science for a changing world

Prepared in cooperation with United States Antarctic Program, National Science Foundation

U.S. Geological Survey Scientific Activities in the Exploration of Antarctica: Introduction to Antarctica (Including USGS Field Personnel: 1946–59)

By Tony K. Meunier

Richard S. Williams, Jr., and Jane G. Ferrigno, Editors

Open-File Report 2006–1117

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Cover: Index map to the principal geographic features of Antarctica and USGS field operational site locations.

Contents

Introduction to this Open-File Report Group Pertaining to Antarctica....1
Conceptualization, Discovery, Exploration, and Mapping of Antarctica....2
Early History of the U.S. Geological Survey in Antarctica....4
USGS Scientific Objectives, Activities, and USGS Personnel in Antarctica in 1946–47, 1947–48, 1954–55, and 1955–59....7
  U.S. Navy Operation Highjump (1946–47)....7
    Airborne Magnetometry....7
    Glaciology and Geomorphology....7
    USGS Personnel in Antarctica during 1946–47....7
  U.S. Navy Operation Windmill (1947–48)....8
    Geology and Geodesy....8
    USGS Personnel in Antarctica during 1947–48....8
  U.S. Navy U.S.S. *Atka* Reconnaissance Cruise (1954–55)
    Geology....8
    USGS Personnel in Antarctica during 1954–55....8
  IGY and U.S. Navy Operation Deep Freeze I, II, III, and IV (1955–56, 1956–57, 1957–58, and 1958–59)....8
    Geology....8
    Geography and Mapping....9
    USGS Personnel in Antarctica during 1955–59 (Deep Freeze I, II, III, and IV)....9
Modernization and Comparative Change....9
Relevant Publications....11
Relevant Maps....13
Relevant Websites....13
Publications, Mapping, and Cartographic Products....14
Acknowledgments....14

Figures

1. Map showing the principal geographic features of Antarctica and locations of 1946–47, 1947–48, 1954–55, and 1955–59 U.S. Navy and USGS Operations in Antarctica....3
2. *A*, Cachet used by personnel of U.S. Navy Operation Highjump in 1946–47....4
   B, Map of Operation Highjump aerial photography coverage....4
3. Cachet used by personnel of U.S. Navy Operation Windmill in 1947–48....5
4. Cachet used by personnel of U.S. Navy U.S.S. *Atka* reconnaissance cruise in 1954–55....5
5. Cachets designed by the Disney Corporation that were used by personnel of U.S. Navy Operation Deep Freeze I in 1955–56, II in 1956–57, III in 1957–58, IV in 1958–59, and Deep Freeze 60 in 1959–60....5
6. *A*, Cachet used by U.S. personnel during the International Geophysical Years (IGY) in 1957–58....6
   B, Cachet used by U.S. personnel at Ellsworth Station in 1957–58....6
7. Emblem of the U.S. Antarctic Program of the National Science Foundation....7

U.S. Geological Survey Scientific Activities in the Exploration of Antarctica: Introduction to Antarctica (Including USGS Field Personnel: 1946-59)

Introduction to this Open-File Report Group Pertaining to Antarctica

Antarctica is the planet's fifth largest continent [13.2 million km^2 (5.1 million mi^2)]; it contains the Earth's largest (of two) remaining ice sheets; it is considered to be one of the most important scientific laboratories on Earth.

This report is the introduction[1] to a series that covers 60 years of U.S. Geological Survey (USGS) scientific activity in Antarctica. It will concentrate primarily on three major topics:

1. A brief chronological record of the historical search, discovery, and exploration of the southern continent by humans.
2. Early USGS scientific activities in Antarctica, listing expeditions, projects, people and resulting professional publications for Operation Highjump, 1946–47; Operation Windmill, 1947–48; USS *Atka* Reconnaissance Cruise, 1954–55; and Operation Deep Freeze I, II, III, and IV, 1955–59, including IGY.
3. Significant changes that have occurred in Antarctic exploration and research since World War II will be discussed at the end of this report.

Subsequent Open-File Reports will provide a year-by-year documentation of USGS scientific activities and accomplishments in Antarctica beginning with the post-IGY, 1959–60 research team. One Open-File Report is planned to be written for each field-based season. For an example of the series format, see Open-File Reports 2006–1113 (Meunier, 2007a) and 2006–1114 (Meunier, 2007b). This report is a companion document to Open-File Report 2006–1116 (Meunier, 2007c).

The USGS mapping and science programs in Antarctica are among the longest continuously funded projects in the United States Antarctic Program (USAP). The 2005–06 field season is the 56th consecutive U.S. expedition in which USGS scientists have been participants, starting in 1946. USGS and the National Science Foundation (NSF) cooperation began with the establishment by NSF of the U.S. Antarctic (Research) Program [USA(R)P] in 1958–59 under Operation Deep Freeze IV (DF IV) and was given the responsibility for the principal coordination and management of all U.S. scientific activities in Antarctica in Deep Freeze 60 (DF 60) (1959–60). Financial support from NSF, mostly in the form of Memorandum of Understandings (MOUs) and Cooperative Agreements, extends back to this period and can be attributed to the need for accurate geologic, geophysical, and topographic base maps of specific field areas or regions where NSF-funded science projects were planned. The epoch of Antarctic exploration during the IGY was driven by science and, in a spirit of peaceful cooperation, the international scientific community wanted to limit military activities on the continent to logistical support (Meunier, 1979, p. 38).

The USGS, a Federal civilian science agency in the Department of the Interior, has, since its founding in 1879, carried out numerous field-based national (and some international) programs in biology, geology, geophysics, hydrology, and mapping. Therefore, the USGS was the obvious choice for these tasks, because it already had a professional staff of experienced mapmakers, scientists, and program managers with the foresight, dedication, and understanding of the need for accurate maps to support the science programs in Antarctica when asked to do so by the U.S. National Academy of Sciences. Public Laws 85-743 and 87-626, signed in August 1958, and in September 1962, respectively, authorized the Secretary, U.S. Department of the Interior, through the USGS, to support mapping and scientific work in Antarctica (Meunier, 1979, appendix A).

Open-File Report 2006-1116 includes scanned facsimiles of postal cachets. It has become an international practice to create postal cachets to commemorate special events and projects in Antarctica. A cachet is defined as a seal or commemorative design printed or stamped on an envelope to mark a philatelic or special event. The inked impression illustrates to the scientist, historian, stamp collector, and general public the multidisciplinary science projects staffed

[1] See Open-File Report 2006-1116, U.S. Geological Survey Scientific Activities in the Exploration of Antarctica: 1946–2006: Record of Personnel in Antarctica and their Postal Cachets; U.S. Navy (1946–48, 1954–60), International Geophysical Year (1957–58), and USGS (1960–2006) at *http://pubs.usgs.gov/of/2006/1116/* , and Meunier (1979).

by USGS and collaborating scientists during the field season. Since 1960, philatelic cachets have been created by team members for each USGS field season and, in most cases, these cachets depict the specific geographic areas and field season program objectives. The cachets become a convenient documentation of the people, projects, and geographic places of interest for that year. Because the cachets are representative of USGS activities, each year's cachet is included as a digital facsimile in that year's Open-File Report. In the 1980s, multiple USGS cachets were prepared each year, one for use by the winter team at Amundsen-Scott South Pole Station and the other for the project work areas of the austral summer field season programs.

