THE 1989 GREENLAND FIELD SEASON AFTER OPERATIONS REPORT FOR NSF-SPONSORED PROJECTS

Polar Ice Coring Office
203 O'Neill Building
University of Alaska Fairbanks
Fairbanks, Alaska 99775

PICO
OR 89-1

December 1989

PICO is operated by UAF under contract to the National Science Foundation, Division of Polar Programs.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

On behalf of the National Science Foundation Division of Polar Programs, and all NSF-sponsored participants, the Polar Ice Coring Office at the University of Alaska Fairbanks (PICO/UAF) extends our appreciation to the many individuals, organizations and colleagues for their continued support and assistance. The success of the 1989 National Science Foundation Greenland field season is largely due to support provided by the following groups and organizations:

Danish Commission for Scientific Research in Greenland
Headquarters United States Air Force (HQ USAF)
Headquarters Military Airlift Command (HQ MAC)
Headquarters USAF Space Command (HQ AFSPACECOM)
The 109th Tactical Airlift Group (109th TAG)
Sondrestrom Air Base, Greenland (1015th ABS)
Thule Air Base, Greenland (1012th ABG)
McGuire Air Force Base, NJ (WRI)
Alaska Air Command, Eielson AFB
US Army, Fort Wainwright
US Army CRREL
4700 Operations Support Squadron (4700 OSS)
Felec Services, Inc. (FSI)
Dewline Station Dye 3 (DYE3)
GreenlandAir A/S (GLAIR)
GreenlandAir Charter A/S (GLACE)
The Royal Greenland Trade Department (KNI)
The Danish Meteorological Institute
STATOIL

Further, the successful administration of this year's field activities are due to the monumental efforts of two extremely competent individuals, Ms. Cathy Shaner of PICO/UNL and Ms. Dorothy Dahl of PICO/UAF.

For eleven years as Administrative Assistant and Logistics Specialist at PICO/UNL, Cathy Shaner has been the administrative anchor, providing timely and effective project support and administration to NSF-sponsored programs half a world away. Although Ms. Shaner elected to remain at the University of Nebraska-Lincoln, "Cathy Site" near the summit of the Greenland ice sheet remains as a tribute to her efforts in support of the international polar community.

The first new employee to join PICO after the move to the University of Alaska Fairbanks, Dorothy Dahl, was faced with the task of administering the movement of nearly 100 researchers, support personnel and their equipment to and from various sites within Greenland. This After Operations Report is tribute and proof that indeed, she did succeed in her efforts.

I. INTRODUCTION

"The 1989 Greenland Field Season After Operations Report for NSF-Sponsored Projects" has been prepared to summarize the field activities of, and logistical support for, 1989 National Science Foundation Division of Polar Programs (NSF-DPP) sponsored research projects in Greenland.

The Polar Ice Coring Office (PICO) at the University of Alaska Fairbanks (UAF) provides administrative support, field operations management and coordination of logistical requirements for NSF-sponsored projects under NSF contract DPP88-20948. PICO's primary responsibilities are to support NSF Division of Polar Programs (DPP) glaciology projects and, secondarily, to support other DPP projects and those sponsored by other Divisions within NSF.

PICO operations support includes: 1) arrangements for personnel and equipment transportation between the U.S. and Greenland, 2) military clearances for personnel access to air base facilities in Greenland, 3) on-site coordination of field activities originating at Sondrestrom Air Base, 4) control and maintenance of an inventory of field camp equipment that includes: oversnow vehicles, shelter/tents, kitchen supplies, radios, generators and fuels, and 5) liaison between NSF, the scientists and civilian and military support subcontractors. PICO also provides: 1) ice core and hot water drilling services, 2) the loan of non-technical drilling equipment, and 3) borehole logging equipment and services to NSF-DPP glaciological and geophysical projects.

A location map of Greenland is provided as Figure 1, page 2. Coastal sites of NSF-sponsored research include Sondrestrom AB, Thule AB, Ilulissat (Jakobshavns), Nuuk (Godthaab), and Isua on the west coast; and Peary Land, Kangerdlugssuaq fjord and Angmagssalik on the north and east coasts. Sites on the ice sheet include Dye 3, the Summit region of central Greenland and Camp Century.

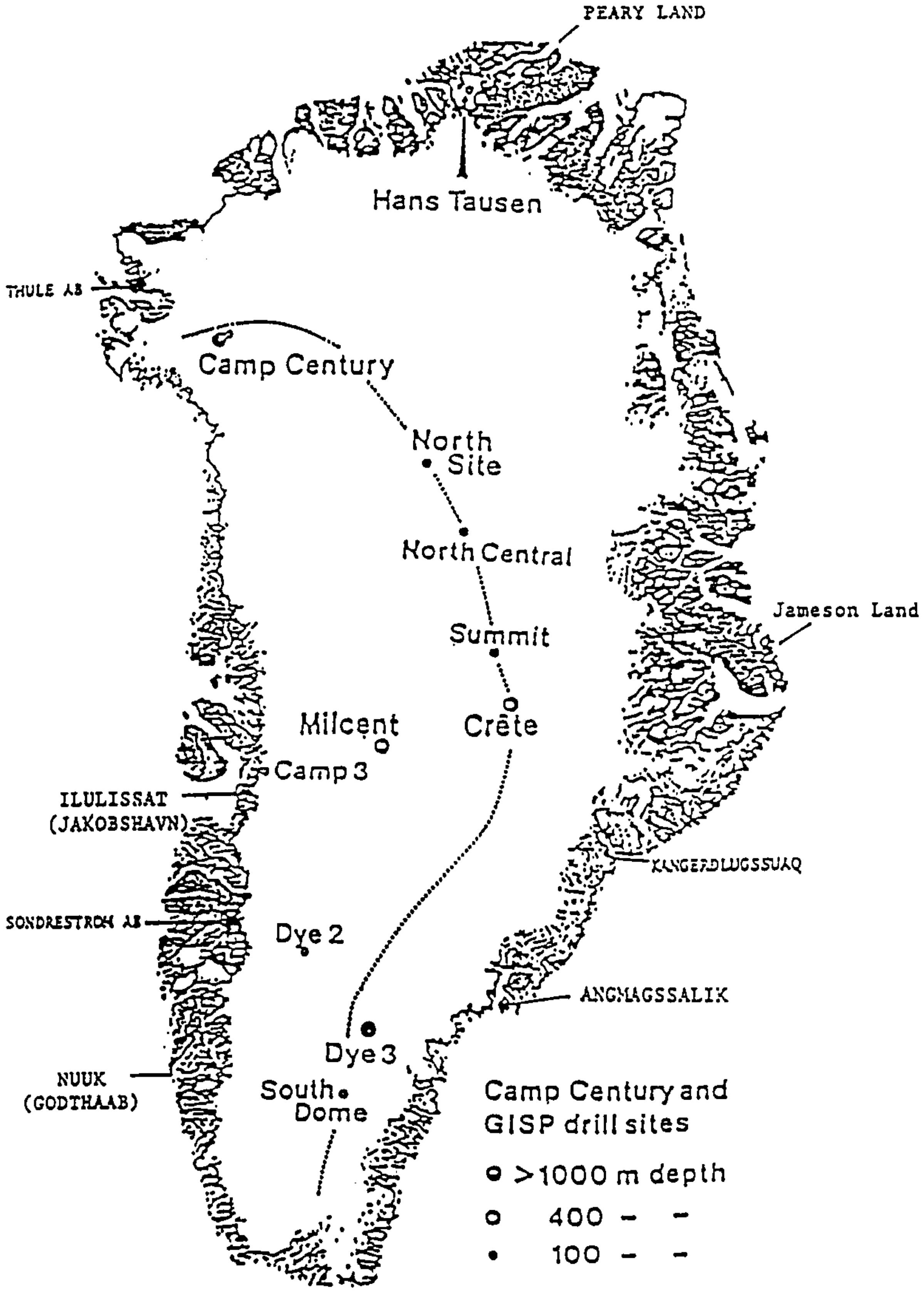


Figure 1. Location Map of Greenland

II. NSF-DPP GLACIOLOGY AND OTHER NSF-SPONSORED PROJECTS

There were a total of 12 NSF-sponsored field projects participating in the 1989 Greenland season. Included were the Greenland Ice Sheet Project II (GISP2) investigators as well as participants in the multi-institutional 12-month continuous atmospheric sampling program at DYE 3. A total of 97 individuals were involved in field activities. Table 1, page 5, provides a list of projects by category:

A. NSF-DPP Sponsored Polar Coordinated Science Programs
B. NSF-DPP Sponsored Polar Glaciology Programs
C. NSF-DPP Sponsored Polar Atmospheric Sciences Programs
D. NSF-DPP Sponsored Polar Earth Sciences Programs
E. Other NSF-Sponsored Programs
F. Distinguished Visitors

Figure 2, page 7, presents a timetable for NSF-sponsored projects fielded during the period April through September.

The individual project summaries are presented in Appendix A pages 19-60.

NSF-DPP POLAR GLACIOLOGY PROJECTS

The 1989 Camp Century Borehole Logging Program draws to an end a four-year collaborative effort of B. Lyle Hansen (PICO-UNL) and Niels Gundestrup (University of Copenhagen-UCPH) to log the three deep boreholes of Dye 3, Byrd Station and Camp Century. This effort focused on the deformation properties of deep ice via logging deep boreholes for inclination and azimuth. A summary of this project appears in Appendix A, Item 2, pages 21-22.

1989 marks the first field season of the Greenland Ice Sheet Project Two (GISP2), which began operations this spring near the summit of the ice sheet. The major thrust of the GISP2 project is to drill and recover an ice core from the entire thickness of the Greenland Ice Sheet, over 3000 meters. This is the most ambitious ice core drilling program in Greenland to date, and will provide researchers with the longest paleoenvironmental record ever achieved in the northern hemisphere. GISP2 shares similar goals with the European "Greenland Ice Core Program" (GRIP) deep drilling effort. The GRIP camp and drilling operations are located approximately 30 Km east of the GISP2 site.

Science activities at GISP this season involved researchers from eleven universities or institutes from across the United States. Institutions involved include: University of New Hampshire; University of Wisconsin; University of Washington, The Desert Research Institute; New York Institute of Health; University of Miami; University of Rhode Island; Carnegie-Mellon University; University of Colorado; and Pennsylvania State University. The GISP2 Science Management Office (SMO) is housed at the University of New Hampshire (UNH), with drilling and operations support provided by PICO at the University of Alaska Fairbanks.

Over 500 meters of snow and ice were collected from four holes completed this season. These samples, along with other surface, snow pit and atmospheric samples, were returned to the Continental United States (CONUS) for detailed chemical and physical studies. The last hole drilled in 1989 to 90 meters will be re-entered in 1990 to begin deep drilling operations expected to continue on a seasonal basis through the summer of 1992. A summary of GISP science activities is provided in Appendix A, Item 3, pages 23-31.

Researchers from the Byrd Polar Research Center at The Ohio State University (BPRC-OSU) were also involved in central Greenland operations this season. Dr. E. Mosely-Thompson conducted ice core and snow pit studies near the summit to complete her program of holocene paleoclimatic reconstruction from Greenland ice cores. Several ice core and snow pit samples were taken from sites at or within close proximity of the GISP2 site. A summary report is located in Appendix A, Item 4, page 32. Dr. J. Bolzan revisited sites along a 150x150 Km survey grid he established in 1987 as part of a central Greenland ice sheet dynamics-GISP2 site selection program. A project summary is located in Appendix A, Item 5, page 33.

Researchers from the University of Alaska Fairbanks Geophysical Institute (UAF) and the Federal Institute of Technology Zürich in Switzerland (ETH-Zentrum) continued their hot water drilling and seismic investigations to determine the mechanisms of rapid flow on the Jakobshavn Ice Stream, west Greenland. Of the ten holes drilled at three sites, several were near 1600m in depth; the deepest hot water holes ever drilled. In addition to other surface measurements and seismic profiling, tilt and temperature sensors were frozen into some of the holes from which the data will be recorded and accessed during the 1990 field season. Project summaries of this program are located in Appendix A, Item 6, pages 34-35.

NSF-DPP POLAR METEOROLOGY PROJECTS

Carnegie-Mellon University (CMU) completed a continuous one-year (August 1988-August 1989) snow and air sampling program at the Dye 3 site. This program, which focused on the transport of airborne contaminants onto the Greenland ice sheet, is summarized in Appendix A, Item 7, pages 36-38.

NSF-DPP POLAR EARTH SCIENCE PROJECTS

A team of researchers from Harvard University completed a second year of investigations into the vertebrate paleontology and geology of the Triassic-Jurassic boundary of east Greenland. A summary of this very successful project and their rather exciting paleontological finds is located in Appendix A, Item 8, pages 39-42.

With the support of a Norwegian seismic vessel, researchers from the University of Wyoming Department of Geology and Geophysics undertook crustal reflection profiling studies across Archean crust and crustal satures in the region of Godthaab Fjord, west Greenland. Project summary is located in Appendix A, Item 9, page 43.

NON-U.S. PROJECTS

Non-U.S. collaborative or cooperative projects that received PICO support include ETH-Zentrum, Jakobshavn Ice Stream project; the University of Copenhagen Geophysical Institute, Camp Century Borehole Logging program and to the GRIP Operations Center. PICO support to the GRIP program includes the coordination of United States Air Force air support provided by the 109th TAG, as well as other minor base services provided by the 1015th ABS, Sondrestrom Air Base, Greenland.

