere a better understanding of anthropogenic versus natural climatic modification processes should result.

Although studies of the chemical constituents of the polar atmosphere have been conducted for some time, very low concentration levels of trace gases require high analytical calibration integrity and refined methodology. Modern analytic chemical techniques are now available to approach these problems, although great care must be exercised in sample-site selection and preparation. Clean-air field sites have been established at distances upwind from the new South Pole Station, with improvements planned for the future. At present, atmospheric chemistry baseline measurements—comprising observations of carbon dioxide, ozone, particulate matter, trace elements and halogens, and carbon-14—are being made at South Pole Station. Recent research has begun to analyze chlorofluorocarbons (freons) and other halocarbons that may have an effect on ozone depletions in the stratosphere.

Because of the presence of a strong surface inversion above the polar ice cap, data obtained for trace gas concentrations may be anomalous. If atmospheric chemistry processes in Antarctica are to be adequately understood, it will be necessary to obtain many measurements above the ground and along horizontal transects. An initial effort has been made in this direction by emphasizing LC-130 Hercules airplanes as "ships-of-opportunity." An isokinetic air sampling port was mounted on a spare emergency hatch, which can be easily exchanged with the standard overhead emergency hatch above the flight deck and forward of any engine exhaust. Air thus is conducted through tubing to the cargo deck where analytical and sampling equipment is mounted on cargo pallets. Sampling missions are flown between McMurdo and South Pole stations. Although this sampling scheme gives a measure of horizontal distribution, it usually does not afford an opportunity for consistent sampling at several elevations or penetrations very far into the stratosphere.

The timetable of meteorological experiments at South Pole Station called for pilot studies and site familiarization in 1973-1974 and 1974-1975, and first winter projects in 1975. The experiment's main phase is planned for 1976-1977, with data analysis in 1978.

South Pole Station has a new central station computer. This system is available for data logging and for necessary computing tasks. An identical system is used as a backup to the primary system and for any required off-line computing. A third computer, similar in all respects to the primary computer, is at Davis, California. This third unit allows any group planning to make use of the South Pole facility to interface their experiments with the system and to train people who will use it. The equipment is manufactured by Hewlett-Packard (model HP 21005).

A large part of the U.S. meteorology program in Antarctica focuses on integrated experiments at South Pole Station. Other meteorological research covers climatological studies of the dry valleys (southern Victoria Land), the mechanism and chemistry of precipitation over the Ross Ice Shelf, the design, construction, and deployment of simple satellite-interrogated weather stations, the collection of routine surface and upper-air meteorological data at U.S. antarctic stations, and the acquisition of a VHRR satellite meteorology system for operational and research use. These studies are based on recommendations of the Committee on Polar Research (National Academy of Sciences, 1970).

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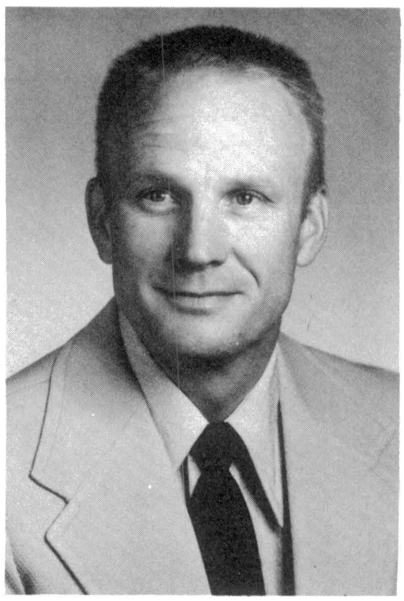
News and notes

New head of polar programs

On April 14, 1975, Robert H. Rutford, a geologist with several years of antarctic and arctic experience, became head of the National Science Foundation's Office of Polar Programs (OPP).

The post had been vacant since May 28, 1974, when the former head, Joseph O. Fletcher, became head of the Foundation's Office for Climate Dynamics. Alfred N. Fowler, deputy head of OPP, and Kendall N. Moulton, OPP's associate manager for polar operations, had alternated as acting head during the interim. Mr. Fletcher since has become deputy director of the National Oceanic and Atmospheric Administration's Environmental Research Laboratories in Boulder, Colorado.

Before joining the National Science Foundation staff, Dr. Rutford was director of the Ross Ice Shelf Project and an associate professor of geology at the University of Nebraska, Lincoln. He received the B.A., M.A., and Ph.D. degrees from the University of Minnesota, where he also served as a research assistant and a research fellow. He was the leader of a University of Minnesota antarctic research team in 1963, after having participated in two previous antarctic expeditions.


NSF

Robert H. Rutford

Dr. Rutford became an assistant professor of geology at the University of South Dakota in 1967, and an associate professor in 1970. He was chairman of the Department of Geology, and later the Department of Geology and Physics, from 1969 until he left to join the University of Nebraska in 1972.