Conceptualization, Discovery, Exploration, and Mapping of Antarctica

Ancient Greeks in the sixth century B.C. hypothesized the existence of a southern landmass to symmetrically and bilaterally offset the known northern landmass. The southern landmass was given the Greek name Antarktikos (the antipode of the cold northern region lying under the constellation "Arkos, the Bear"). In Spain, the Roman geographer Pomponius Mela, who was influenced by writings of the ancient Greeks, was the first (ca. 43 A.D.) to illustrate a spherical world with a large inhabited landmass in the Southern Hemisphere (Lewis, 1965, p. 5). Ptolemy's world map (ca. 140 A.D.) incorporated the concept of the unknown southern land, "Terra Australis Incognita." During the Renaissance (14th to 17th centuries), the southern landmass became known on maps as Terra Australis. Its size and character, as an oversized, pseudo-supercontinent changed as reports of voyages into new regions filtered back to cartographers in Europe (Lewis, 1965, p. 5–11). Though the concept of a gigantic continent persisted for 200 years, mapmakers and their charts eventually pushed the boundaries of the southern continent further and further south (Meunier, 1979, p. 3). The term Antarctica was used for the first time on Fine's 1531 world map to represent the Antarctic Circle. More accurate knowledge about the fanciful southern continent is generally attributed to the three scientific voyages made by the English explorer Captain James Cook (Gurney, 1997). His 1768–70 voyage circumnavigated New Zealand, dispelling the myth that it was a part of the Antarctic continent. During Cook's second voyage, from 1772–75, he successfully used the newly invented Harrison chronometers (Sobel, 1995) to determine, for the first time, accurate longitude during long sea voyages. With this new technology, Cook successfully circumnavigated and produced accurate charts of the ice-filled polar seas surrounding the south polar region. He concluded there were no habitable lands to the south, because he encountered only ice-filled seas. Similar correct conjecture about land to the south was made by A.F. Frezier in a 1712 French voyage to the South Atlantic Ocean and by Captain De Bosses' 1756 conclusion of its existence based on Captain Pierre Bouvet's report of fresh-water tabular icebergs drifting from the south on a 1738–39 voyage (Meunier, 1979, appendix A). Unfortunately, the world lost one of its most gifted scientists, navigators, and explorers when Captain Cook was killed on 8 August 1779 in the Sandwich (Hawaiian) Islands during the homeward leg of his third voyage to the South Pacific region (1776–80). Around the same time, according to Bertrand (1971), Nantucket whalers were operating from the Falkland Islands (Islas Malvinas, prior to 1775).

Captain Nathaniel B. Palmer (Stonington, Connecticut) crossed the ice-filled Bransfield Strait, between the South Shetland Islands and the rocky and cryospheric shores of the Antarctic Peninsula on 16–17 November 1820. A Russian expedition commanded by Thaddeus von Bellingshausen, after having circumnavigated the south polar region during 1819–20, came across Captain Palmer already exploring the Antarctic continent (considered its first sighting). This period also saw the beginning of the naming of Antarctic features after explorers, the ships that carried them to the south polar seas, and the people who sponsored their voyages. The use of geographic place-names was also used, until recently, by international colonial interests to reinforce their territorial claims and priorities in the region (Meunier, 1979, p. 25; see also Alberts, 1995).

During the United States Exploring Expedition (1838–42), under the command of Lt. Charles Wilkes, U.S. Navy, there were two successful austral summer exploratory expeditions (1838–39 and 1839–40) in Antarctica, including an 1839–40 attempt to locate the South Magnetic Pole, which resulted in reconnaissance charting of the coastal waters of East Antarctica (160°E. to 98°E.) and reported "the existence of an Antarctic continent" (Bertrand, 1971, p. 5). The next year, 1840–41, the English navigator and explorer Captain James Ross, in a similar effort to locate the South Magnetic Pole, penetrated the Ross Sea pack ice to discover the edge of the Ross Ice Shelf, whose terminus is floating on the most southerly part of the "Southern Ocean."

The discovery by Captain Ross eventually led to the best access route for exploring the interior of the continent. This access route was successfully exploited during the 20th century by several expeditions by famous explorers, in their respective ascents to the South Polar Plateau, including the Englishmen Robert F. Scott and Ernest Shackleton, the Norwegian Roald Amundsen (the first explorer to reach the geographic South Pole), and Admiral Richard Byrd. Additional mapping of the Antarctica continent after the Wilkes and Ross expeditions (1838–41) was mostly confined to encounters with the coastline by commercial whaling and sealing interests for the next half century (Meunier, 1979

p. 8 and p. 25). It wasn't until after World War II, when the U.S. Navy in 1946–47 launched the peacetime military Operation Highjump (U.S. Navy Task Force 68, Atlantic Fleet, 1947), the largest expedition ever sent to Antarctica (figs. 1, 2), and Operation Windmill (U.S. Navy Task Force 39, 1948), that the most accurate information about the continent in its entirety became more widely known. This effort was able to penetrate beyond the coast and well into the interior using World War II-era aerial photographic reconnaissance survey methods (Trimetrogon) to record and map many of the remaining prominent, undiscovered surface features in Antarctica (fig. 2*B*).

In the 1950s, the international scientific community organized a global scientific year called the International Geophysical Year (IGY) in which the Antarctic continent became an international community for science. This spirit of cooperation in the south polar region was extended after the IGY and formalized by The Antarctic Treaty in 1963, successfully establishing a scientific epoch of discovery and exploration that is still ongoing today (Meunier, 1979, p. 21).

Figure 1. Index map to the principal geographic features of Antarctica and USGS field operational site locations (•). U.S. Navy Operation Highjump (1946–47), U.S. Navy Operation Windmill (1947–48), U.S. Navy U.S.S. *Atka* Reconnaissance Cruise (1954–55), and U.S. Navy Operation Deep Freeze I–IV (1955–56, 1956–57, 1957–58, and 1958–59) provided support for the exploration of many areas of Antarctica during the 1946–59 period.

Early History of the U.S. Geological Survey in Antarctica

USGS employees have been on every modern U.S. expedition to Antarctica since U.S. Navy Operation Highjump in 1946–47 (fig. 2) (U.S. Navy Task Force 68, Atlantic Fleet, 1947), under the command of Rear Admiral Richard E. Byrd. “Highjump” was the codeword the U.S. Navy used for the expedition. The codeword is often equated with the first successful use of helicopter transport for vertical takeoffs and landings in Antarctica. USGS personnel were included as the expeditionary scientists in the three post-World War II U.S. Navy expeditions to Antarctica. James R. Balsley, Jr., a USGS geologist/geophysicist, carried out airborne magnetometer studies, and USGS glaciologist Arthur D. Howard (1948a) studied snow-and-ice deformation and deposition rates while he worked at Little America IV base camp and from U.S.S. *Mt. Olympus* during Operation Highjump. Operation Highjump did not include map-control surveys for geodetic ground control needed to produce accurate maps.