DISTINGUISHED VISITORS

PICO, the U.S. Air Force and Greenland Home Rule Government were again hosts to a Greenland site visit by Dr. Peter Wilkniss, Division Director; Dr. Carol Roberts, Division Deputy Director and Dr. Jerry Brown, Head of the Arctic Staff, National Science Foundation Division of Polar Programs. The site visits included a mission briefing of the 1015th ABS, site visits to both the GISP2 and GRIP summit camps and travel to Nuuk (Godthaab) for meetings with Greenland Home Rule Government officials.

Table 1. NSF-DPP, Other NSF-Sponsored Projects and Non-U.S. Projects
Greenland 1989

	Institution	Project Title	Principal Investigator(s)	Dates in Field
	A. NSF/DPP Polar Coordinated Science Projects			
1.	Polar Ice Coring Office Univ. Alaska Fairbanks (PICO/LG)	Coordination of Greenland 1989 Operations and Logistics	Dr. Luis Proenza	8 May - 30 August
2.	Polar Ice Coring Office UNL	Logging of Camp Century Borehole	B. Lyle Hansen	22 April - 4 May
	B. NSF/DPP Polar Glaciology Projects			
3.	Glacier Research Group Univ. of New Hampshire (UNH)	Greenland Ice Sheet Project II (GISP2) Science Management Office	Dr. Paul Mayewski	18 May - 5 August
4.	Byrd Polar Research Center Ohio State University (OSU-T)	Holocene Paleoclimatic Reconstruction from Greenland Ice Cores	Dr. Ellen Mosley-Thompson	22 May - 17 June
5.	Byrd Polar Research Center Ohio State University (OSU-B)	Ice Sheet Dynamics in Central Greenland	Dr. John Bolzan	24 May - 15 June
6.	Geophysical Institute University of Alaska and ETH-Zentrum, Z0rich (UAF/ETH)	Determination of the Mechanisms of Rapid Flow on Jakobshavn Glacier, Greenland By Borehole Measurements	Dr. Keith Echelmeyer Dr. William Harrison Dr. Almut Iken	15 June - 7 August
	C. NSF/DPP Polar Meteorology Projects			
7.	Department of Civil Engr. Carnegie-Mellon University (CMU)	Processes Influencing Species Concentrations in Ice Cores from Dye 3, Greenland	Dr. Clifford Davidson	9 May - 15 August
	D. NSF/DPP Polar Earth Sciences			
8.	Museum of Comp. Zool. Harvard University (Harvard)	Vertebrate Paleontology and Geology of the Triassic-Jurassic Boundary in East Greenland	Dr. Farish Jenkins, Jr.	28 June - 4 August
9.	Dept. Geol./Geophys. University of Wyoming (UWyo)	Crustal Reflection Profiling Across Oldest Archean Crust and Crustal Satures in West Greenland	Dr. Scott Smithson	10 September - 3 October

E. Other NSF-Sponsored Projects

10.	Geological Sciences State Univ. of New York at Binghampton (SUNY)	Petrofabric Analysis of Igneous Lamination in Layered Mafic Intrusions	Dr. H. R. Naslund	16 July - 19 August
11.	Department of Geology Stanford University (Stanford)	Tertiary Magma-Hydrothermal Systems of East Greenland	Dr. Dennis Bird	21 July - 16 September
12.	Lamont-Doherty Geological Obs. Columbia University (L-DGO)	1989 Lamont-Doherty Geological Observatory Expedition to the Kangerdlugssuaq Area	Dr. Charles E. Lesher	5 August - 6 September

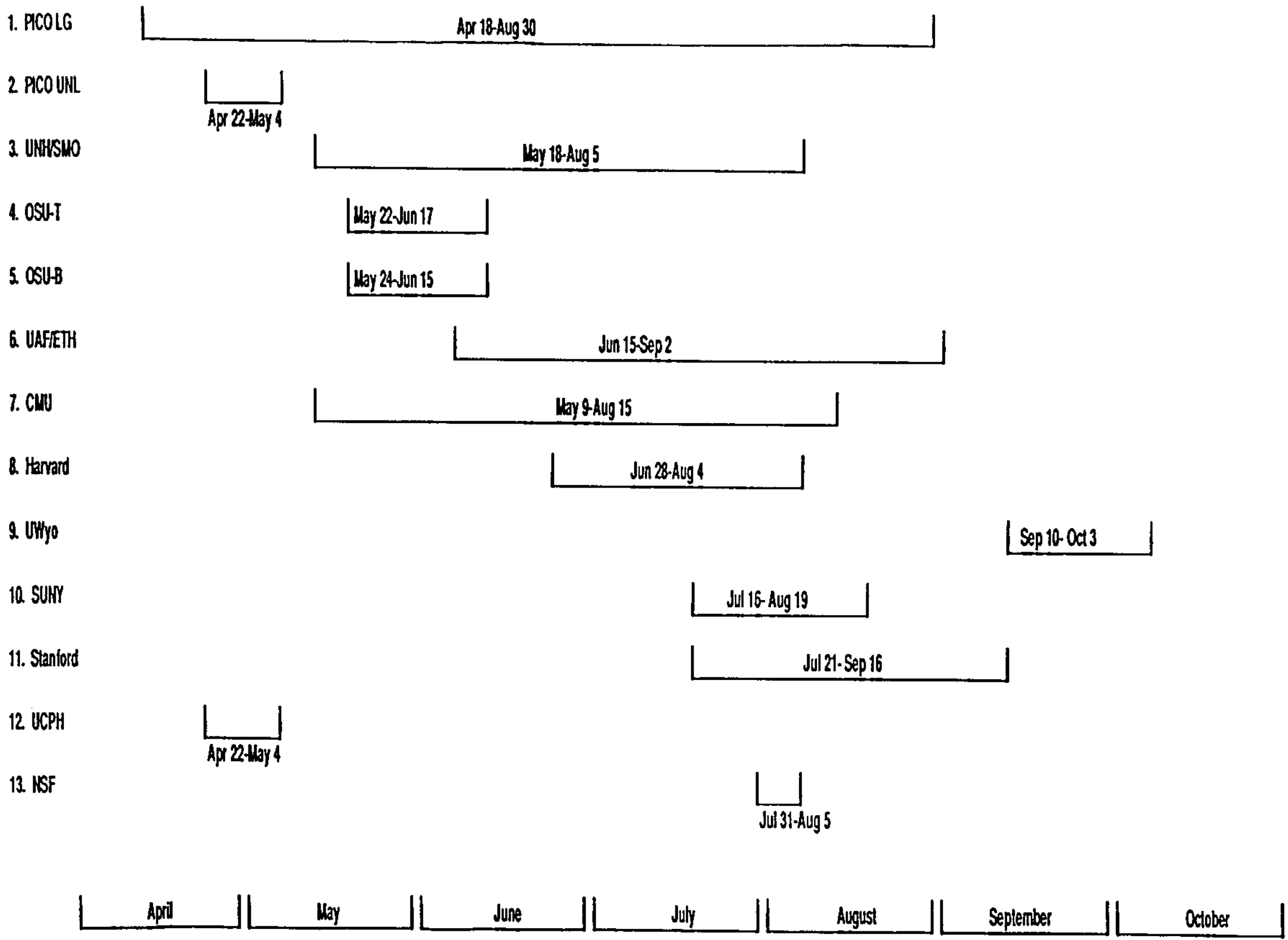
F. Non-U.S. Projects

13.	University of Copenhagen Geophysical Institute (UCPH)	Camp Century, Greenland	Niels Gundestrup	22 April - 4 May

G. Distinguished Visitors

14.	NSF	Site Visits to Thule, Sondrestrom, Nuuk, Dye 3, GISP2	Wilkniss, Roberts, Brown	31 July - 5 August

Figure 2: Timetable for NSF-Sponsored and Other Projects in Greenland, 1989



III. LOGISTICAL COORDINATION AND MANAGEMENT

In September of each year, PICO establishes a field operations management schedule which outlines the administrative process and requirements for the coordination of the following Greenland field season.

The 1989 schedule was supported by the distribution or transmittal of the following documents:

1) "1989 Greenland Field Requirements and Personnel Information" memorandum dated November 30, 1988 and the "Facilities and Services Available to NSF-Sponsored Projects in Greenland" were distributed by PICO to all PIs who submitted proposals to NSF-DPP involving Greenland fieldwork.

2) "Preliminary Logistics Support Requirements and Cost Projections for 1989 NSF-Sponsored Greenland Research" was transmitted by PICO to the NSF-DPP Program Manager, Polar Earth Science Programs on January 26, 1989. The document presents PICO's preliminary support requirements and cost projections for 10 of the 14 research non-GISP related grants proposed for 1989.

3) PICO submitted on May 5, 1989, a proposal and budget for Amendment No. 2 to NSF Contract DPP88-20948 to provide logistical support for Greenland fieldwork in response to NSF-DPP tasking letters.

4) A "Field Operations Plan for NSF-Sponsored 1989 Greenland Programs" dated May 1, 1989 was distributed to PIs and support contractors participating in the 1989 NSF-sponsored Greenland program. This document defined the scope, schedule and support requirements of the year's field activities and was the final planning report prior to commencement of the 1989 field season.

5) NSF-DPP's authorization to proceed with support of the 1989 Greenland field activities as outlined in Amendment No. 2 above was sent from the NSF-DPP Program Manager for Polar Coordinated Science Programs on September 8, 1989.

Administration of field operations and support functions provided by PICO include the following activities:

1) Clearances for individuals to work within and travel through U.S. military installations. These include Military Airlift Command (MAC) travel authorizations, Foreign National Clearances, DEW Line Clearances and Sondrestrom and Thule Air Base Clearances;

2) Coordination of personnel and cargo movements to, from and within Greenland with regular updates to agencies and personnel utilizing both scheduled and chartered air service;

3) Distribution of briefing packets which include clearances, itineraries and general travel information to all participants prior to departure to the field;

4) Research and procurement of field equipment and supplies to include shelters, oversnow and wheeled vehicles, generators, camp support and communications equipment; and

5) Maintenance of third party support documents between NSF-DPP and the U.S. Air Force and the subcontracted agents, as well as applications for single-side band and other radio frequency clearances from Danish authorities.

PICO stations two Field Operations Managers (FOMs) at Sondrestrom AB to provide project and air support coordination, expedite resupply requests and maintain remote field party communications. In addition, PICO serves as a liaison between the various NSF science groups and base support functions.
An administrative assistant remains at PICO/UAF to provide project coordination and military travel arrangements prior to projects departing the Continental United States (CONUS).

IV. LOGISTICAL SUPPORT FACILITIES

A. Sondrestrom Air Base

Sondrestrom Air Base has been the primary staging area for the majority of NSF-sponsored projects in Greenland over the past 15 years. The air base and the accompanying civilian community offer the widest range and greatest availability of logistical support materials and services in Greenland.

1. 1015 Air Base Squadron (1015ABS).

Recently downgraded from Air Base Group, the 1015ABS provides NSF-sponsored projects with the majority of required materials, supplies and services. This support is provided under an Interservice Support Agreement (ISSA) between the U.S. Air Force Headquarters Space Command (HQ AFSPACECOM) and the NSF-DPP. The Sondrestrom AB ISSA became effective 1 September 1985 and will remain the active document of support authority through May 1991 unless otherwise renegotiated under the provisions stated within the ISSA.

Under the guidelines of the ISSA, the 1015ABS and its civilian contractors, Greenland Contractors (GC) and Felec Services, Inc. (FSI) provide third party reimbursable support to NSF-sponsored programs which includes: space-available billeting, Twin Otter air support, open mess privileges, commissary services, equipment rental, cargo handling, vehicle maintenance, base supply items, fuels and warehouse/office space.

Field operations during 1989 utilized the following major reimbursable support items:

a) Petroleum/Oil/Lubricants (POL):

Shop-Vehicle Use	
MOGAS:	828 gal
DFA:	

GISP2 Fuel from Sondrestrom	
MOGAS:	1563 gal.
DFA:	9968 gal.

Remote Camp/Field Use	
MOGAS:	54 gal.
DFA:	1158 gal.

b) Commissary: foodstuffs were procured to supply GISP2 and central Greenland operations to support 1375 personnel days on site.

c) Base supply: materials and supplies procurements in support of the NSF sponsored research programs.

2. NSF/PICO Support Facilities.

PICO continues to maintain two support facilities provided by the USAF at Sondrestrom Air Base. Since 1974, PICO has maintained the old fire station (Building T-436), as a staging and warehouse space. PICO has occupied building #387 as the primary support facility and field center since 1988. Administrative offices, storage, communications center and maintenance shop are the primary uses of this heated, secure space. Remodeling and facilities upgrades scheduled for 1989 yet not completed will be rescheduled for 1990. These projects include kitchen/wash area, secure storage cages, sewing center, expansion of radio room and permanent HF antenna anchors for the field center. The T-436 warehouse will receive three new overhead doors and one additional access door.

Additional facilities: PICO requires additional freezer space on base to support additional core programmed for transport and storage from GISP2. Such a request has been submitted to the 1015th for consideration.

3. NSF/PICO Vehicles

PICO maintains three wheeled vehicles: a 1987 Ford 3/4-ton crew cab pickup, a 1976 Ford 1/2-ton pickup and a 1956 Dodge M-37 4-wheel drive personnel carrier. The 1987 Ford is operational and without major mechanical difficulties. It is anticipated that the 1976 Ford 1/2-ton will require replacement in 1990. The Dodge M-37 will be operational for the 1990 season.

The long-standing requirement for a 10-15,000 lb. forklift capable of loading and off-loading C-130 aircraft has been met with the provision of a 15K Taylor forktruck acquired by the GRIP Operations Center (GOC). This vehicle, purchased by GRIP, is intended for joint general use and ground support of Sondrestrom based air operations. Maintenance and general upkeep is shared by PICO and GOC.

PICO has also recently acquired from USAF salvage a 4,000 lb. forklift to support warehouse and staging operations. Although operational, this vehicle will require minor maintenance and modification prior to the start of the 1990 season.