Antarctic researcher gets Belding Award

A Duke University graduate student in zoology, who for the past 2 years has participated in a National Science Foundationsponsored study of antarctic penguins, has received the annual Harwood C. Belding Award for outstanding work in environmental physiology.

Berry Pinshow received the award on April 15, 1975, at the annual spring meeting of the American Physiological Society. The award recognizes his research on energy expenditure, thermoregulation, and cost of locomotion in fasting emperor penguins. The project's principal investigator is Knut Schmidt-Nielsen, a Duke University professor of physiology.

Antarctic Journal **readers active in the U.S. antarctic program are an important source of information for each issue's "News and notes" section. Do you have news relevant to the U.S. antarctic program that might be of wide interest to** *Journal* **readers? If so, please contact the Polar Information Service, Office of Polar Programs, National Science Foundation, Washington, D.C. 20550 (phone: 202/632-4076).**

Soviet literature translated

Volume 41 of *Problems of the Arctic and the Antarctic* (A. F. Treshnikov, editor-in-chief) has been translated and printed for the National Science Foundation. The 152-page hardbound translation contains 19 papers, including a discussion of the results of the Arctic and Antarctic Institute in 1971. The volume originally was published by the Hydro-

U.S. Navy

An October view of the *Discovery* hut at the tip of Hut Point Peninsula, Ross Island. Part of McMurdo Station is visible in the background, along with Observation Hill (right). The hut was erected in February and early March 1902 by Robert F. Scott and members of the British National Antarctic Expedition (1901-1904). The N.Z. Antarctic Society, with help from the U.S. Navy, restored it in 1963 and 1964.

meteorological Press, Leningrad, in 1973.

Microfiche ($2.25) and hardbound ($6.25) copies are available from the National Technical Information Service, Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. Cite number TT-74-52009 when ordering.

Death

Herfried Hoinkes, a University of Innsbruck, Austria, professor of meteorology who wintered at Little America V during the International Geophysical Year (1957-1958), died on April 4, 1975, at Innsbruck.

Since 1956 Dr. Hoinkes, who was born in Bielitz, Austrian Silesia, in 1916, was director of the University of Innsbruck's Institute for Meteorology and Geophysics. From 1963 to 1967 he was president of the International Commission for Snow and Ice, International Union for Geodesy and Geophysics, and he was its vice president from 1967 to 1971. From 1964 to 1967 he was also vice president of the International Glaciological Society. His many other memberships included the International Commission for Polar Meteorology, International Association for Meteorology and Atmospheric Physics. Dr. Hoinkes held the Austrian Honor Cross for Science and Art (first class).

For the record

Geoceiver doppler data collected by Max Voight, U.S. Geological Survey, were used to establish the precise location of Siple Station during the 1974-1975 austral summer: latitude 75°56′23.6″S., longitude 84°15′ 56.6″W. The station's elevation (ellipsoid height) also was determined: 1.054 kilometers. These values were considered accurate to within ±5 meters.

Monthly climate summary

Feature		March 1975			April 1975	
	McMurdo (date)	Palmer* (date)	South Pole (date)	McMurdo (date)	Palmer* (date)	South Pole (date)
Average temperature (°C.)	−16.5	1	−52.1	−21.5	−1	−58.3
Temperature maximum (°C.)	−3.9 (3/26)	4 (3/5)	−26.7 (3/25)	−6.7 (4/24)	6 (4/5)	−49.4 (4/1)
Temperature minimum (°C.)	−31.1 (3/18)	−4 (3/14)	−66.1 (3/22)	−33.3 (4/13)	−5 (4/9)	−70.6 (4/27)
Average station pressure (mb)	988.83		683.37	983.75		677.96
Pressure maximum (mb)	998.98 (3/1)		703.01 (3/25)	996.95 (4/20)		694.21 (4/24)
Pressure minimum (mb)	972.23 (3/28)		671.86 (3/9)	966.14 (4/9)		664.75 (4/8)
Precipitation (mm)	4.83		trace	6.35		trace
Snowfall (mm)	48.30		trace	63.50		trace
Prevailing wind direction	115°		70°	90°		70°
Average wind speed (m/sec)	6.4		5.6	5.6		5.2
Fastest wind speed (m/sec)	20.6 (45°) (3/27)		12.3 (340°) (3/18)	25.0 180° (4/24)		11.9 0° (4/10)
Average sky cover (tenths)	6.4		4.7	4.7		2.5
Number clear days	0		16	2		22
Number partly cloudy days	28		4	25		6
Number cloudy days	3		11	3		2
Number days with visibility less than 0.4 km.	0		6	1		3

*Temperature data unverified.

U. S. Navy

The Director of the National Science Foundation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this agency. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through September 30, 1979.

☆U.S. Government Printing Office: 1974—586–482/2

National Science Foundation
Washington, D.C. 20550