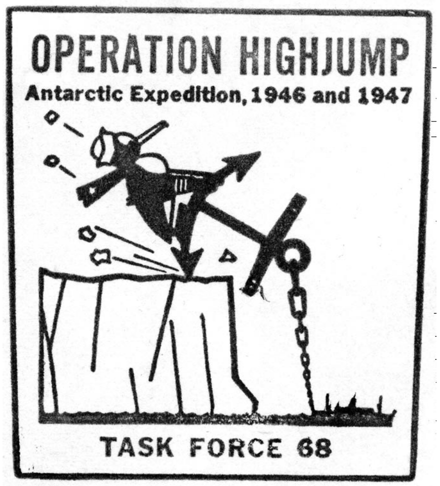

Figure 2A. Cachet used by personnel of the U.S. Navy Operation Highjump in 1946–47.

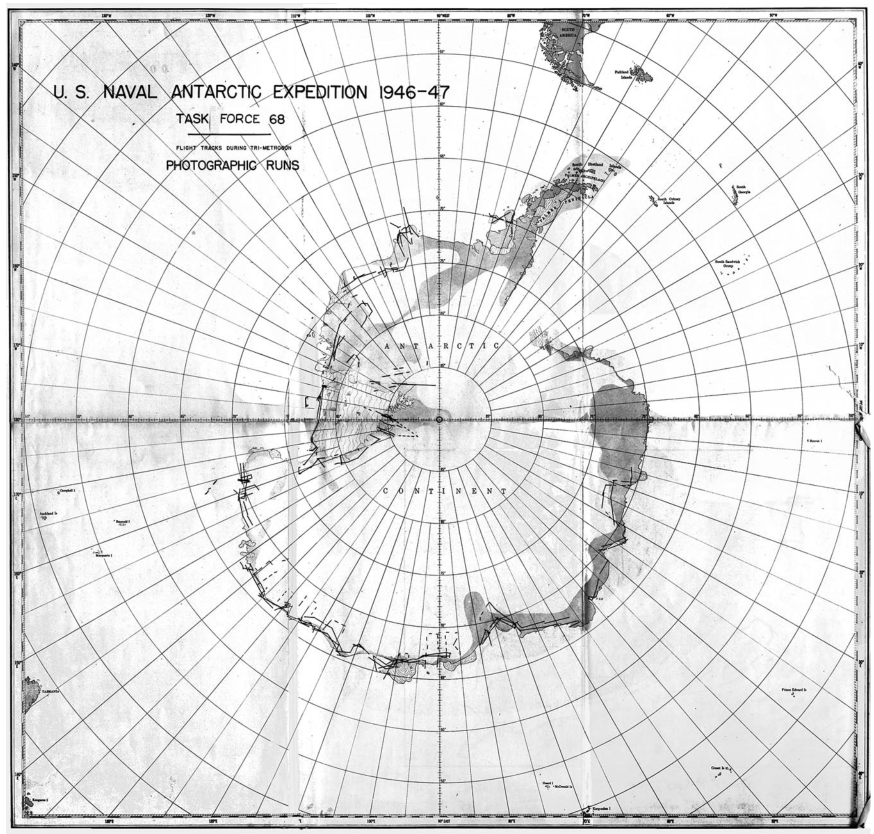

Figure 2B. The 60 percent area of the Antarctic coast and some of the interior that was photographed by Operation Highjump during 50 flights (25 percent of which were first time sightings). Area covered was about 1.5 million mi^2 (3.9 million km^2), of which 750,000 mi^2 was unexplored, including first sighting of 18 major mountain ranges and the discovery of the Lambert Glacier.

The follow-up U.S. Navy Operation Windmill Hydrographic Survey and Oceanographic Research expedition in 1947–48 (fig. 3), which was tasked, as its most important objective, to obtain geodetic ground control for mapping, established 17 astronomical geodetic ground-control stations along the Queen Mary, Knox, and Budd Coasts and in the Antarctic Peninsula area. The icebreakers U.S.S. *Burton Island* and U.S.S. *Edisto* worked in tandem during the expedition. USGS geologist Earl T. Apfel, the expedition geologist, worked in areas photographed from the air during the previous year, including the newly discovered ice-free Bunger Hills on the Knox Coast in East Antarctica (Apfel, 1948; Apfel and Huang, 1954). After a 6-year hiatus in Antarctic activities caused by domestic political issues, including a lack of budgetary support, and international events, such as the onset of the "Cold War" and the world's involvement in the Korean War, the U.S. Navy returned again to the continent in the mid-1950s, focusing primarily on the preparation for and participation in the IGY by U.S. scientists. USGS geologist William E. Davies (Davies, 1956, 1974) was with the U.S. Navy's reconnaissance cruise aboard the U.S.S. *Atka* during 1954–55 (fig. 4), in search of suitable, geologically sound sites for planning U.S. IGY stations (U.S. Navy Hydrographic Office, 1956).

The international scientific community set the official start date for IGY to begin on 1 July 1957 and end on 31 December 1958. Subsequent to the U.S.S. *Atka* cruise, the U.S. Navy established the four-phase Operation Deep Freeze for IGY from beginning to end: Phase I, station construction; Phases II and III, IGY operations; and Phase IV, termination. The first phase, Operation Deep Freeze I (DF I) (fig. 5), in 1955–56, initiated construction for IGY of Byrd, Ellsworth, Hallett, Little America, McMurdo, South Pole, and Wilkes Stations and established the logistical pipeline needed to support IGY. During Operation DF I, USGS geologist Charles R. Lewis (U.S. Navy Task Force 43, 1956; United States Navy, 1956) carried out geologic research from various U.S. icebreakers (U.S.S. *Wyandot*, U.S.S. *Glacier*, and U.S.S. *Eastwind*) on the Balæna and Windmill Islands (U.S. Wilkes Station for IGY) and in the McMurdo Sound region.

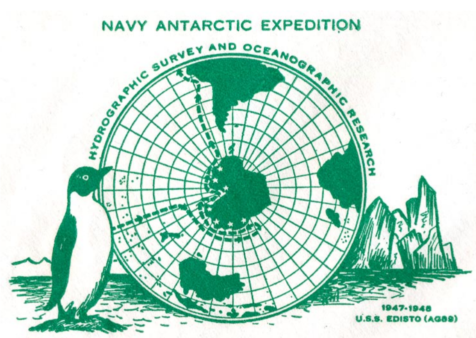

Figure 3. Cachet used by personnel of the U.S. Navy Operation Windmill in 1947–48.

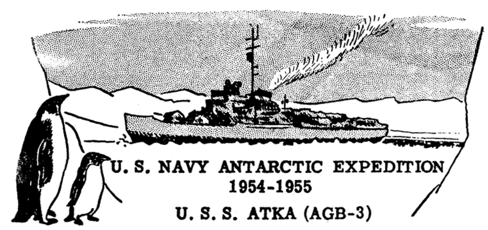

Figure 4. Cachet used by personnel of U.S. Navy U.S.S. *Atka* reconnaissance cruise in 1954–55.

Figure 5. Cachets designed by the Disney Corporation that were used by personnel of U.S. Navy Operation Deep Freeze: *A*, I in 1955–56, *B*, II in 1956–57 and III in 1957–58, and *C*, IV in 1958–59 and Deep Freeze 60 in 1959–60.

From the IGY to the present, the main U.S. logistical-support station in Antarctica has been McMurdo Station, which is located on Ross Island at the junction of the Ross Ice Shelf, the Ross Sea, and the Transantarctic Mountains. Historically, this unique land-based site has afforded one of the best anchorages for accessing the interior of Antarctica (77°30'S.) and has been a logistical base of operations for inland traverses by the U.S., New Zealand, and a number of other countries since first pioneered by the National Antarctic Expedition (U.K.) led by Captain Robert Falcon Scott in 1902. Even today, the USAP logistical requirements rely heavily on annual resupply by ship to this and other stations to supplement intercontinental airborne transport.