The 1640 series Tucker Sno-Cat and 2 (ea) 2-ton cargo sleds remain in operation supporting central Greenland operations after being cached and thus completely buried near Summit between August 1987 and May 1989. 1989 upgrades include 6-way U blade and VHF land mobile radio. This vehicle will remain at GISP to support camp, skiway and remote traverse operations.

The Caterpillar LGP 931 was deployed to GISP2 in May to support camp construction and skiway development. This turbo-charged 931 continues to operate flawlessly at the 10,000+ ft. elevation of the central Greenland Summit region. The standard uni-bucket and quick connect was retrograded to CONUS for upgrade to a low-density, high-volume bucket. This vehicle will remain at GISP2 for the duration of the project.

The Bombardier SkiDozer remains in Sondrestrom. This vehicle has not been actively used on the ice since conclusion of GISP1 operations at Dye 3 in 1982. Old and tired, this vehicle will require a complete inspection and rebuild prior to its upgrade in status to a field worthy vehicle. There are no current requirements at GISP2 or any other site for this vehicle.

4. Field Camp Equipment

Current inventories of field equipment will provide adequate support for projected non-GISP2 project requirements in 1990. The GISP2 field site will require additional structures, communications, first aid and fueling/refueling equipment to meet the projected requirements through 1992.

5. Sondrestrom Baseloading

In past seasons, Sondrestrom AB has been faced with sever overcrowding during the summer months. However, since the phase-down of USAF-sponsored personnel beginning in 1988, berthing of NSF-sponsored personnel on base has not been a concern nor is it likely to be so in the future.

6. Off-Base Support

Off-base support for 1989 was provided by Gronlandsbanken (funds transfer), the Greenland Trade Department-KNI (materials handling, civilian sealift), STATOIL (POL products and containers), GreenlandAir-GLAIR (passenger and air cargo service), Scandinavian Airlines-SAS (passenger and air cargo service, ground equipment repair), Gronlands Tekniske Organization-GTO (civilian telecommunications) and Danish Arctic Contractors-DAC (heavy equipment services).

B. Thule Air Base

Thule AB, located on the northwest coast is the larger of the two U.S. air bases in Greenland. Equally equipped as Sondrestrom to provide bulk products and support services to field research teams, Thule has often been a staging point for NSF-sponsored projects conducting studies in North Greenland. Moreover, because of its ample hangar space and related services, Thule is often the preferred location to base research aircraft.

However, lacking commercial scheduled air service, Thule is more isolated in terms of commercial and governmental services, with charter air services limited to a permanently stationed GreenlandAir Bell 212 helicopter.

Logistical support at Thule is provided to NSF-sponsored projects under the same provisions governing the Sondrestrom ISSA. A separate support document for Thule is still under consideration.

It is recommended that an annual Thule pre-season site visit be included with that of Sondrestrom's to brief the 1012 Air Base Group (1012ABG) command on upcoming NSF-sponsored research in Greenland. Regardless of the extent of the NSF operations planned for Thule each season, the number of NSF-sponsored personnel transiting through Thule in a given season alone warrants such a courtesy visit.

C. Dye 3

Because of the GISP2 deep borehole and the convenience of the logistical base the Dye site station provides, Dye 3 has continued to be a popular location for geophysical and atmospheric studies. Since August of 1988, Dye 3 had been the site of a year-round continuous sampling program which concluded in August of 1989.

The major support requirements for NSF-sponsored programs at Dye 3 have included: billeting and messing facilities, heavy equipment support for excavating NSF structures and equipment, aircraft on- and off-loading, communications to Sondrestrom and CONUS, and POL products.

The DEWline station at Dye 3 will close effective November 15, 1989. Historically the 4700th OSS has supported PICO activities at this station but future support capabilities will cease upon site closure.

D. GISP2 Site

The GISP2 site (N 72° 34 35; W 38° 27 47) was established May 22 after put-in by the 109th TAG. The exact deep drilling site was located by a PICO survey team using Doppler satellite survey techniques based on coordinates supplied by the GISP2 Science Management Office (SMO). The survey team remained on site to layout a 200x10,000 ft. skiway and flag lines to the atmospheric sampling site ("Clean Air," 29 Km, bearing south 24° 02 11) and to the GRIP camp approximately 30 Km to the east. Facilities, equipment and supplies positioned in support of 1989 operations include:

Facilities:

1 ea. 15x30 Weatherport (galley)
1 ea. 15x30 Weatherport (berthing)
1 ea. 15x30 Weatherport (shop/storage)
1 ea. 12x15 Weatherport (generator hut)
1 ea. 12x14 Weatherport traverse hut
1 ea. 10x100 Science Trench

Moss Optimus series, Scott Polar and The North Face 2m fabric tents provided additional berthing and support facilities at GISP2 and the ATM Clean Air Site.

Vehicles/Equipment:

Tucker Sno-Cat 1640
2 ea. 2-ton traverse sleds
Caterpillar LGP 931
2 ea. Ski-doo, Alpine
4 ea. Ski-doo, Skandic

Fuel:

GISP2 fuel from Sondrestrom

MOGAS:	1563 gal.
DFA:	9968 gal.

GISP2 fuel from Cathy Site

MOGAS:	770 gal.
DFA:	2,061 gal.

Total Fuel positioned at GISP2

Mogas: 2,333 gal.
DFA: 12,029 gal.

1989 GISP2/central Greenland Programs fuel consumption:

MOGAS:	1,146 gal.
DFA:	6,439 gal.

GISP2 on-site fuel inventory

MOGAS:	1,187.5 gal.
DFA:	5,590 gal.

In addition to GISP2 related drilling activities, the camp and facilities provided support to the ATM sampling site, the installation of three automatic weather stations in the Summit region and The Ohio State drilling program and Bolzan, surface traverse based from "Cathy Site."

In preparation for continued GISP2 operations in 1990 construction began on an elevated Galley/Administration building. This 56x25 facility, based on a concept design by Wayne Tobiason of the US Army Cold Regions Research Laboratory (CRREL), will house offices and messing facilities for up to 40 personnel. The steel support structure built upon a 4-foot compacted snow surface elevates the structure approximately 18 feet above the existing 1989 snow surface. Based on calculated accumulation rates, this height should provide unrestricted access to the facility through 1993. At the conclusion of 1989 operations the snow surface, steel structure and plywood deck were completed, with the single-story panelled building delivered to the site. Completion of this facility is scheduled for June of 1990.

Other additional facilities planned for 1990 include: 54' geodesic dome drill shelter; generator module; head and shower module; water well; core storage trench; and additional Weatherports for berthing, science and storage.

Camp operations concluded with the final pull-out of camp support personnel on August 4, 1989. All facilities, equipment and supplies remain on site.

E. Communications

1. **Telecommunications.** The NSF/PICO administrative office at Sondrestrom is serviced by both commercial and USAF telephone systems. These systems provide internal communications within Greenland, including ship-to-shore, as well as long distance service to the U.S. and Europe. NSF-sponsored personnel in Greenland can be accessed as follows:

AUTOVON:	834-1211 Extension 565
Commercial:	Country Code (299) 11153 Extension 565
Telefax:	Country Code (299) 11247

   It is anticipated that Telex and electronic mail service via Omnet will be installed at the PICO office and available to NSF-sponsored personnel in Greenland by the 1990 field season.

2. **High Frequency Single Side Band (HF-SSB).** At present, PICO maintains an HF radio inventory of six Southcom SC-120 crystallized field radios, and one Southcom SC-130 synthesized field radio. The base station in Sondrestrom is a Shipmate 9000, 200 Watt marine radio belonging to UCPH with an ICOM M-700 providing base camp communications for GISP2.

   Several efforts have been made to improve HF communications in support of NSF-sponsored programs in Greenland.

   The most significant improvements were made in 1988 with the installation of new multi-band dipole and trapped vertical antennas in Sondrestrom, and the construction of new field dipole antennas and porta-masts for remote camps. Both the base station and field dipole antennas are configured as inverted Vs erected on a single fiberglass mast. These configurations have provided a remarkable improvement in field communications, especially for camps along the west coast. An additional multi-band dipole will be erected in Sondrestrom in 1990.

3. **VHF-Air.** PICO continues to maintain both Terra and ICOM VHF-Air radios. Each field party is issued a minimum of two air-band radios.

4. **VHF-Land Mobile.** VHF land mobile systems comprised of both hand-held and base station radios make up the "local" network for GISP2 communications. 45 watt base stations provide direct communications between GISP2, the ATM site, GRIP and the Tucker traverse vehicle. Hand-held radios are also available to other projects that require line-of-site communications.

5. **Emergency Locator Transmitters.** All NSF-sponsored programs are issued Emergency Locator Transmitters (ELT or EPIRB) operating on 121.5 and 243 Mhz.

6. **Satellite Communications.** After successful field trials of the new INMARSAT Standard C format in 1989 a Standard C terminal will be deployed at GISP2 to provide store forward Telex capability from site.

7. **Equipment Upgrades.** HF equipment upgrades programmed for 1990 include two additional 100 watt SSB transceivers to support the GISP2 atmospheric sampling station and main camp emergency hut. Sondrestrom and GISP2 will be equipped with two new 150 watt HF data packet systems for text and non-text data transmission.

V. FIELD OPERATIONS AND LOGISTICS

A. Personnel in Greenland

Table 2, page 15, provides a summary of projected versus actual mandays of personnel participating by project and location during the 1989 Greenland field season. Actual personnel days spent were: 673 at Sondrestrom AB, 33 at Thule AB, 121 at Dye 3, 1,375 at GISP2, and at remote camps in Jakobshavn, east Greenland and Nuuk, a total of 673.

B. Air Operations

Air support for the 1989 Greenland field season was provided by MAC Channel, 109th TAG, FSI Twin Otter, GreenlandAir Commercial, GreenlandAir Charter, Scandinavian Airlines and Icelandair. A summary of air operations is provided in Table 4, page 16.

1. MAC Channel. The MAC Channel system was used by PICO to support the majority of personnel and cargo transported between McGuire AFB and Sondrestrom and Thule Air Bases. A total of 135 passengers and 98,437 lbs. cargo were transported during the season.

2. 109th TAG. The 109th TAG provided LC-130 transport to NSF-sponsored projects between CONUS, Sondrestrom, Thule, Camp Century and GISP. A total of 96 passengers and 384,697 lbs. cargo were transported by the 109th TAG.

3. FSI Twin Otter. FSI Twin Otter provided space-available ski-equipped Twin Otter support to NSF-sponsored personnel transiting to and from Dye 3. A total of 11 passengers were transported on a routine basis throughout the 1989 season.

4. GreenlandAir Commercial. GreenlandAir Commercial flew transient support for coastal operations via regularly scheduled passenger and cargo flights. A total of 22 passengers and 12,900 lbs. cargo were transported from Sondrestrom to coastal villages and return.

5. GreenlandAir Charter A/S. GLACE provided NSF-sponsored projects with both fixed-wing and helicopter support. Twin Otter support was provided between Keflavik Naval Air Station and Constable Pynt on Greenland's east coast. KingAir support was provided between Sondrestrom and Nuuk. Helicopter charter totals include Bell 206: 31.8 hours; Bell 212: 11.8 hours; and Sikorsky 61: 12.4 hours.

6. Commercial air and ship transport. SAS and Icelandair provided passenger and cargo movements to both Sondrestrom and Keflavik. Local KNI ship transport was utilized to ship nominal amounts of cargo to coastal villages in support of west coast programs.

Table 2. Personnel Site Loading by Project -- Greenland 1989

	Sondrestrom AB		Thule AB		DYE3		GISP2		Remote Camps	
	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual	Projected	Actual
A. NSF/DPP Polar Coordinated Science Projects										
1. PICO Operations	397	392	10	7	8	3	358	348		
2. PICO Drilling	74	81	0	2			362	384	46	40
3. PICO Borehole Logging			22	20						
SUBTOTAL	471	473	32	29	8	3	720	732	46	40
B. NSF/DPP Polar Glaciology Projects										
1. Byrd Polar Research Center-E. M-Thompson	14	12					62	56		
2. Byrd Polar Research Center-J. Bolżan	49	45					48	46	26	23
3. University of Alaska-K. Echelmeyer	20	12							196	228
4. GISP2/UNH-P. Mayewski	74	86	0	4			550	539		
SUBTOTAL	157	155	0	4	0	0	660	641	222	251
C. NSF/DPP Polar Meterolology Projects										
1. Carnegie Mellon University-C. Davidson	28	16			147	118				
SUBTOTAL	28	16			147	118				
D. NSF/DPP Polar Earth Science Projects										
1. Harvard University-F. Jenkins									185	185
2. University of Wyoming-S. Smithson	20	13							148	197
SUBTOTAL	20	13							333	382
E. Distinguished Visitors										
1. National Science Foundation	0	16					0	2		
SUBTOTAL	0	16					0	2		
TOTAL	676	673	32	33	155	121	1380	1375	601	673

Table 3.
Project Air Support Summary
Greenland, 1989

MAC CHANNEL	Total PAX	Total Cargo	Total Flt Hrs (N/A)
PICO LG	24	47,791	
PICO DRILLING	20	27,958	
PICO UAF	13		
UNH	9	4,240	
OSU-Bolzan	4		
OSU-Thompson	2	1,474	
University of Alaska/ETH	6		
Carnegie Mellon University	13	10	
Univ. of Washington	6	676	
Univ. of Wyoming	18	3,484	
UCPH	3		
NSF	1		
UNL	1		
Univ. of Colorado	5	190	
Pennsylvania State	3	466	
Desert Research Institute	2	856	
University of Arizona	1		
University of Miami	1	70	
University of Rhode Island	3	1,456	
Harvard		1,476	
UAF		8290	
TOTAL MAC CHANNEL	**135**	**98,437**	

109th TAG	Total PAX	Total Cargo	Total Flt Hrs
PICO LG	46	340,225	3.5
PICO DRILLING	16	29,764	
GISP	16	7,954	73.8
OSU-Bolzan	4	1,810	
OSU-Thompson	7	1,474	
Carnegie Mellon University	3	3,470	
NSF	4	0	
TOTAL 109TH TAG	**96**	**384,697**	**77.3**

FSI TWIN OTTER	Total PAX	Total Cargo	Total Flt Hrs
Carnegie Mellon University	11	0	0
TOTAL FSI	**11**	**0**	**0**

Project Air Support Summary - 2

GreenlandAir Commercial	Total PAX	Total Cargo	Total Flt Hrs
			(N/A)
OSU-Bolzan	2	22	
UAF/ETH	10	12,878	
PICO/UAF	6	0	
NSF	4	0	
University of Wyoming	20	10,475	
TOTAL GLAIR	**22**	**12,900**	

GreenlandAir Charter	Total PAX	Total Cargo	Total Flt Hrs
	(N/A)	(N/A)	
DHC-6			
Harvard			Block Time
KINGAIR			
NSF			Block Time
PICO			Block Time
BELL 206			
UAF/ETH			20.4
University of Wyoming			11.2
SUBTOTAL			**31.8**
BELL 212			
UAF/ETH			3.1
Harvard			5.2
University of Wyoming			3.5
SUBTOTAL			**11.8**
SIKORSKY 61			
UAF/ETH			12.4
SUBTOTAL			**12.4**
TOTAL GLAIR CHARTER			**56**

Scandinavian Air	Total PAX	Total Cargo	Total Flt Hrs
			(N/A)
		44	
NSF	1		
UAF/ETH	14		
Univ. of Wyoming	2		
TOTAL SAS	**17**	**44**	

Project Air Support Summary - 3

	Total PAX	Total Cargo	Total Flt Hrs
ICELANDAIR			(N/A)
Harvard	10		
TOTAL ICELANDAIR	**10**		

APPENDIX A

Project Summaries for:

A. NSF-DPP POLAR COORDINATED SCIENCE PROJECTS
B. NSF-DPP POLAR GLACIOLOGY PROJECTS
C. NSF-DPP METEOROLOGY PROJECTS
D. NSF-DPP POLAR EARTH SCIENCES
E. OTHER NSF-SPONSORED PROJECTS
F. NON-U.S. PROJECTS

A. NSF-DPP POLAR COORDINATED SCIENCE PROJECTS

1. Coordination of Greenland 1989 Operations and Logistics
Polar Ice Coring Office
University of Alaska Fairbanks
Principal Investigator: Dr. Luis Proenza

Field Personnel:
Kent Swanson
Jay Sonderup
Bruce Koci
Jay Klinck
Steven Peterzen
Terry Gacke
Alan Rosenbaum
Cathleen Cavin
A.C. Hitch
Alan Bronston
Tyler Burton
Victor Mimken
Jay Kyne
Herb Ueda
Walt Hancock

Dates in Field: May 8 - August 30

Location: Sondrestrom AB, Thule AB, Dye 3, Summit Region, Jakobshavn, Camp Century, Keflavik, Constable Pynt

Summary:
Logistical support of all projects as outlined in Sections III-IV.

2. Logging of Camp Century Borehole
University of Nebraska-Lincoln
Principal Investigator: B. Lyle Hansen

Field Personnel: B. Lyle Hansen
Bill Boller
John Kelty
Niels Gundestrup
Thorsteinson

Dates In Field: April 22 - May 4

Location: Camp Century

Summary:
Attached: After Operations Report by B. Lyle Hansen

Resurvey of the Borehole at Camp Century, Greenland

Lyle Hansen
University of Nebraska-Lincoln

This project began several years ago. In May, 1986 an expedition to Camp Century was made to measure the surface velocity, surface topography, and, if possible, locate the drill hole for future measurements (Gundestrup, Clausen, Hansen and Rand, 1987).

In May 1988 another expedition to Camp Century (Hansen, Gundestrup and Clausen, 1989) reopened the borehole and extended the casing to 5m above the 1988 snow surface.

The resurvey of the Borehole at Camp Century, Greenland was successfully completed on April 25, 1989. The University of Nebraska-Lincoln participants were B. Lyle Hansen, John R. Kelty and Bill Boller. Their effort was supported by a UNL subcontract from the University of Alaska. The other participants were Niels Gundestrup, T. Thorsteinsson and Lars RissØjgaard from the University of Copenhagen. Their effort was supported by Danish funds

The data from the survey is being analyzed. A joint paper will be submitted for publication in Cold Regions Science and Technology. The preliminary results confirm the findings of other surveys in Greenland and Antarctica. Most of the deformation is occurring in the Wisconsin ice comprising the bottom 230 meters of the ice sheet at Camp Century Very little deformation is occurring in the Holocene ice overlying the Wisconsin ice.

References:

Gundestrup, N.S., Clausen, H. B., Hansen, B. L. and Rand, J., 1987. Camp Century Survey 1986. Cold Reg. Sci Technol., 14:281-288.

Hansen, B. L., Gundestrup, N. S. and Clausen, H. B., 1989. Camp Century Hole Reopened. Cold Reg. Sci. Technol. 16:315-317.

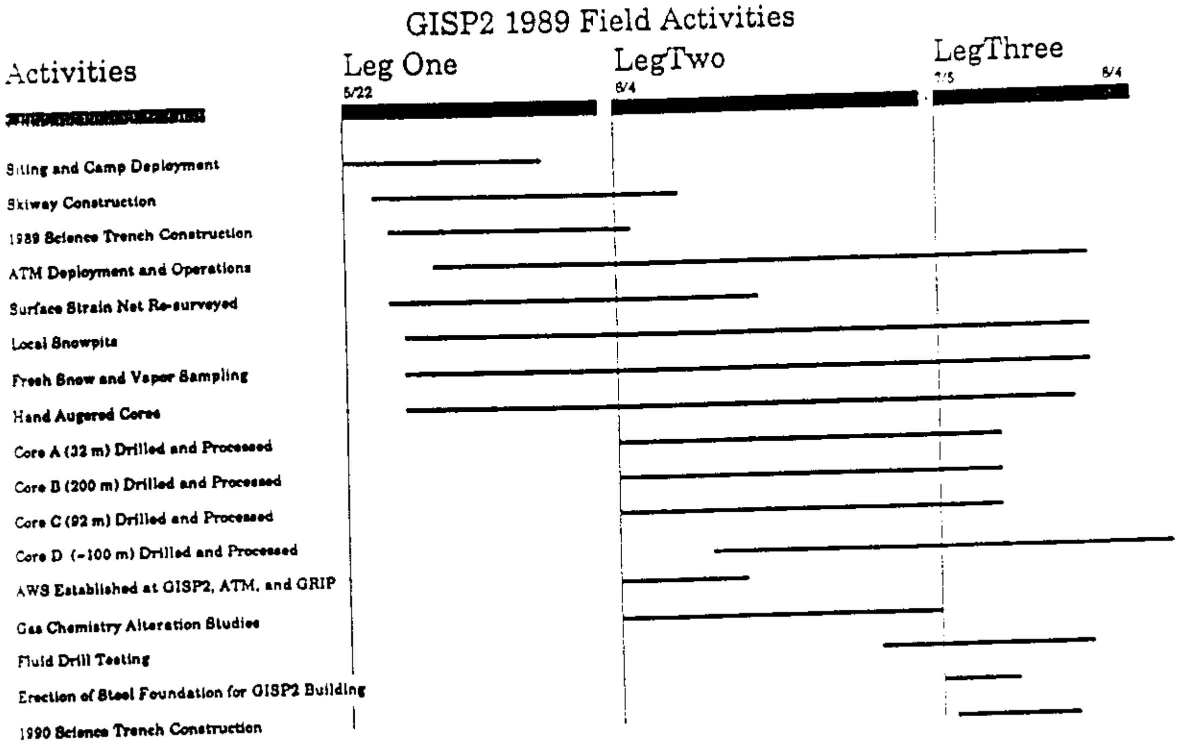
Camp Century 1989
Niels Gundestrup
GRIP Operations Center
Geophysical Institute
Department of Glaciology
University of Copenhagen

Purpose: To log the Camp Century Deep Hole for Inclination and Azimuth

Background: During previous expeditions in 1986 and 1988, the Camp Century deep hole was located, excavated, the casing extended above the present surface and the upper part of the hole was found to be open. In 1989 the purpose was the measure the deformation of the hole with depth and to compare the results with the measurements from DYE3 and Byrd Station. The previous low resolution measurements from Camp Century indicated a relatively strong deformation of the Holocene ice compared to the Wisconsin ice. As the deformation properties of deep ice is fundamental to ice core dating, as well as to ice flow modeling in general, it was vital to confirm this apparent discrepancy.

Field Program: The 5-man field team, (Dr. B.L. Hansen, PI., Mr. John Kelty, Mr. Bill Boller, Mr. T. Thorsteinson and Mr. N.S. Gundestrup P.I.) was flown from Thule Air Base to Camp Century on a U.S. Air National Guard C-130 on April 24, 1989. Mr. L. RiishØjgaard served as Field Operations Manager and remained at Thule. The measurements were completed on April 26. As it was possible to penetrate down into Wisconsin ice, all main goals had been reached. The hole diameter could only be measured to a depth of 250m, as the heavy deformation of the hole would have caused the calliper to get trapped below this depth. The team returned to Thule on May 1, again using a C-130.

Acknowlegement: The assistance from the U.S. Air Force at Thule Air Base, Greenland, the Air National Guard and the Danish Liaison Officer in Thule is appreciated. This program was sponsored by the U.S. National Science Foundation, the University of Copenhagen and the Danish Commission for Scientific Research in Greenland.



Core A: 32 m of 5.2" core dedicated to high resolution radionuclide measurements.
Core B: 0 - 152 m of 5.2" core and 152 - 200 m of 4" core processed in the field for physical properties, ECM, and stable isotopes (10 samples per year); remaining core to be processed for other properties at UNH.
Core C: 92 m of 5.2" are processed in the field for physical porperties, ECM, and stable isotopes (1 sample per year); remaining core to be processed for other properties at UNH.
Core D: ~100 m of 5.2 core processing same as core C.

B. NSF/DPP POLAR GLACIOLOGY PROJECTS

3 Greenland Ice Sheet Project II (GISP2)
University of New Hampshire
Principal Investigator: Dr. Paul Mayewski

Field Personnel:
Paul Mayewski, UNH/SMO
Michael Morrison, UNH/SMO
Pieter Grootes, UWA
Mark Twickler, UNH/SMO
Wm. Berry Lyons, UNH
Jack Dibb, UNH/CMU
Jean-Luc Jaffrezo, CMU
Kendrick Taylor, DRI
Martin Wahlen, N.Y. State Dept. Health
Richard Alley, Penn State
Erick Saltzman, UMiami
Pai-Yei Whung, UMiami
Chris Kingma, UNH
Michael Bender, URI
Todd Sowers, URI
Travis Saling, UWA
Charles Stearns, UWisc
George Weidner, UWisc

Dates In Field: May 18 - August 5

Location: Summit Region

Summary:
Attached: After Operations Report by all involved PIs

GISP2 1989 FIELD ACTIVITIES

GISP2 Science Management Office-University of New Hampshire
Dr. Paul Mayewski

During the 1989 field season the following individuals were involved in the scientific organization of the field season:

Michael Morrison, Associate Director SMO-Leg 1-camp set-up followed by remainder of year running SMO

Pieter Grootes, Executive Committee-Leg 2-Chief Scientist

Mark Twickler, Laboratory Manager-Leg 1-Camp set-up and science trench construction; Leg2-Science trench coordinator

Paul Mayewski, Director SMO; Chairman Executive Committee-Leg 2-Chief Scientist and planning and coordinator of 1990 science trench and core processing line

Wm. Berry Lyons-Leg 3-Chief Scientist

Dr. Paul Mayewski
University of New Hampshire

Participants: Legs 1&2: Mark Twickler, Chris Kingma
Leg 2: Paul Mayewski
Leg 3: W. Berry Lyons

The major chemistry contained in the GISP2 core will provide a detailed paleoenvironmental history including characterizations of: the chemical composition of the remote atmosphere; transport pathways, input timing and sources of the major chemical species in Greenland snow; volcanic events and their effect on the remote atmosphere; local precipitation balance; sea and land ice extent; dustiness of the atmosphere; biospheric influences; and the signature of anthropogenic activity on the remote atmosphere.

During the 1989 GISP2 field season several major chemistry experiments were undertaken including:

1) Investigations of the spatial distribution of chemical species.

Four snowpits (2-4 m deep) at 3 cm sample intervals to add to the seven snowpits (sampled in 1987) to add to the 150 km X 150 km established around the drill site (Mayewski et al., in press, Seattle IGS). Local scale investigations were stressed this year since two snowpits were sampled at the GISP2 site and two at ATM. In both cases, snowpits were within 1 km of each other. In addition, lateral sampling was conducted within snowpits. Samples for oxygen isotopes, radionuclides and MSA were taken at the same time.

2) Investigation of physical controls on chemical species, distribution and post-depositional alteration

The four snowpits referred to above were all sampled in detail (down to 1 cm resolution at selected levels) based on existence of recognizable physical features (e.g. hoar layers, wind slides) in the snowpits in order to test for controls. This sampling was closely correlated with stratigraphy defined by back-lighted snowpits in conjunction with R. Alley.