During Operation DF II in 1956–57, James D. O'Neal (1957), a USGS Topographic Division cartographer on loan to the U.S. Department of the Defense (DOD), was a U.S. observer on an inspection team that traveled with the Chilean Antarctic program aboard the flagship *Rankagoa* (O'Neal, 1958). Edward W. Remington, Geologic Division (GD) from 1945–1955, left USGS to become the IGY winter-over glaciologist at South Pole Station (1956–57). Also, during DF II, the IGY winter-over seismologist at Ellsworth Station, John C. Behrendt (Thiel and Behrendt, 1959a), and the IGY winter-over glaciologist at Little America V, Walter W. Boyd, Jr. (1960), later became USGS GD regulars in Antarctic research. During Operation DF III, USGS geologists Troy L. Péwé (Péwé, 1958, 1960; Péwé and others, 1959) and Norman R. Rivard studied the geology in the McMurdo Dry Valleys, and glaciologists Walter W. Boyd, Jr. (1960), and Albert P. Crary and others (1962) did glaciology studies on a round-trip Byrd Station-Marie Byrd Land-Ross Ice Shelf seismic and glaciological traverse, while geophysicist John C. Behrendt (Behrendt, 1998; Thiel and Behrendt, 1959b, 1959c; Thiel and others, 1958, 1959) conducted seismic-reflection surveys in the Pensacola Mountains. Also in 1957–58, William H. Chapman (Chapman, 1966, 1983), USGS Topographic Division civil engineer, was the navigator on the first flight into Ellsworth Station. Chapman also tested new electronic positioning devices in the newly discovered Pensacola Mountains. During Operation DF IV, 1958-59, USGS geologists W. B. Hamilton (Hamilton, 1960, 1961; Hamilton and Hayes, 1959) and Philip T. Hayes (Hamilton and Hayes, 1960, 1961, 1963) studied the geology of the McMurdo Dry Valleys, including looking for evidence to confirm the theory of continental drift (Hamilton, 1963; Hamilton and others, 1962). USGS geologist Charles G. Johnson (Alberts, 1995) did geological research on Beauford Island and Cape Bird via U.S.S. *Glacier.* John C. Behrendt (1998; Neuberg and others, 1959) worked in the Weddell Sea, the Filchner Ice Shelf, and Coates Land from Ellsworth Station.

The 12-nation, 60-station south polar IGY effort (fig. 6) was a part of a 67-nation, 18-month worldwide effort directed at an international study of global geophysics. U.S. Navy Operation DF IV was originally designed as the final phase of the IGY by providing the logistical means to terminate the program. Instead, Operation Deep Freeze became the mechanism that led to a permanent presence of the U.S. in Antarctica, when the nation came to realize the important social, political, economic, and scientific changes and the results that had been achieved during the massive station-building effort in the Antarctic. The termination of the 18-month IGY would have been an anticlimax to the huge expense of material, monies, time, and effort by all nations, if the scientific programs had simply ended on 31 December

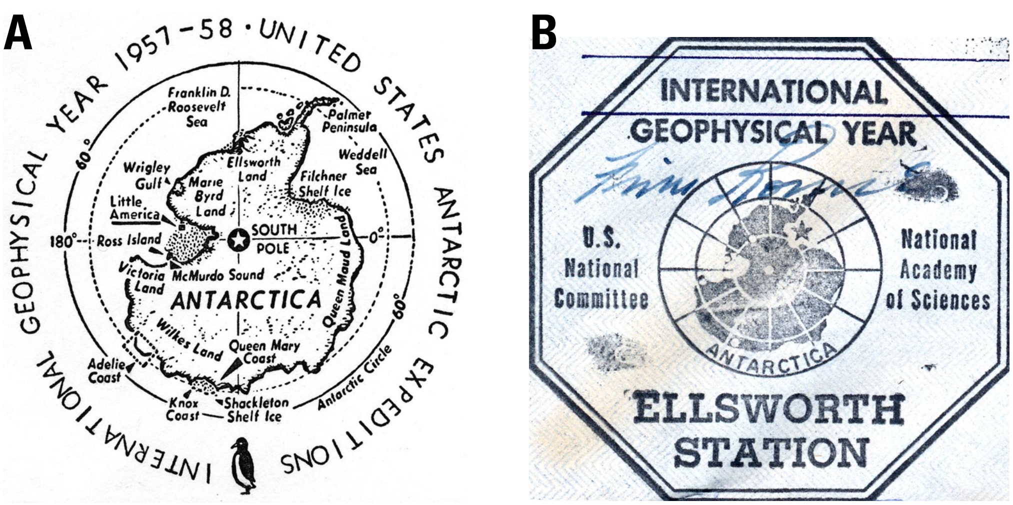

Figure 6. *A*, Cachet used by U.S. personnel during the International Geophysical Year (IGY) in 1957–58. *B*, Cachet used by U.S. personnel at Ellsworth Station in 1957–58.

1958. The monumental logistical effort and cost required to set up the United States Antarctic Program (fig. 7), as well as the other national programs, logically evolved into an extension and expansion of Antarctic research beyond IGY that would eventually include 40 or more field-based sciences (Meunier, 1979, p. 22). The post-IGY continuation of scientific research evolved quickly into a permanent presence on the continent, when the participating nations formally entered into an Antarctic Treaty System on 23 June 1961. The Antarctic Treaty has been such a successful instrument that it is still effective in encouraging international scientific cooperation today, more than four decades later. The treaty is expected to remain in force for the foreseeable future, and the USGS mapping and science programs continue to play a significant role in the advancement of science in Antarctica.

Figure 7. Emblem of the U.S. Antarctic Program of the National Science Foundation.

USGS Scientific Objectives, Activities, and USGS Personnel in Antarctica in 1946–47, 1947–48, 1954–55, and 1955–59

U.S. Navy Operation Highjump (1946–47)

Airborne Magnetometry

USGS geophysicist James R. Balsley, Jr., planned the use of a newly developed Magnetic Airborne Detector designed to rapidly and accurately determine subsurface geology over large, unexplored, and inaccessible areas (J.R. Balsley, Jr., oral commun., 1978). In February 1947, flying out of Little America IV, the U.S. station located at the Bay of Whales, Balsley was successful in using the airborne magnetometer on flight surveys from Alexandra Mountains on the Edward VII Peninsula to Roosevelt Island (79°08'S., 163°05'W.) to differentiate between islands composed of igneous and sedimentary rocks, including rock formations covered by the Ross Ice Shelf (Keller and others, 1947).

Glaciology and Geomorphology

USGS glaciologist Arthur D. Howard, using measurements and historiographic records, planned on determining the rate of change in density, deposition, and movement of yearly snow deposits at snow pits dug during previous expeditions to Little America (Howard, 1948a). His measurements in February 1947 confirmed that the Ross Shelf Ice was moving forward as a composite entity. Another objective was to develop a method of refrigerating and transporting to laboratories in the United States intact ice samples from Antarctica (Howard, 1948b). Small ice samples, including thin section and delicate crystals, were successfully transported back to Washington, D.C., proving the feasibility of this method of study of polar ice.