Fresh and aged snow samples were collected in the clean air sector and at the atmospheric sampling site (ATM) in order to define source cores for chemical species, based on back trajectory data for known storms and to assess post-depositional alteration.

3) Air snow fractionation was investigated in order to provide transfer functions for down core interpretations by collected aerosol filters at the ATM.

4) A temporal recording extending back to ~ AD 1250 and the two shorter records (~ 300 y BP) were collected for processing of major chemical samples back at UNH. Sampling will be conducted in two ways:

a) regular sampling of levels every two to four decades at 10 samples/year and

b) selected sampling of sections defined by ECM and stable isotope studies to include specific emphasis on volcanic and dust events and seasonal cycles (at 10 samples/year).

Dr. Pieter Grootes
University of Washington

Participants: Legs 1&2) Pieter Grootes
Leg 2) Travis Saling

The goals of the UW Isotope sampling program and the progress toward achieving these goals are:

1. An isotope proxy record of climate/environmental fluctuations over the last millennium
   approximately 7,000 samples were collected from Core B (~ 200m dry drilled core) at ~ 3 cm/sample.

2. A time scale being developed based on the identification of seasonal delta18O and deltaD cycles in snow for the upper 200m (800 years of firn and ice).
   about 9 samples/year on Core B.

3. The beginning of a multi-year study of the relationship between the isotopic composition of snow and firn (delta18O and deltaD and deuterium excess) and climate in central Greenland. This consists of collecting data that will allow us to understand:

a) isotopic processes during the aging of sub-surface snow and firn;
   tracking specific snow layers over five years.

   -initial 10m cores (2) approx. 650 samples
   -snowpits (4 2m pits) approx. 200
   -(3 4m pits) approx. 400

b) isotopic processes during the aging of surface snow;
   identification and modeling of important processes (sublimation, hoar frost/rime and depth hoar formation, etc.)

   -sampling of upper 50 cm of snow
   -repeated sampling of fresh snow falls at ATM camp
   -detailed (1 cm) sampling across 2 depth hoars in 2 snowpits
   -daily sampling of atmospheric vapor at different heights above the snow surface

c) spatial variability

   1. implications for above aging studies. Can we resample upper 10m each year and compare samples?

      -sampled three marker layers (depth hoars and wind slab) for meter scale variability (50 samples)
      -sampled two pits and five cores for variability scale of meters to tens of meters

   2. implications for modeling of stable isotope - climate relationships and interpretation of the deep core.

      -sampling of isotopes in pits and hand-augured cores on the scale of kilometers to tens of kilometers (includes Bolzan's traverse and possible previously collected cores)

d. improved models of isotope climate relationships. This requires concurrent observations of weather and sampling of precipitation events (snow, rime, hoarfrost) and water vapor.

ATMOSPHERIC SAMPLING PROGRAM (ATM)

Field Participants: Jack Dibb (UNH, Legs 1 and 2)
Jean-Luc Jaffrezo (CMU, Leg 3)

Legs 1 and 2, GISP2 1989

Between 2 June and 28 July samples were collected for several different investigators (Dibb, Mayewski, Grootes, Davidson, Boutron, Cachier, Thompson, White, Dansgard, Rasmussen, Lowenthal and Borys).

As each new experiment was set up maintenance of it became part of the routine. At the end of the second leg we had collected 25 radionuclide aerosol samples (Dibb) and 8 aerosol samples for major ions (Davidson). One very large volume aerosol sample was collected for INAA (Lowenthal) to assess the possibility of using the powerful analytical technique on aerosol samples from this supposedly pristine site in future years. Over 200 snow samples were also collected. Fresh snow was sampled for 9 different investigators (Dibb, Mayewski et al., Grootes, Davidson, Boutron, Cachier, Thompson, White, Dansgard) and detailed sampling of aging snow and replica sampling to examine spatial variability to be analyzed by Mayewski and Grootes. In addition, snow flake replicas and cloud water samples were collected from several events for Borys. Rime ice was collected for stable isotope analysis (Grootes, White) after every event.

An accumulation stake array (the bamboo forest) consisting of a 10' X 10' grid of stakes was measured 15 times in an attempt to document short-term events (snowfalls and wind storms). The 30 km accumulation line (ATM to GISP) was measured on every traverse and the 5 km line was resurveyed approximately weekly.

Solar panels and batteries proved to be a huge success. Over 6 weeks a total of 3.5 sampling days were lost due to low power (and these probably could have been avoided with an experienced operator constantly aiming the panels) Major ion sampling was not possible on 9 days due to winds out of the contaminated sector. Radionuclide aerosol sampling can apparently be accomplished with 24 hour resolution, although we ran the samples for 36 hours.

All in all the first season seems to have been a huge success and it appears that solar powered sampling in central Greenland is an extremely viable mechanism for maintaining a remote atmospheric sampling site free of local contamination.

ELECTRICAL CONDUCTIVITY MEASUREMENT

Dr. Kendrick Taylor
Desert Research Institute, University of Nevada

Electrical conductivity measurements were conducted by the Desert Research Institute. The measurement is an indicator of the presence of strong acids and can be used to detect annual layers and identify segments of the core that have an anomalous chemistry. The method can be used to date the core by 1) counting annual layers and 2) identification of numerous well dated volcanic events that have altered the core chemistry. It can also be used to indicate segments of the core that are chemically anomalous, which assists other investigators in determining which sections of the core are the most suitable for a particular study.

The measurement is made by first preparing a smooth ice surface with a combination of a band saw and microtome knife. Two electrodes, with a total surface area of 5 mm^2 and a separation of 1 cm are then dragged along the surface. The current that is conducted by the ice when the electrodes have a potential difference of 2100 volts is measured as an indication of the ice electrical conductivity. The current is digitally recorded each millimeter along the surface and can then be plotted and digitally processed as desired.

The conductivity was recorded along the entire length of Hole A (32 m), Hole B (193 m), Hole C (85 m) and Hole D (90m). Breaks in the core resulted in a loss of approximately 5% of the data, which occurred at random intervals for several centimeters segments. A high level of visual correlation exists between the holes.

Preliminary analysis of the data reveals several interesting points. The seasonal recorded is well preserved in most of the core and will lend itself to counting of the annual layers as a method to date the core. The ability to catenate and high frequency filter the digital data will make this task more accurate. Numerous volcanic events have been identified which also serve as important time marks. The Laki, Iceland event (1783 A.D.) was unmistakable at a depth of 71 m. From this single time bench mark it was possible to determine the accumulate rate that had been assumed to calculate a preliminary time/depth scale was low by 6%.

Figure 1 is an example of the data produced in the field. The data has been filtered with a 2 cm moving average. The seasonal component of the signal is pronounced. The Tarumani, Japan (1667 A.D.) volcanic event is clearly evident and can be used as a time bench mark and the Katla, Iceland (1660 A.D.) event is less evident but is suggested in the data.

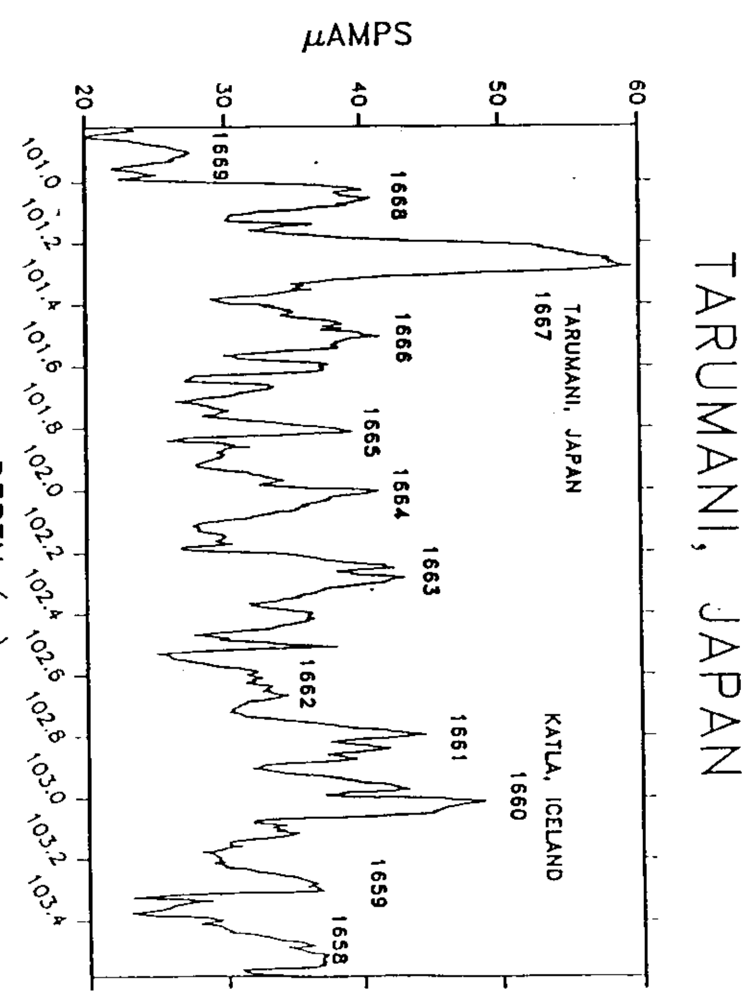


FIG. 1 KEN TAYLOR, ECM

Dr. Richard Alley
Pennsylvania State University

An ambitious program of sampling for physical properties and visual stratigraphy was undertaken in pits and cores. Sampling was conducted for:

Visual stratigraphy. Annual events and some storm events are readily apparent in snow pits and can be identified in cores, although diagenesis makes annual features increasingly hard to see below 100m. Accuracy is better than 5% over the last 200 years, based on comparison to a volcanic marker horizon identified by ECM (Dr. K. Taylor). Only a single unequivocal melt event was identified in the upper 200m, at 39.85 m in core B.

Density. Densities were measured continuously in snow pits and firn using the volume-mass method, and in ice using isostatic weighing. An annual cycle is evident from the snowpit densities.

Grain Texture: Approximately 10 thin sections were cut and photographed for size, shape and arrangement of grains and pores. Sections were cut in three mutually perpendicular directions at selected intervals to study grain and pore shape orientations. Contiguous vertical sections spanning as much as 1 m were cut to study causes of visible stratification evolution of grain sizes, and for correlation with other continuously measured parameters.

Grain Fabrics: C-axis fabrics were measured at about 20m intervals in ice. A weak fabric is inherited from the firn, and changes little or not at all by 200m.

Pending further analysis of the data collected, the preliminary data are quite encouraging and indicate that the season was quite successful.

Dr. Martin Wahlen
New York State Department of Health
Participant: Bruce Deck (Leg 3)

Our research effort for this year did not require direct field sampling and thus my main responsibilities were to watch, learn and support the research of others. In all of these aspects I feel that positive results were obtained. Upon my arrival I assumed responsibility for the core isotope sampling and vapor and precipitation sampling programs previously conducted by J. White and P. Grootes. On these projects 176 core isotope samples from cores C and D were collected. In addition, 38 vapor, 18 rime and 41 snow samples were processed (includes some taken at ATM site). Four large precipitation samples were also taken for J. Dibb. During collection of the core isotope samples assistance in many other aspects of the core processing procedure was given. Following the completion of the core processing I participated in the digging and sampling of a snow pit. When the scientific work was concluded and the equipment packed up for storage or shipment I assisted in the movement of the fuel supply, the construction of the new scientific trench, breakdown of the old trench and various other activities in the packing and shutting down of the camp. During my stay I also assisted in the daily weather observations.

Erick Saltzman
University of Miami
Field Participant: Pai-Yei Whung

The main responsibility of University of Miami for this season was to assist in the science trench with core processing and ECM. The ice core samples and snowpit samples collected during this field season will be used for both MSA and iodide analysis by University of Miami. Snowpit samples were also collected from ATM camp. The location of the snowpit is 2 km northwest of the ATM camp. It is a 2 m-deep, 3 cm sample interval. In conjunction with C. Kingma we sampled for chemistry (both anions and cations), delta18O, MSA, iodide and H_2O_2 analysis. The stratigraphy mapping and sampling as well as the density of the snowpits were also recorded in detail.

Dr. Michael Bender
University of Rhode Island

Participant: Todd Sowers

1. To determine whether the composition of trapped gases in ice are modified as the core relaxes;

2. to make a detailed sampling of the firn-ice transition region with the hope that we will better understand the gas trapping process;

3. to run some porosity measurements on the firn-ice transition to establish where the gases are actually trapped. Since we did not have the equipment to make porosity measurements, they were made at the Eurocore camp.

The following samples were taken for the elemental and isotopic analysis of occluded gases:

ALL SAMPLES ARE FROM CORE B (mbs)

1) 64.1 - 64.2	6) 75.35 - 75.45	11) 125.0 - 125.1
2) 66.1 - 66.2	7) 78.3 - 78.4	12) 145.4 - 145.5
3) 68.2 - 68.3	8) 80.9 - 81.0	13) 154.0 - 164.15*
4) 69.7 - 69.8	9) 84.6 - 84.7	14) 197.5 - 197.7*
5) 72.9 - 73.0	10) 105.08-105.18	

* = 4" core

1989 Field Season Results

Ice samples were extracted (duplicate) in the field and transferred to glass ampules which were returned to URI for mass spectrometric analysis. In addition, 3 air samples were processed to ensure that the extraction procedure did not modify the trapped gas samples. The samples of ice from which gases were extracted were returned to URI and will be analyzed throughout the next year to check for alterations associated with core relaxation. The 1.5 ice samples which could not be extracted in the field were returned to URI for immediate extraction. All samples extracted in the field were processed within 5 days after removal.

POROSITY ANALYSIS

The porosity measurements conducted at Eurocore Camp came from core C at the following depths. Each sample was 6 cm long, and the whole core was taken.

59.0	72.0
60.0*	73.0
61.0	74.03
62.0	75.02*
63.0	76.0
65.0	77.02
65.0*	78.02
66.0	79.03
67.0	80.04*
68.0	81.0
69.0	82.01
70.0*	83.0
71.0	84.0*

* These samples were sectioned for thin section analysis by Richard Alley.

The reason for making the porosity measurements was to determine precisely, at what depth, the bubbles were closed off. This information is important in estimating the age difference between the ice and the trapped gases. It will also be helpful in deciphering the mechanisms by which the bubbles are closed off and the composition of the closed bubbles as a function of depth.

AUTOMATIC WEATHER STATIONS ON THE GREENLAND ICE CAP: JUNE 1989

Dr. Charles R. Stearns and George Weidner
University of Wisconsin, Department of Meteorology

1. Purpose

The purpose of the automatic weather station units on the Greenland ice cap is to support Greenland Ice Sheet Program Two (GISP2) and to improve the understanding of the climate of the Greenland ice cap.

The basic automatic weather station (AWS) measures wind speed, wind direction, and air temperature at a nominal height of three meters and air pressure at the electronics enclosure. Additional measurements may be added for special purposes. The data are transmitted at 200-second intervals to polar-orbiting satellites of the NOAA series and are updated at ten-minute intervals. The present and past four values are transmitted in each 256 bit data word. Service ARGOS collects and sends the data on magnetic tape to the Department of Meteorology at the University of Wisconsin. The data are processed to scientific units at monthly intervals and can be distributed to members of GISP2 as a complete data set on magnetic tape, as three hourly values on paper and as three hourly values on magnetic disketies.

2. AWS Installation

At Sondrestrom on 6 and 7 June 1989 the two AWS units were checked. One AWS unit had been damaged during transit possibly by the x-ray machines at the airports. The damaged AWS unit was repaired but we were not confident that the repairs were reliable. On 7 June the weather at the GISP2 site cleared for landing of aircraft and the flight was made to the site by LC-130 aircraft of the 109th Air National Guard.

2.1 GISP2 Site

AWS 8936 was installed at GISP2 Site on 8 June 1989. The installed height of the boom above the snow surface was 4.0 meters. In addition to the standard measurements, the AWS unit measures relative humidity, solar radiation, vertical air temperature difference between 3.9 and 1 meter, snow temperature at -1.05 m and snow temperature differences between the depths of -4.05 m, -2.05, -1.05, -0.55, -0.30, -0.-5 and 0.20 meters. The depth of the -4.05 m sensor is uncertain. A pit was dug in the snow down to a depth slightly below 2 meters. Then a hole was drilled to -4.7 meters and the temperature sensor dropped into the hole. The remaining snow temperature sensors were installed using a stick to measure the depth of installation. A hole was poked into the snow at the correct depth and the sensor was installed in the snow. The 0.20 and 0.45 m temperature sensors were supported above the snow surface by a Styrofoam frame.

2.2 Fresh Air Site

AWS 8922 was removed from Cathy Site by John Bolzan on 30 May 1989 and was installed at the Fresh Air Site on 9 June. The height of the boom above the snow surface is 3.4 m. In addition to the standard measurements the AWS unit measures relative humidity, air temperature difference between 3.2 and 1 meter, and distance to the snow surface. The unit does not measure snow temperatures or solar radiation.

2.3 GRIP Site

AWS 8937 was installed at GRIP Site on 10 June 1989. The installed height of the boom above the snow surface was 4.0 meters. The additional measurements and the method of installing the snow temperature sensors were similar to those for the GISP2 AWS unit. The -4.05 m snow temperature sensor was at approximately -3 m. The unit stopped after a few days, was returned to Madison, WI, repaired and will be installed approximately 3 August 1989. The unit operated properly until it stopped due to a failure in the computer clock.

Table 1 gives the site locations for the installed AWS units.

Table 1. Site name, ARGOS identification number, latitude, longitude, elevation and start date for AWS units installed on the Greenland ice cap during June 1989.

Site Name	ARGOS ID	Latitude Degrees	Longitude Degrees	Elevation Meters	Start Date
GISP2	8936	72.58 N	38.46 W	3205	8 June
Fresh Air (Kenton)	8922	72.28 N	38.80 W	3185	9 June
GRIP	8937	72.57 N	37.62 W	3280	10 June

The locations above are tentative as the AWS units will be located by satellite through the ARGOS system.

Figure 1 gives the tentative AWS locations on the crest of Greenland, Figure 2 is a map of Greenland with the AWS locations, Figure 3 is the initial layout of the GISP2 camp with the approximate location of the AWS unit, and Figure 4 is the layout of the AWS units at GRIP and GISP2. The Fresh Air AWS has an acoustic depth gauge but does not measure snow temperatures.

3. Future Activities

During the coming year the data will be processed to scientific units and delivered to those requesting the data. The program for decoding the data will be provided to the Danish Meteorological Service and GISP so that the data will be available to them in near-real time. Plans for 1990 include the installation of two more AWS units approximately 100 km east and west of the GRIP site.

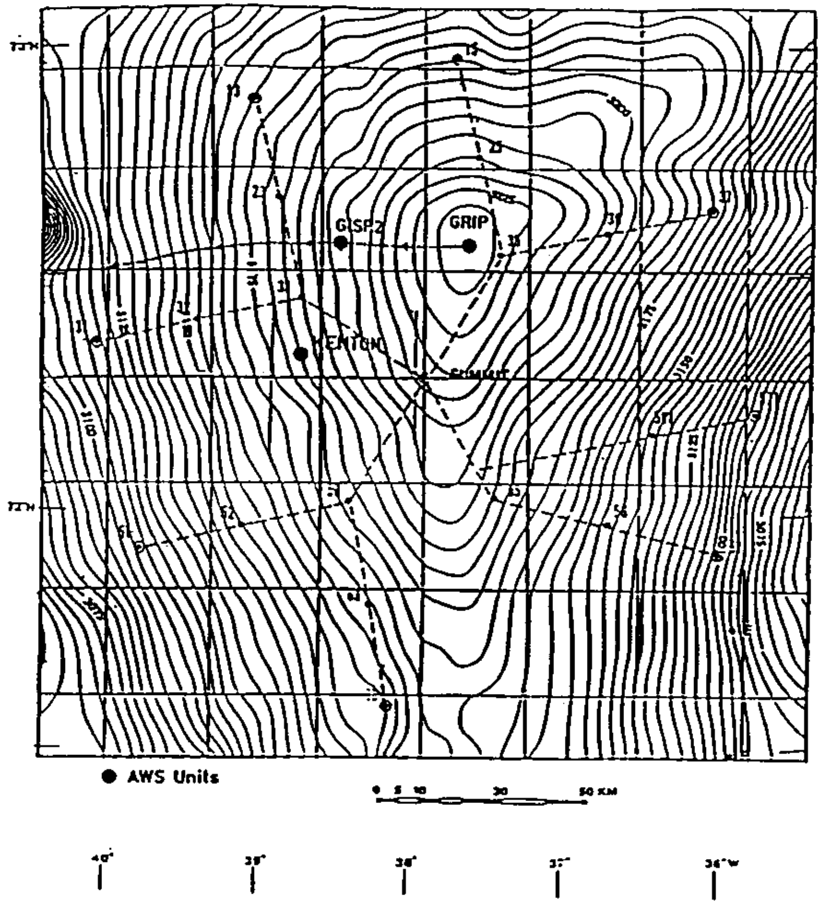


Figure 1. Map of the Greenland crest showing the locations of the three AWS units installed in June 1989.

-4-

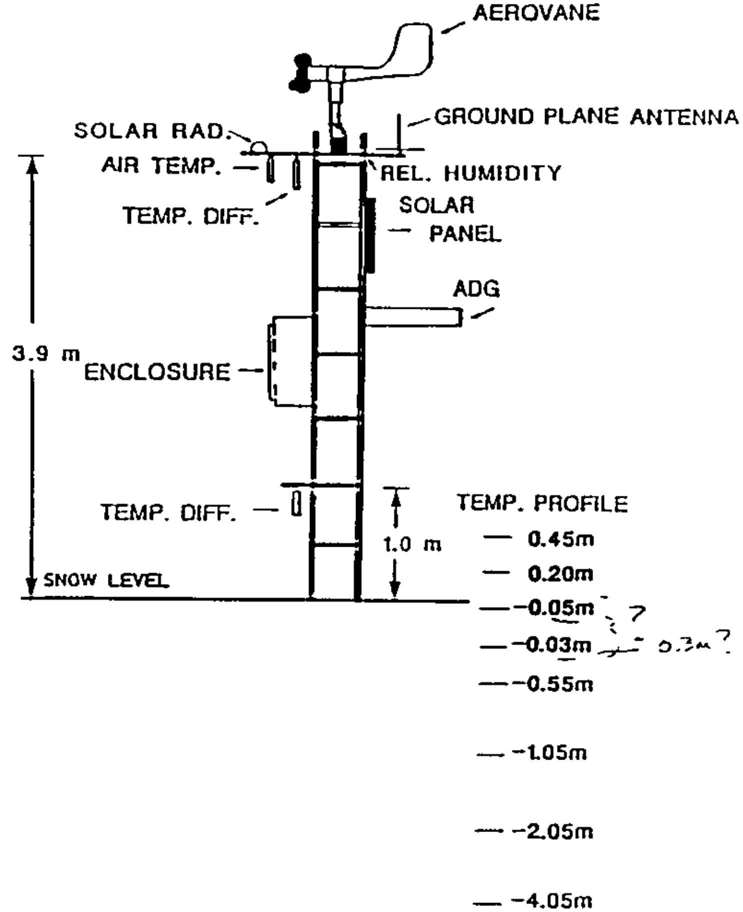


Figure 4. Layout of the AWS units. The GRIP and GISP2 measure snow temperature and solar radiation. The installed depth of the -4.05 m snow temperature sensor is uncertain. The Fresh Air AWS unit is similar and has an acoustic depth gauge (ADC) for measuring the distance to the snow from about the mid-point of the tower but does not measure snow temperatures or solar radiation.

-7-

4. Holocene Paleoclimatic Reconstruction from Greenland Ice Cores
Byrd Polar Research Center
Ohio State University
Principal Investigator: Dr. Ellen Mosley-Thompson

Field Personnel: Ellen Mosley-Thompson
Keith Najmulski
Keith Mountain

Dates In Field: May 22 - June 17

Location: Summit Region

Summary:
Attached: After Operations Report by Dr. Ellen Mosley-Thompson

DRILLING PROGRAM FOR OHIO STATE UNIVERSITY NEAR THE GREENLAND ICE SHEET SUMMIT

Dr. Ellen Mosley-Thompson
Ohio State University
Byrd Polar Research Center

Prior to the initiation of the GISP2 drilling program a suite of shallow cores and one intermediate depth core (204 meters) were drilled. The program began on May 24, 1989 and was completed on June 15, 1989. All cores were recovered with the PICO standard 4" diameter electromechanical drill. A light-weight, portable ice core processing line was installed in a trench near the drill site. The system was designed to set up easily and to break down into small units capable of transportation to remote sites by horseback.

The principal focus of the research program is to extract a very high resolution (sub-annual to annual) record encompassing the entire Little Ice Age (Neoglacial) period. The longest core should contain approximately 700 years. In order to assess the spatial variability of the preserved records, one 82-meter core and three 24-meter cores were drilled at sites up to 5 km from the main drill hole. Additionally, two 2-meter pits were excavated at the remote drilling locations and samples were collected for microparticle concentrations and size distributions, oxygen isotopic ratios, liquid conductivity, anion concentrations (Cl^-, SO_4^{2-} and NO_3^-), total Beta radioactivity and pH.

5. Ice Sheet Dynamics In Central Greenland
Byrd Polar Research Center
Ohio State University
Principal Investigator: Dr. John Bolzan

Field Personnel: John Bolzan
Richard Graham
Jim McDonald
Al Rosenbaum
Mike Strobel

Dates In Field: May 24 - June 15

Location: Cathy Site, Sondrestromfjord, Angmagssalik

Summary:
Attached: After Operations Report by Dr. John Bolzan

ICE SHEET DYNAMICS IN CENTRAL GREENLAND

Dr. John Bolzan
Byrd Polar Research Center, Ohio State University

Personnel and Dates in Field:

John Bolzan
Richard Graham (Angmagssalik geoceiver operator)
Jim McDonald (Sondrestrom geoceiver operator)
Al Rosenbaum (PICO)
Mike Strobel

May 24-June 15

Location: Cathy Site (N 72° 17 38, W 37° 55 18), base camp
Sondrestromfjord (geoceiver station)
Angmagssalik (geoceiver station)

The central objective of this year's field program was to re-occupy the survey sites established in 1987 and re-measure the positions using Doppler satellite surveying techniques. As a result, the surface velocity field over the 150 X 150 km survey grid would be determined.

The field party consisting of John Bolzan and Mike Strobel from the Byrd Polar Research Center, and Al Rosenbaum from PICO, was put-in near Cathy Site (Summit) on May 24. Two geoceiver sites were established at Sondrestromfjord and at Angmagssalik, where geoceivers tracked continuously. The first phase of the program was to dig out equipment and supplies that had been left at the end of the 1987 field season, including a Tucker Sno cat, 2 traverse sleds, 5 pallets of Mogas and DFA, and a 16' X 16' Weatherport shelter. With the assistance of Jay Sonderup of PICO, the dig-out was completed in about 6 days.

A series of traverses was made using the Tucker Sno-cat to re-visit the survey sites. Magnavox MX1502 geoceivers tracked for 18-24 hours at each grid dug and sampled for stable isotope analyses. After hot-point drilling to about 11 meter depth, cooling curves at 10 meter depth were measured at these sites in order to estimate the mean annual temperature. The field work was completed in June.