USGS Personnel in Antarctica during 1946–47

James R. Balsley, Jr., Airborne Geophysicist, Little America IV, Ross Ice Shelf, Edward VII Peninsula; via U.S.S. *Mt. Olympus*

Arthur D. Howard, Glaciologist, Little America IV, Ross Ice Shelf; via U.S.S. *Mt. Olympus*

U.S. Navy Operation Windmill (1947–48)

Geology and Geodesy

The following important objectives of Operation Windmill (1947–48) were achieved: (1) the needed geodetic ground control was obtained along the Antarctic coast for making accurate maps based on some of the 70,000 trimetrogon aerial photographs (vertical, left, and right oblique images over the same point) taken during Operation Highjump the previous year; (2) U.S. Navy Task Force 39 (1948) carried out scientific investigations while sailing from 90°E. longitude eastward along the Queen Mary, Knox, and Budd (future site of the U.S. Wilkes Station) Coasts, continuing to the Balleny Islands, to McMurdo Sound, and to the Bay of Whales to inspect the Little America base sites; (3) continuing eastward, the U.S. Navy attempted penetration of the ice pack along the coast of West Antarctica, to the tip of Antarctic Peninsula at 68°W. longitude, after completing investigations in the vicinity of Peter I, Adelaide, and Stonington Islands; (4) USGS geologist Earl T. Apfel collected rock and mineral specimens (Apfel and Huang, 1954) while accompanying the surveying landing parties.

A geologic study of an ice-free area, now called Bunger Hills (*Bunger Oasis*) along the Knox Coast, which was discovered during Operation Highjump, was of special interest. Dr. Apfel concluded that high hills around the oasis deflected the ice mass into the sea (Apfel, 1948). Fresh-water ponds were found to be quite brackish because of dissolved salts of local origin. In spite of the subzero temperatures, the area was so dry, a true desert, that the soil could not freeze and as a result was loose on the ground. (Author's note: Conditions perhaps analogous to what U.S. robotic "geologists" are seeing on Mars more than 50 years later). In addition, two tons of unique rock and mineral specimens were returned for further study. No mineral deposits of any commercial value were discovered.

The area on Stonington Island in Marguerite Bay was also the location of the privately run U.S. Ronne Antarctic Research Expedition base and the U.K. Falkland Islands Dependencies Survey (FIDS) base during 1947–48.

USGS Personnel in Antarctica during 1947–48

Earl T. Apfel, Geologist, coast of East Antarctica, including Queen Mary Coast, the Bunger Hills, and the Windmill Islands on Knott and Budd Coasts; coast of West Antarctica, including Peter I and Adelaide Islands via U.S.S. *Burton Island* and U.S.S. *Edisto*

U.S. Navy U.S.S. *Atka* Reconnaissance Cruise (1954-55)

Geology

Geologic studies were carried out at coastal sites in the Ross Sea (future site of Little America V; McMurdo Station), Edward VII Peninsula, Weddell Sea (future site of Ellsworth Station). Potential sites for IGY station locations were also recommended.

USGS Personnel in Antarctica during 1954–55

William E. Davies, Geologist, Ross Sea and Weddell Sea site studies via U.S.S. *Atka*

IGY and U.S. Navy Operation Deep Freeze I, II, III, and IV (1955–56, 1956–57, 1957–58 and 1958–59)

Geology

In Deep Freeze I, Charles R. Lewis conducted geological research working from various U.S. vessels in coastal areas at Wilkes Land (Windmill and Balæna Islands) sites and in the McMurdo Sound region.

In Deep Freeze II, Edward W. Remington, an early USGS geophysicist, was the IGY winter-over glaciologist at South Pole Station. Walter W. Boyd, Jr. (later USGS), was the IGY winter-over glaciologist at Little America V Station. John C. Behrendt (later USGS) was the IGY winter-over geophysicist at Ellsworth Station and did geophysical research on the Filchner and Ronne Ice Shelves.

In Deep Freeze III, Troy L. Péwé (Péwé, 1960; Péwé and others, 1959) studied the geology in the McMurdo Dry Valleys. John C. Behrendt did geophysical studies on the Filchner and Ronne Ice Shelves and at Dufek Massif. Walter

W. Boyd, Jr., did glaciological studies on the Marie Byrd Land-Ross Ice Shelf seismic and glaciological traverse from Little America V.

In Deep Freeze IV, W. B. Hamilton and Philip T. Hayes did geologic research and mapping extending from the upper and lower Taylor Glacier near Beacon Heights (ski-equipped DeHavilland Twin Otter aircraft support), including some previously unexplored areas, to Lake Bonney and the rest of the Taylor Valley (helicopter support) to McMurdo Sound. The mountain system of the McMurdo Dry Valley areas was determined to be the result of the Early Paleozoic Ross orogeny rather than the prevailing block faulting theories. Geologists were also looking for evidence to support the theory of continental drift (Hamilton, 1963) in the McMurdo Dry Valleys. Charles G. Johnson studied the geology of Beaufort Island and Cape Bird via U.S.S. *Glacier*.

Geography and Mapping

During Deep Freeze II, James D. O'Neal, Topographic Division (TD), geographer, was one of the first U.S. observers and chroniclers for the USAP when he traveled with the Chilean Antarctic Expedition to the South Shetland Islands and to the northwestern part of the Antarctic Peninsula via the Chilean vessel *Rankagoa*.

During Deep Freeze III, William H. Chapman (TD), civil engineer, was the navigator on the first intercontinental airplane flight into Ellsworth Station. He carried out map-control surveys with experimental electronic test units in the Filchner Ice Shelf and Pensacola Mountains region.

During Deep Freeze IV, William H. Chapman was the winter-over surveyor at Byrd Station. He did nighttime stellar observations to determine a station's geographic location. During the summer field season, he did map-control surveys on the round-trip traverse from Byrd Station to the Horlick Mountains.

USGS Personnel in Antarctica during 1955-59 (Deep Freeze I, II, III, and IV)

DF I	Charles R. Lewis, Geologist, Wilkes Land coast and McMurdo Sound
DF II	John C. Behrendt, Geophysicist, Ellsworth Station; Filchner and Ronne Ice Shelves
	Walter W. Boyd, Jr., Glaciologist, Little America V
	Edward W. Remington, Glaciologist, South Pole Station
	James D. O'Neal, Geographer, South Shetland Islands and Antarctic Peninsula
DF III	John C. Behrendt, Geophysicist, Ellsworth Station; Filchner and Ronne Ice Shelves; Dufek Massif, Pensacola Mountains
	Walter W. Boyd, Jr., Glaciologist, Little America V to Ross Ice Shelf traverse
	Troy L. Péwé, Geologist, Lake Fryxell and McMurdo Dry Valleys
	William H. Chapman, Civil Engineer, Filchner Ice Shelf and Pensacola Mountains
DF IV	W. B. Hamilton, Geologist, McMurdo Dry Valleys
	Philip T. Hayes, Geologist, McMurdo Dry Valleys
	Charles G. Johnson, Geologist, Beaufort Island; Cape Bird
	John C. Behrendt, Geophysicist, Weddell Sea, Coats Land, Filchner Ice Shelf from Ellsworth Station
	William H. Chapman, Civil Engineer, winter-over Byrd Station; map-control surveys round trip from Byrd Station to the Horlick Mountains

Modernization and Comparative Change

What will become evident from these reports describing USGS mapping and scientific activities in the exploration of Antarctica is the enormous changes that have occurred during the past century in instruments, transportation, materials, and national/international objectives and methods employed by scientists and logistical support staffs of Antarctic Treaty nations to carry out scientific research and exploration of the Antarctic continent. Equally important, and the significance cannot be ignored, are things that have not changed. For instance, working conditions in the field are still harsh and unforgiving on people and equipment that still rely on long logistical supply lines. Also, the south polar region is still a pristine scientific laboratory where cutting-edge science often results in remarkable discoveries. The Antarctic Treaty System can be credited with much of this success, including the lack of exploitation of the resources of the region, which have been put in abeyance for the foreseeable future, as can the establishment, within the Antarctic Treaty System, of the Committee on Environmental Protection (26 full member countries ratified the Antarctic Environmental Protocol in 1998).