We would like to acknowledge the excellent support provided by the Polar Ice Coring Office, in particular Kent Swanson, Al Rosenbaum and Jay Sonderup. Their efforts were central to the success of this program, and were much appreciated.

6. Determination of the Mechanisms of Rapid Flow on Jakobshavns Glacier, Greenland by Borehole Measurement
Geophysical Institute
University of Alaska Fairbanks
and ETH-Zentrum, Zürich
Principal Investigators: Dr. Keith Echelmeyer, Dr. William Harrison, Dr. Almut Iken

Field Personnel: Keith Echelmeyer
William Harrison
Almut Iken
Carol Petersen
Ted Clarke
Paul Will
Brigitta Jenny
Hansford Jenny
Paul Gnos
Jurg Steiner

Dates In Field: June 15 - August 7

Location: Jakobshavns Glacier

Summary:
Attached: After Operations Reports by Dr. Keith Echelmeyer and Dr. Almut Iken.

1989 JAKOBSHAVNS ISBRAE DRILLING AND SEISMIC PROGRAM

Drs. Keith Echelmeyer and William D. Harrison
University of Alaska Fairbanks
Geophysical Institute
Other personnel: Ted Clarke, Carol Petersen, Paul Will
Joint Project with Almut Iken, ETH, Zürich, Switzerland

During the period from 16 June to 29 August 1989, a hot-water drilling program was undertaken on the fast-moving Jakobshavns Isbrae in west Greenland. In a joint project with Almut Iken of ETH, Zürich, Switzerland, we drilled several (ten) holes in the glacier at three sites across a transverse profile about 45 km inland form the calving front. Several of those boreholes were close to 1600m deep, making them the deepest ever drilled using hot water methods. One of the drill sites was at the center of the ice stream, where the 1550m hole did not reach the bed (depth≈2500m). The other two sites were located near the margins of the ice stream, with holes reaching 1630m to the bed at the northern site and 1560+m to the bed at the southern margin. A small bed sample of crystalline rock was recovered. Till and ice temperature sensors were emplaced in some of the holes. Preliminary results indicate a general decrease in ice temperature from the surface downward until a depth of 300m at the margins and approximately 1300m in the center. Below these depths the temperature increases to the melting point at the bed.

At the same time a detailed set of seismic reflection experiments was performed about the drill sites and across two other transverse profiles near the grounding zone. In all cases, the glacier was found to lie in a deep, U-shaped bedrock trough. This finding is in direct contrast to the ice streams of west Antarctica and to previous Danish (TUD) radio-echo sounding in the Jakobshavns region. No sub-bottom layer (till or otherwise) was found in this high-resolution study.

Surveying measurements (terrestrial and satellite Doppler) across three transverse surface profiles shows a marked influx of ice into the ice stream from the margins near the drill sites. Average surface speed is about 1110m/yr.

REPORT ON THE CONTINUATION OF DEEP DRILLING IN JAKOBSHAVNS GLACIER IN 1989

Almut Iken, ETH
(Joint project of University of Alaska and ETH Zurich)

Drilling was started on 27 June at the same site as in 1988, 45km inland from the calving front of Jakobshavns Glacier. After a test of the updated equipment and after drilling one 1000m-deep hole which had to be abandoned during blowing snow, a hole to 1550m depth was completed and instrumented with thermistors. The drilling equipment was then moved closer to the southern margin where the ice is 1500m deep. This site was selected based on seismic investigations by a team of the University of Alaska led by T. Clarke. Several holes were drilled here, the deepest to 1584m. In this case the drill may have followed the steep slope of the bed for some 10 meters. Sampling pockets in the drill tip collected silt-size material and small stones from the glacier base and brought it to the surface when the drill was pulled up. 50 to 100 meters before the drill reached the bed, boreholes started to drain rapidly. The decrease and stabilization of water levels--during and after the pumps were shut off--were recorded. Immediately after drilling the boreholes were equipped with thermistors and one hole with a string of tilt sensors.

Next, we had intended to drill near the centerline of the glacier, 30km downstream of the present drill site. The seismic team had investigated this area and located a place with an ice depth of less than 1700m, which was suitable for drilling. The ice is very broken up there, but an acceptable place had been found. The seismic team had then received excellent jet ranger (206) support; however, this pilot left Greenland at the end of July. We expected transportation to the new site on 31 July. A 212 helicopter arrived with a delay of one week (on 7 August). Unfortunately, at the first attempt to land on the new place it broke a skid. We received the information that the skid was repaired the following night and that the helicopter would be available for us on 11 August; this did not become true. On 10 August a 206 arrived for additional reconnaissance requested by GLACE. This helicopter had problems with overheating and had to return directly to Jakobshavn for repair of its turbine. We provided a jump start with our car batteries. The pilot intended to return to our camp the next day, but the helicopter was not available for us after its repair. Meanwhile, three members of our crew needed to get back urgently to their work, and responsibilities in Switzerland and Alaska. They were not flown out as requested and the two Swiss missed their APEX return flights to Copenhagen (14 August) and Zürich (15 August) by one week. We were informed that only a 2-engine helicopter (212) should land in crevassed areas; however, the 212 was not available at any definite date. The only helicopters available were a Sikorsky (without sling frame) and a 206, both on 20 August. under these circumstances we had to give up the plan to drill through the glacier near the center line, which would have been most desirable from a scientific point of view.

On 20 August we moved our equipment to the northern side of the ice stream and three members of our crew were flown out. Four of us remained--too small a number for deep drilling. Thanks to the initiative of K. Swanson (PICO), Thorsteinn Thorsteinsson (who had been working for GRIP) arrived on the same day in order to help us. At the new site we drilled a hole to 1627m depth where the drill reached the bed as indicated by the force sensor of the drilling winch (the hole connected with the subglacial drainage system already when it was 1520m deep).

The hole was equipped with tilt sensors and thermistors; the data will be recorded over winter. The completion of this hole had required a particular effort: the air temperature dropped to -15°C and it was already dark for a few hours at night. During 48 hours no one slept more than 5 hours. On 27 August we returned with all equipment to Jakobshavn.

The investigations were seriously hampered by the insufficient helicopter support. In this way an important part of the project for which appropriate techniques had been developed and extensive preparations had been made, could not be realized.

As in 1988 the logistic support by PICO (Polar Ice Coring Office) was invaluable. Kent Swanson and his team in Sondrestromfjord organized not only the helicopter support--a demanding and unrewarding task--but also organized repairs, new tickets, the shipment of spare parts (some from Europe), equipment and food, which had become scarce. For most of the time we had daily or more frequent radio contacts with this team. When the short-wave radio communication broke down for more than a week, due to intense sunspot activity, Kent Swanson succeeded in finding a member of the Aero-Club in Sondrestromfjord who would fly close to our camp. In this way a much needed radio contact could be established. For the sake of our project, Kent also extended his stay in Sondrestromfjord.

C. NSF/DPP METEOROLOGY PROJECTS

7. Processes Influencing Chemical Species Concentrations in Ice Cores from Dye3, Greenland
Department of Civil Engineering
Carnegie-Mellon University
Principal Investigator: Dr. Clifford Davidson

Field Personnel: Cliff Davidson
Jean-Luc Jaffrezo
Chitsan Lin
Byard Mosher
Niol Tindale
Robert Gandley

Dates In Field: June 15, 1988 - August 7, 1989

Location: Dye 3

Summary:
Attached: After Operations Report by Dr. Clifford Davidson

THE TRANSPORT OF AIRBORNE PARTICLES ONTO THE GREENLAND ICE SHEET

Dr. Cliff Davidson
Department of Civil Engineering, Carnegie Mellon University

Personnel and Dates in the Field:

Cliff Davidson	July - August 1988, August 1989
Frank Boscoe	July - August 1988
Jack Dibb	July - August 1988, February 1989
Robert Gandley	July - August 1988, July - August 1989
Risto Hillamo	March 1989
Jean Luc Jaffrezo	July - September 1988, November - December 1988, April June 1989, August 1989
Chitsan Lin	October 1988, June - July 1989
Byard Mosher	January 1989, July 1989
Neil Tindale	April - May 1989

Location: Dye 3

Summary: This project involves sampling the air and snow at Dye 3 over a one-year continuous period. Personnel were rotated at 1-2 month intervals between August 1988 and August 1989. The equipment was set up in July 1988, and removed from the site in August 1989.

The primary aim of this program was to improve our ability to interpret glacial record data, focusing on the transport of airborne contaminants to the Greenland Ice Sheet. There are three basic objectives:

1. To determine mid-latitude source regions and transport pathways for contaminants reaching the southern Greenland atmosphere,
2. To identify mechanisms and rates of deposition from the atmosphere onto the Ice Sheet at Dye 3, and
3. To examine the annual cycle of air and snow contaminant concentrations as a means of identifying seasonal variations in deposition.

Numerous sampling activities took place during the year. An updated list of these activities may be summarized as follows:

1. A condensation nuclei counter, nephelometer, and ozone monitor operated semi-continuously for the one-year period. This equipment was provided by Drs. Russell Schnell and Barry Bodhaine of the National Oceanic and Atmospheric Administration (NOAA).
2. Several types of filters sampled aerosols for chemical analysis. Most of the sampling was for time periods varying from 24 hours to several days.

Some experiments involved <24 hour sampling during precipitation. Two similar sampling stations were established 500m West of Dye 3 and 500m East of Dye 3, permitting aerosol collection upwing of local pollutant emissions for any wind direction. The following chemical species were of interest and will be analyzed over the next several months:

a) Anions (SO^{2-}_4, NO^-_3 Cl^-) and cations (Ca^{2+}, K^+, Mg^{2+}, Na^+, NH^+_4) in aerosols as well as HNO_3 and SO_2 vapors will be measured by ion chromatography. A filterpack consisting of Teflon, nylon and potassium carbonate-coated Whatman filters was used. The analysis will be conducted at CMU.

b) An aliquot of each Teflon filter sample from the runs described in (a) will be sent to Eric Saltzman at the University of Miami for analysis of methyl sulfuric acid. The analyses will be conducted by ion chromatography.

c) A limited number of trace elements from anthropogenic emissions (Ag, Cd, Cu and Pb) and from crustal and marine sources (Al, Fe, K, Mg, Mn and Na) will be measured by flameless atomic absorption spectrophotometry. Nuclepore 0.4 m polyester filters were used for this purpose.

d) A larger number of trace elements will be measured by neutron activation analysis using a Teflon filter. Analyses will be conducted by Byard Mosher of the University of New Hampshire in cooperation with the University of Rhode Island.

e) Additional analyses of filters will be conducted in France. Total carbon and soot carbon will be measured on glass fiber filters by H. Cashier of the Centre des Faibles Radioactivities in Gif s/Yvette. Polynuclear aromatic hydrocarbons will be measured in particulate and vapor phases using quartz fiber filters and SAD resin by P. Masclet of the Universite Paris VII. Aerosols collected on nuclepore filters will be analyzed by J.L. Colin of the Universite Paris VII for a variety of trace elements using X-ray fluorescence. Finally, particle morphology and mineralogy will be assessed by A. Gaudichet, University of Paris XII, using scanning electron microscopy and related techniques.

f) Several radionuclides have been measured using additional filters. Species of interest include ^{7}Be, ^{10}Be and ^{36}Cl (indicators of solar activity), ^{137}Cs (bomb debris from the stratosphere) and ^{210}Pb (indicator of continental material). Analyses of ^{7}Be, ^{137}Cs and ^{210}Pb are being conducted using nondestructive direct gamma spectrometry by Jack Dibb at the University of New Hampshire, while analyses of ^{10}Be and ^{36}Cl will be conducted using accelerator mass spectrometry by Robert Finkel of Lawrence Livermore Laboratory.

3. Snow was collected at a site 1 km from Dye 3 during or immediately following each major precipitation event (>1 cm snow) throughout the year. Aging surface snow was also collected between storms on a limited number of occasions to assess dry deposition. In coordination with the filter sampling described in (2), the following chemical species are of interest:

a) The anions and cations listed in (2a) will be measured. Clean polyethylene sheets were placed on the surface prior to snowfall, and samples were collected from these sheets using 120 ml polyethylene bottles.

b) As in (2b), an aliquot of each snow sample described above will be sent to the University of Miami for analysis of methyl sulfuric acid.

c) The trace metals listed in (2c) will be measured. Fresh snow samples were collected and sent to C. Boutron at the Laboratoire de Glaciologie in Grenoble, France, who will conduct the analyses by flameless atomic absorption spectrophotometry. In addition, blocks of snow from the top 1.6 m of the Ice Sheet were sampled and sent to Grenoble for analyses. These will allow trace metal data for snow samples representing about one year.

d) As in (2e), snow was collected and sent to France for several types of analyses. These include total carbon and soot carbon, trace elements in insoluble matter in the snow analyzed by X-ray fluorescence, and particle mineralogy and morphology by scanning electron microscopy and related techniques.

e) As in (2f), analysis of radionuclides will be conducted by the University of New Hampshire and Lawrence Livermore Laboratory. The snow was collected in 1 liter polyethylene bottles.

f) Snow from each precipitation event will be analyzed for microparticles using a Coulter Counter. The analyses will be conducted by Ellen Mosley-Thompson at Ohio State University.

g) Snow from each precipitation event will be analyzed for delta^{18}O and deltaD. Discussions are under way with Niels Gundestrup of the University of Copenhagen and with James White of the Institute of Arctic and Alpine Research to arrange for these analyses.

4. Individual snowflakes were collected on glass microslides from each precipitation event. The snowflakes were sealed in formvar and examined using optical microscopy to determine the extent of riming. The samples were sent to Randy Borys at Desert Research Institute and A. Gaudichet of the Universite Paris XII for identification of possible in-cloud processes during formation of the snow.