While resource exploitation and most other commercial activities are still nonexistent in Antarctica, tourism, mostly on cruise ships, has rapidly become a large, viable enterprise. Tour operators have been complying with the provisions of the Antarctic Treaty. Another interesting factor is bipartisan U.S. political support for a continuing presence in Antarctica. Other nations also continue to support the treaty principles; therefore, the Antarctic Treaty should continue indefinitely.

The unbridled enthusiasm to want to return to “the ice” by most of the people who have worked in Antarctica probably comes as a surprise to people who have not worked there. This “Antarctic fever” seems to be a psychological response by persons having the opportunity to come in contact with or to work with scientific leaders in their field and in an environment where state-of-the-art science is commonplace.

The international, collaborative focus on Antarctica has benefited many programs and projects, leading to a significant increase in the number and types of programs that have resulted in numerous scientific advancements. One obvious positive change that occurred in the 1970s and 1980s is the participation of women scientists in national Antarctic science programs. USGS female geologists Christine Carlson and Constance J. Nutt were the first American women to be included in a deep-field deployment as team members of the USGS 1976–77 Dufek Massif field party.

Each nation’s acceptance of progressive change in Antarctica, human and technical, has led to a marked increase in the number and type of programs undertaken during the continent’s limited seasonal access, due to the Earth’s most extreme temperatures and weather conditions. For example, aircraft hydraulic systems do not operate properly when South Pole Station’s surface temperature is colder than –50°F (from February to November). Recent emergencies in mid-winter resulted in the use of the DeHavilland Twin Otter aircraft because the skis needed for landing use mechanical springs that function as shock absorbers even at extremely low temperatures.

Early Antarctic expeditions, which had a tendency to be large undertakings, were sponsored by nations with economic and political interests and were usually carried out by the military of various nations that had the requisite logistical capabilities for operating in such a severe, remote environment. Today, all U.S. Antarctic activities are under civilian management (Office of Polar Programs, National Science Foundation). Pre-IGY logistical transport of people, equipment, and supplies was only by ship with support by onboard aircraft. Today’s critical elements are delivered by a logistical support system using commercial, military, and contract air transport and using ships for year-end resupply of bulk materials and removal of waste materials (a recent Antarctic environmental improvement by all nations).

The increased reliance on aircraft to support science on the continent was gradual until the IGY requirements led to major developments in intercontinental transport capabilities to Antarctica, along with the need for close air support for field parties; these resulted in a new era in polar aviation.

As technology improved, World War II-type aircraft were used, including helicopters (first used during Operation Highjump (1946–47)). Early U.S. aircraft included the DC-3 “Dakota,” the Navy R4D version of the DC-3, which used jet-assisted take-off (JATO) rockets and skis to become airborne. These aircraft were gradually replaced by the ski-equipped four-engine (turboprop) Lockheed LC-130 Hercules (D model), the post-IGY workhorse of the polar regions, which was introduced in 1960 for transport and aerial surveying and photogrammetric mapping. Today, close field support is provided by use of the DeHavilland Twin Otter. One of the largest aircraft in the world, the C-5A, a wheeled aircraft, was used to transport large amounts of material via the ice runway prepared on the Ross Ice Shelf until operations ceased in 2003.

Prior to the end of World War II, knowledge relating to the interior of the unmapped, unexplored continent was scant (Meunier, 1979, p. 19). Today, the surface and most subglacier features in Antarctica are known, although most subglacier geologic stratigraphy and structure are still poorly known. Early expeditions (pre-radio era) were totally isolated; later expeditions experienced periods of partial isolation, with infrequent letters and radio contact to the outside world. Today, instant phone calls and Internet access via satellite telecommunication are not only available but expected. This improved communication has made problem solving while on the continent so much easier. However, 24-hour telecommunication (voice and data transmission) in the field is yet to be realized by all scientists.

Another major change is in transportation. Early explorers made long-duration oversnow traverses by man hauling and dog sleds. This was first replaced by motorized vehicles, which, in turn, have been replaced by helicopter traverses and rugged ski-equipped DeHavilland Twin Otter aircraft capable of going anywhere in Antarctica (with fuel caches en route for long traverses) to drop off and pick up field parties. By agreement of the Scientific Committee on Antarctic Research (SCAR) nations, dogs are considered unnecessary and are no longer allowed in Antarctica.

In the early days of fieldwork, the only way to record scientific data was through the use of ground sensors operated by scientists at or supported by major bases, including winter-over crews. Today, satellite sensors are able to record and obtain data that are being continuously transmitted by automatic instrumentation, operating unattended at remote sites on the continent, year-round, in temperatures that can reach –89°C (–129°F) (at Vostok Station on the

Polar Plateau near the South Geomagnetic Pole on 21 July 1983). Included in South Pole Station's numerous science programs is the operation of an important infrared (IR) astronomical observatory.

One of the most significant developments in Antarctica science is in rapid determination of geodetic ground position at remote field sites by use of satellite technology. Early surveying in Antarctica required the use of optical instrumentation, such as theodolites on overland traverses, and long-duration nighttime star fixes that are subject to refractive effects of the atmosphere. Because Antarctica is surrounded entirely by the "Southern Ocean," geodetic networks from South Africa and South America could not be accessed through line of sight to tie Antarctica into the rest of the world's geodetic network. Astronomic observations were used to determine the coordinates for a geodetic reference datum point established at McMurdo Station, called the "Camp Area Datum" (Chapman, 1966). The Camp Area Datum station served as the reference for extension of the geodetic network to remote locations of scientific interest for making maps of these areas. However, extending the Camp Area Datum network to remote locations was not practical (distance exceeding many hundreds of kilometers) on the continent without introducing systematic errors in latitude, longitude, and elevation (Chapman, 1983).

The advent of satellite geodesy led to the introduction and use of navigational satellites that were based on an Earth-centered, Earth-fixed reference system rather than an astronomically based datum reference network. By the 1970s, USGS surveyors were using the U.S. polar-orbiting Navy navigational satellite system (called Transit) to determine accurate geodetic control in remote, often featureless places such as the Polar Plateau.

During the 1980s and 1990s, the datum for U.S. Antarctic mapping transitioned from referencing coordinates to the Camp Area Datum to the U.S.-established World Geodetic System 1984 (WGS-84), an Earth-centered, Earth-fixed datum. In the 1990s, the SCAR expert group on Geodetic Infrastructure for Antarctica (GIANT) was created, and it has involved active participation of USGS physical scientists. In 1998, at the SCAR meeting in Concepción, Chile, GIANT was adopted as the official continent-wide datum, the International Terrestrial Reference Frame (ITRF), currently referred to as ITRF 2000 (SCAR, 1999). Today, WGS-84 is referenced to the ITRF 2000.

Satellite geodesy is dramatically changing the way mapping and science are conducted in Antarctica. The revolutionary Transit satellite was eventually replaced in the 1980s by the Global Positioning System (GPS) satellite constellation. Today, with the availability of low-cost receivers, GPS is used extensively by the international scientists and operations support personnel in all areas of Antarctica. In real time, scientists can georeference spatial features with accuracies for positions (vertically and horizontally) at the level of a few meters. Post-processing of raw observation data will yield position accuracies ranging from the sub-centimeter to sub-meter level, the time span for the observations, and methodology employed in the data processing. In some cases, surface elevations can be obtained to within a spherical centimeter of the Earth's center. The capability to quickly and precisely determine a field party's geographic location is perhaps one of the most significant technological advances in the history of Antarctic science.

The Antarctic continues to be a mysterious and exhilarating place to work with highly motivated people who produce significant scientific discoveries about our planet and the universe beyond. It is one of the few locations on Earth that has been uniquely protected and preserved for scientific research from the disturbances of human cultures and should continue in this role under the auspices of the current Antarctic Treaty System.

Relevant Publications

Alberts, F.G., ed., 1995, Geographic names of the Antarctic, 2d ed.: Reston, VA, U.S. Board on Geographic Names, National Science Foundation Report No. NSF95–157, 834 p.

Apfel, E.T., 1948, Bunger's "Oasis," Antarctica [abs.]: Geological Society of America Bulletin, v. 59, no. 12, p. 1,308–1,309.

Apfel, E.T., and Huang, W.T., 1954, Charnockite series in Bunger Lakes area, Antarctica [abs.]: Geological Society of America Bulletin, v. 65, no. 12, p. 1,226–1,227.

Behrendt, J.C., 1998, Innocents on the ice. A memoir of Antarctic exploration, 1957: Niwot, CO, University Press of Colorado, 428 p.

Bertrand, K.J., 1971, Americans in Antarctica 1775–1948: New York, American Geographical Society, 554 p.

Boyd, W.W., Jr., 1960, IGY Little America-Ross Ice Shelf traverse in United States National Committee for the IGY (USNC–IGY) Antarctic glaciological data field work, 1958–59: Columbus, OH, Ohio State University Research Foundation Report 825, Report No. 1, Pt. 4, 193 p.

Chapman, W.H., 1966, Adjustment of the Byrd Station Strain Net, Antarctica, and procedures for determining strain rate: Columbus, OH, The Ohio State University, Master's dissertation, 142 p.

Chapman, W.H., 1983, Surveying in Antarctica during the International Geophysical Year, *in* U.S. Geological Survey Polar Research Symposium: Reston, VA , U.S. Geological Survey Circular 911, p. C6–C7.

Crary, A.P., Bennett, H.F., Boyd, W.W., Jr., and Robinson, E.S., 1962, Glaciological studies of the Ross Ice Shelf, Antarctica, 1957–1960: Washington, D.C., International Geophysical Year (IGY), World Data Center-A, IGY Glaciology Report 6, 193 p.

Davies, W.E., 1956, Antarctic stratigraphy and structure: Washington, D.C, American Geophysical Union, Geophysical Monograph v. 1, p. 44–51.

Davies, W.E., 1974, Geological and limnological factors of cold deserts, *in* Polar deserts and modern man; Part One, Natural Environment: Tucson, AZ, University of Arizona Press, p. 53–61.

Gurney, Alan, 1997, Below the convergence. Voyages toward Antarctica 1699–1839: New York, Penguin Books, 315 p.

Hamilton, W. E., 1960, New interpretation of Antarctic tectonics: U.S. Geological Survey Professional Paper 400-B: p. B379–B380.

Hamilton, W. E., 1961, Petrochemistry of probable paleozoic granitic rocks from the Ross Sea region, Antarctica: U.S. Geological Survey Professional Paper 424-C, p.C209–C212.

Hamilton, W. E., 1963, Antarctic tectonics and continental drift, *in* Munyan, A.C., ed.: Paleontological and Mineralogists Special Publication 10, p. 75–93.

Hamilton, W. E., and Hayes, P.T., 1959, United States Geological Survey field work in South Victoria Land, 1958–59: Cambridge, Polar Record, v. 63, Sept. 1959, p. 757.

Hamilton, W. E., and Hayes, P.T., 1960, Geology of Taylor Glacier-Taylor Dry Valley Region, South Victoria Land: U.S. Geological Survey Professional Paper 400-B: p. B376–B378.

Hamilton, W. E., and Hayes, P.T., 1961, Structure of lower Taylor Glacier, South Victoria Land, Antarctica: U.S. Geological Survey Professional Paper 424-C, p. C206–C209.

Hamilton, W. E., and Hayes, P.T., 1963, Type section of the Beacon Sandstone of Antarctica: U.S. Geological Survey Professional Paper 456-A, p. A1–A18.

Hamilton, W. E. and others, 1962, Saline features of a small ice platform in Taylor Valley, Antarctica, *in* Ecological Survey Research 1962, Chapter B: U.S. Geological Survey Professional Paper 450-B, p. B72–B76.

Howard, A.D., 1948a, Further observations on the Ross Shelf Ice, Antarctica: Geological Society of America Bulletin, v. 59, no. 9, p. 919–926.

Howard, A.D., 1948b, The preservation of Antarctic ice specimens: Journal of Geology, v. 56, no. 1, p. 67–71.

Keller, Fred, Balsley, J.R., Jr., Dempsey, W.J., 1947, Field operations and compilation procedure incidental to the preparation of isomagnetic maps: Falls Church, VA, Photogrammetric Engineering and Remote Sensing, v. 13, no. 4, p. 644–647.

Lewis, R.S., 1965, A continent for science: New York, Viking Press, 300 p.

Meunier, T.K., 1979, Geography of Antarctica: Brockport, New York, State University of New York, College at Brockport, Master's dissertation, 120 p. (including 118 illustrations, 10 tables, 12 color and 71 black-and-white maps, photographs, bibliography (6 p.), appendixes and fold-out color map of Antarctica).

Meunier, T. K., 2007a, U.S. Geological Survey scientific activities in the exploration of Antarctica, 2002–03 field season, *in* Williams, R.S., Jr., and Ferrigno, J.G., eds.: U.S. Geological Survey Open-File Report 2006–1113, 5 p.

Meunier, T. K., 2007b, U.S. Geological Survey scientific activities in the exploration of Antarctica, 1995–96 field season, *in* Williams, R.S., Jr., and Ferrigno, J.G., eds.: U.S. Geological Survey Open-File Report 2006–1114, 6 p.

Meunier, T. K., 2007c, U.S. Geological Survey scientific activities in the exploration of Antarctica: 1946–2006 record of personnel in Antarctica and their postal cachets; U.S. Navy (1946–48, 1954–60), International Geophysical Year (1957–58), and USGS (1960–2006), *in* Williams, R.S., Jr., and Ferrigno, J.G., eds.: U.S. Geological Survey Open-File Report 2006–1116, 57 p.

Neuberg, H.A.C., and Thiel, E.C., Walker, P.T., Behrendt, J.C., Aughenbaugh, N.B., 1959, The Filchner Ice Shelf: Annals of Association of American Geographers, v. 49, no. 2, p. 110–119.

O'Neal, J.D., 1957, Report of James O'Neal, United States observer with Chilean Antarctic Expedition, 1956–57: Washington, D.C., U.S. Office of Antarctic Programs, 60 p.

O'Neal, J.D., 1958, The political geography of the Argentine-British-Chilean Sector of Antarctica: Washington, D.C., George Washington University, Master's dissertation, 136 p.

Péwé, T.L., 1958, Glacial fluctuation between 1911 and 1958 in the McMurdo Sound region: Geological Society of America Bulletin, v. 69, no. 12, p. 1,755–1,756.

Péwé, T.L., 1960, Multiple glaciation in the McMurdo Sound, Antarctica in United States National Committee for the IGY (USNC-IGY) Antarctic glaciological data field work, 1958–59: Columbus, OH, Ohio State University Research Foundation Project 825, Report No. 2, 27 p. (includes 9 plates).

Péwé, T.L., Rivard, N.R., and Llano, G.A., 1959, Mummified seal carcasses in the McMurdo Sound Region: Antarctic Science, no. 13, p. 716.

Scientific Committee on Antarctic Research, 1999, SCAR Recommendation XXV-8: "Adopt ITRF as the basic geodetic reference frame in Antarctica": Hobart, SCAR Bulletin No. 134.

Sobel, Dava, 1995, Longitude. The true story of a lone genius who solved the greatest scientific problem of his time: New York, Penguin Books, 184 p.

Thiel, E.C., and Behrendt, J.C., 1959a, Seismic studies at the Ellsworth snow pit: Washington, D.C., International Geophysical Year (IGY), World Data Centre-A (Glaciology), IGY Glaciology Report 2, 14 p.

Thiel, E.C., and Behrendt, J.C., 1959b, Seismic studies on the Filchner Ice Shelf, Antarctica, 1957–58: New York, American Geographical Society, International Geophysical Year (IGY), World Data Centre-A (Glaciology) v. 2, p. 1–14.

Thiel, E.C., and Behrendt, J.C., 1959c, Gravity and magnetic measurements on the Ellsworth oversnow traverse, 1957–1958: Washington, D.C., International Geophysical Year (IGY), World Data Centre-A (Glaciology), IGY Glaciology Report 2, 21 p.

Thiel, E.C., Behrendt, J.C., Bradley, E.A., and Turcotte, F.T., 1959, Ice thickness and bottom topography of the Filchner Ice Shelf and along the Ellsworth-Byrd traverse route: IGY Bulletin 29, Transactions, American Geophysical Union, v. 40, p. 423–426.

Thiel, E.C., Ostenso, N.A., Bennett, H.F., Robinson, E.S., Behrendt, J.C., 1958, IGY Antarctic oversnow traverse program 1957–1958: Washington, D.C., International Geophysical Year (IGY), World Data Centre-A (Glaciology), IGY Glaciology Report 1, p. I.1–I.14.

U.S. Navy Hydrographic Office, 1956, Field reports, oceanographic observations, U.S. Navy Antarctic Expedition 1954–55, U.S.S. *Atka*: Washington, D.C., U.S. Navy Hydrographic Office, H.O. TR 48, 82 p., 26 figs., 19 pl.

U.S. Navy Task Force 68, Atlantic Fleet, 1947, Report of Operation Highjump: U.S. Navy Antarctic Development Project 1947: Washington, D.C., U.S. Department of the Navy, Office of the Chief of Naval Operations, 3 v. (includes illustrations, folded charts, and photographs).

U.S. Navy Task Force 39, 1948, Report of operations: Second Antarctic Development Project (1947–1948): Washington, D.C., U.S. Department of the Navy, 4 v. (includes illustrations, charts, and photographs).

U.S. Navy Task Force 43, 1956, Report of Operation Deep Freeze I: Washington, D.C., U.S. Naval Support Force, Antarctica, 1 v. (contains illustrations, charts, and photographs).

U.S. Navy, 1956, U.S.S. *Wyandot* (*AKA*-92) Operation Deep Freeze 1955–1956 Cruise book: Norfolk, VA, Tiffany Publishing, 70 p. (includes illustrations).

Relevant Maps

USGS Antarctica Reconnaissance Preliminary Base (topographic map series)

- 1958, Australian Quadrant (Knox Coast) Experimental Chart, 1:1,000,000 scale
- 1956, Australian Quadrant – E2-64-10, 1:500,000 scale
- 1956, Australian Quadrant – E2-66-11, 1:500,000 scale
- 1956, Australian Quadrant – E2-66-12, 1:500,000 scale
- 1961, African Quadrant – E1-66-8, 1:500,000 scale
- 1961, African Quadrant – E1-66-12, 1:500,000 scale
- 1961, Australian Quadrant – E2-64-9, 1:500,000 scale
- 1961, Australian Quadrant – E2-64-11, 1:500,000 scale
- 1961, Australian Quadrant – E2-66-7, 1:500,000 scale
- 1961, Australian Quadrant – E2-66-8, 1:500,000 scale
- 1961, Australian Quadrant – E2-66-9, 1:500,000 scale

USGS Antarctica 1:250,000 Reconnaissance Series (topographic map series)

- 1959, Pagano Nunatak
- 1959, Stewart Nunataks

Relevant Websites

http://usarc.usgs.gov
http://www.geoscience.scar.org
http://www.nsf.gov
http://www.usgs.gov
http://www.glaciers.er.usgs.gov
http://pubs.usgs.gov
http://pubs.usgs.gov/of/2006/1113/
http://pubs.usgs.gov/of/2006/1114/
http://pubs.usgs.gov/of/2006/1115/
http://pubs.usgs.gov/of/2006/1116/
http://pubs.usgs.gov/of/2006/1117/

Publications, Mapping, and Cartographic Products

To order USGS maps, photographs, and publications on Antarctica, contact *http://www.usgs.gov*, call 1-888-275-8747, or write to USGS Information Services, Box 25286, Denver, CO 80225.

Acknowledgments

Funding of the 1946–47 and 1947–48 U.S. Antarctic Expeditions was by the United States Department of the Navy. USGS personnel were included in this all-U.S. Navy project as civilian expeditionary scientists. Current funding of USGS activities is provided by NSF Award No. 02–33246. I want to gratefully acknowledge the assistance of Betsy Ann Meunier and the following USGS personnel who assisted me with this report: Jerry L. Mullins, Chief, Antarctica, Arctic, and Canadian Programs, Office of International Programs; Larry D. Hothem, Eastern Geographic Science Center; Daniel R. Sechrist and Robert J. Allen (ret.), U.S. Antarctic Resource Center; Peter F. Bermel (ret.), Director's Office; R. Lee Hadden, Reference Librarian, Geographic Information Office, Reston, VA; Jane G. Ferrigno, Geologic Discipline (GD), Earth Surface Dynamics Program (ESDP), Reston, VA; Richard S. Williams, Jr., GD, ESDP; Janice G. Goodell, ETI, Woods Hole Science Center, Woods Hole, MA; Kirsten C. Healey, ETI, Eden, UT; and Arthur B. Ford, GD (ret.).