5. Samples were obtained from stratigraphically identified layers in snowpits at 10 km, 23 km and 25 km from Dye 3. Accumulation stakes positioned at these locations and at 1 km from the station were used to determine amount of precipitation at the respective locations. The 1 km site had snow accumulation readings at frequent intervals throughout the year, enabling an accumulation history.

6. Once per week, air samples were collected in stainless steel cylinders provided by Dr. Rei Rasmussen of Oregon Graduate Center. Dr. Rasmussen has analyzed these samples for CO, CO_2, CH_4, Freons and a variety of other trace gases. These concentrations will be compared with similar data from sea level sites in the Arctic to assess the influence of elevation on trace gas concentrations on a year-round basis. The Dye 3 data will be added to the main data set maintained by Dr. Rasmussen, which includes a number of remote sites. These data are being used to investigate global cycling of trace gases and possible effects on climate.

7. Backward airmass trajectories from Dye 3 will be computed as part of an existing cooperative agreement with Atmospheric Environment Service, Canada. The trajectories will be computed for each of the sampling dates in the present study. Trajectories will also be computed for dates in other years to assess representatively of the 1988-1989 sampling year. These results will be used to help identify mid-latitude source regions and transport pathways influencing atmospheric contaminants at Dye 3.

Following is a brief summary of the number of samples collected.

Summary of Samples Collected during DGASP
August 1988-August 1989

Aerosol Filters Number of samples

Radionuclides	114
Anions/Cations (IC)	91
Trace elements (INAA)	100
Trace elements (XRF)	57
PAH (aerosols plus gas)	5
Carbon	3

Continuous Monitors

CNC	260 days
Ozone	200 days
Nephelometer	200 days

Other Air/Aerosol Samples

Trace gases - collected in stainless steel canisters	50 sets of samples (67 canisters)
Impactors - Berner Battelle	6 runs 6 runs (simultaneous, March 3-26)

Precipitation

Fresh and old snow	74 sets of samples*
Snowflake/ice crystal replicas	350 slides for 43 snowstorms
Snowpits - 10 km	0-135 cm depths (53 layers)
23 km	130-286 cm depths (55 layers)
25 km	10-130.5 cm depths (42 layers)

Accumulation - measured periodically at 1 km, 10 km and 23 km sites*

*Additional information available upon request

D. NSF/DPP POLAR EARTH SCIENCES

8. Vertebrate Paleontology and Geology of the Triassic-Jurassic Boundary in East Greenland
Museum of Comparative Zoology
Harvard University
Principal Investigator: Dr. Farish Jenkins, Jr.

Field Personnel: Farish Jenkins, Jr.
William Amaral
Stephen Gatesy
Neil Shubin
Edgar Jenkins

Dates In Field: May 9 - August 15

Location: East Greenland

Summary:
Attached: After Operations Report by Dr. Farish Jenkins, Jr.

MUSEUM OF COMPARATIVE ZOOLOGY
The Agassiz Museum
HARVARD UNIVERSITY · CAMBRIDGE, MASSACHUSETTS 02138 · TEL. 617 495 2466

PRELIMINARY REPORT

of the Museum of Comparative Zoology

(Harvard University)

1989 Vertebrate Paleontological Expedition

to Jamesonland, Eastern Greenland

September 28, 1989

Farish A. Jenkins, Jr.
Professor of Anatomy and Biology
Curator of Vertebrate Paleontology
Harvard University

A. Background

The 1989 Vertebrate Paleontological Expedition to Eastern Greenland was conducted with the financial assistance of a research grant from the U. S. National Science Foundation (Grant #DPP-87-21757), logistical and technical support from the Polar Ice Coring Office (University of Alaska, Fairbanks), and with the permission of the Kommissionen For Videnskabelige Undersogelser I Gronland. This expedition, the second field season spent in Jameson Land (see Report previously submitted for 1988), operated for a period of 35 days from 30 June through 4 August, 1989, and was staffed by Professor Farish A. Jenkins, Jr., Mr. William W. Amaral, Dr. Stephen M. Gatesy (all of Harvard University), Dr. Neil H. Shubin (University of California, Berkeley), and Mr. H. Edgar Jenkins II.

This investigation was made possible by the extensive sedimentological and stratigraphic analyses undertaken previously by Danish geologists, most notably K. Perch-Nielsen et al. (1972, 1974) and Lars B. Clemmenson (1980). Additional lithostratigraphic studies are currently being pursued by Mr. Gregers Dam under the auspices of Gronlands Geologiske Undersogelse and supported by British Petroleum. Mr. Dam's work focuses on a detailed lithofacies analysis of the Upper Triassic to Lower Jurassic sedimentary series in this region and proposes to include palanology, ichnology, source rock analyses and porosity/permeability analyses where relevant (see G. Dam, "Sedimentological Studies of the Fluviatile-Shallow Marine Upper Triassic to Lower Jurassic Succession in Jameson Land, East Greenland," Rapp. Gronlands geol. Unders. 140, pp. 76-79, 1988). The scope of the MCZ-Harvard University project was specifically defined during the process of review by the National Science Foundation (Division of Polar Programs) and by the Commission for Scientific Research in Greenland to include the study of fossil vertebrate remains that might be preserved in the Triassic-Jurassic sediments of this region. Prior to the first MCZ-Harvard paleontological expedition in 1988, no fossil vertebrate specimens of substantial scientific significance had ever been recovered from this period of geological time represented in Greenland.

B. Purpose.

Late Triassic tetrapod faunas are significantly different from those of the Early Jurassic; nonetheless, during the Late Triassic representatives of diverse groups (mammals, dinosaurs, crocodilians, turtles) first appeared and these groups continued to diversify through the remainder of Mesozoic times. Knowledge of these Late Triassic forms is thus extremely important to understanding the evolutionary transitions that gave rise to such major groups as mammals and dinosaurs, and for this reason the project was designed to explore various formations of the Scoresby Land Group in eastern Greenland for evidence relating to this critical period in the history of life. Exploration was specifically focussed on the upper parts of the Fleming Fjord Formation (Malmrose Klint and Orsted Dal Members, and the Tait Bjerg beds) which in terms of both geochronology and bedrock exposure offered the greatest potential interest.

C. Areas of study.

Paleontological reconnaissance, excavation and collecting were undertaken from three base camps in which the following areas were surveyed; all

of these areas (see also Section H: Map of Study Areas) lie within the southern half of the Triassic rift basin as interpreted by Clemmenson.

Camp II (30 June - 11 July). The western side of the Paselv valley at the head of Carlsberg Fjord, an area bounded to the north by Lepidoperiselv. This locality offers an extensive, moderately sloping exposure of the Orsted Dal Member of the Fleming Fjord Formation, with more limited exposure of the Tait Bjerg beds representing the uppermost part of the formation. The expedition returned to this site, which was extensively examined during the 1988 expedition, principally for the purpose of attempting to locate additional material of a specimen (22/88/G) which turned out to be a turtle. Turtles first appear in the geological record in the Late Triassic, and therefore this specimen is of considerable importance. Extensive excavation and screening of the site proved productive; numerous additional fragments were recovered, including distal femora, a proximal humerus, vertebrae, and other elements that were found to be missing when the specimen was prepared during the winter of 1988-89. The fact that this specimen was not completely collected in 1988 was the result of unusual solifluction conditions at the site which we did not appreciate at the time. With extensive screening, however, we are confident that we now have all of the available material and are proceeding to prepare this specimen as the subject of the first publication resulting from our work.

Utilizing the same screening technique at another site from which we collected fragmentary dinosaur vertebrae last year (4/88/G) enabled us to discover an entire prosauropod dinosaur in situ (Fig. 1, page 8). Although the specimen remains to be prepared and assembled, positive field identification was made of all four limbs, cervical, dorsal and caudal vertebrae, and most importantly, the skull (Figs. 2-4, pages 9-11). This is, we believe, the first dinosaur known from Greenland and may be referrable to the genus Plateosaurus. At yet another site, again using the screening technique, we were able to add substantially to another specimen, probably that of a juvenile prosauropod (7/88/G), for which we now have numerous limb elements, vertebrae, and a few fragments of the skull.

Camp V (12 July - 24 July). An area bounded to the east by Carlsberg Fjord, to the north by Passagen, to the west by Wood Bjerg and Gule Horn, and to the south by Liaselv. The central topographic feature in this region is Macknight Bjerg, and here and on adjacent mountains are extensive exposures of the Fleming Fjord Formation, including the Malmrose Klint and Orsted Dal Members, as well as the Tait Bjerg beds. From the channel sandstones within the Malmrose Klint were recovered a number of amphibian and reptilian specimens that are unquestionable evidence of a varied tetrapod fauna. Among these are a very large amphibian (skull length estimated at 90 cm), a reptile (dinosaur or thecodont) with a triangularly shaped skull, "pseudosuchians" with tuberculated scutes, a phytosaur, and other partial tetrapod skulls/skeletons that require laboratory preparation for positive identification. At a number of levels in the Tait Bjerg beds dinosaur tracks are abundant in thin mudstone lenses (Figs. 5-7, pages 12-14). The remains of small vertebrates, including fish and lungfish, are found at various levels as bone accumulations within the Orsted Dal Member. Two dinosaur skeletons, one in the Malmrose Klint and the other in the Tait Bjerg beds (Fig. 8, page 15), were discovered but had to be left in place for future collecting because their size exceeded the expedition's logistical capabilities (their collection would have entailed the entire expeditionary effort for the rest of the season, and the weight of the specimens would have exceeded the planned allowances for shipment to CONUS). However, both specimens represent excellent potential for future work.

The most important discovery in the Camp V area is a fine-grained sandstone lense some 30 cm in thickness that apparently represents unusual preservational conditions. Within the lense are preserved innumerable tetrapod bones in good condition and exhibiting very little evidence of transport. Unlike other "bone beds" that may be found locally throughout the upper part of the Fleming Fjord Formation (which consist mostly of fish bones and scales that have been extensively transported), this site offers the possibility of sampling the entire local fauna of small to medium size tetrapods. It is at this locality, as well as others like it that were found subsequently elsewhere, that mammals and other paleontologically rare but significant forms may be expected to be found. Preliminary quarrying at the site produced complete bones of various amphibians and reptiles, including jaws that ranged in size from 2 to 7 cm in length (Fig. 9, page 16). Inasmuch as this lense is highly indurated, and bones could not be safely removed by conventional quarrying techniques, samples of the locality were taken (G/12/89) for laboratory examination and specifically for processing with acetic or formic acid to determine the most suitable technique for recovering specimens without any mechanical damage. The unusual abundance of bone at this locality, together with the broad representation of different elements of the fauna, represents our potentially most important discovery to date.

Camp VI (25 July - 4 August). An area encompassing the entirety of Tait Bjerg, bounded by Passagen to the south, Buch Bjerg to the north, and Carlsberg Fjord to the east. This area likewise provided excellent exposures of the Malmrose Klint and Orsted Dal Members, as well as the type locality for the Tait Bjerg beds at the summit of the mountain. Sandstone channels in the Malmrose Klint yielded various partial skeletons and skulls of amphibians and reptiles; dinosaur tracks again occur in the Orsted Dal Member as well as in the Tait Bjerg beds. Another large dinosaur, of uncertain taxonomic affinity, was located within the Malmrose Klint but, for the same logistical reasons that prevented collecting certain specimens in the Camp V area, it was marked for excavation in the future. Two additional sites of abundant tetrapod bone concentration were located and samples taken for acid preparation and laboratory examination. We thus have three localities at different stratigraphic levels within the upper part of the Fleming Fjord Formation that have the potential to provide an excellent compositional sample of the Late Triassic, small to medium size tetrapod fauna.

D. Summary of findings to date.

1) A diverse fossil vertebrate fauna of Late Triassic age has been discovered in the Fleming Fjord Formation in eastern Greenland. Fossil localities occur throughout the upper Fleming Fjord, namely in the Malmrose Klint and Orsted Dal Members, including the uppermost Tait Bjerg beds. Vertebrate remains are associated with a variety of lacustrine, fluviatile and subaerial environments; terrestrial tetrapods occur predominantly in red channel sandstones within the Malmrose Klint Member and also in local but very abundant concentrations within limestone lenses.

2) The Fleming Fjord fauna appears to be a diverse assemblage. Preliminary identifications based on unprepared material indicate that the faunal list will at least include prosauropod dinosaurs, theropod dinosaurs, other (as yet unidentified) reptiles, a phytosaur, a turtle, several species of amphibians and various fish species (including lung fish).

3) The turtle specimen is an extremely important addition to our knowledge of chelonian evolution which, on present evidence, began during Late Triassic times. The only other taxon with which this specimen may be compared is the Late Triassic Proganochelys, but the carapace/plastron structure of the Fleming Fjord specimen appears to be significantly different and evidently represents a new genus.

4) All of the specimens collected (Section G, attached) in 1989 require preparation before further study and a positive identification can be made. Interpretations made of this material at the time of collection, as represented on the Field List, can only be considered tentative. Additions to the faunal list will almost certainly be made once the limestone/bone accumulation samples have been broken down by acid processing, and the smaller specimens removed.

E. Proposed future work.

At the present time, we anticipate that future field work will concentrate on quarrying and processing at those localities where significant accumulations of small to medium size tetrapods occur. At these sites there is excellent potential for recovering remains of mammals and/or mammal-like reptiles that would document the evolutionary transition between these groups and fulfill one of the original goals of the project. However, one major goal has already been fulfilled, i.e., the discovery of a Late Triassic (Norian) terrestrial tetrapod fauna, and preparation and laboratory study of the specimens thus far collected will proceed over the next year.

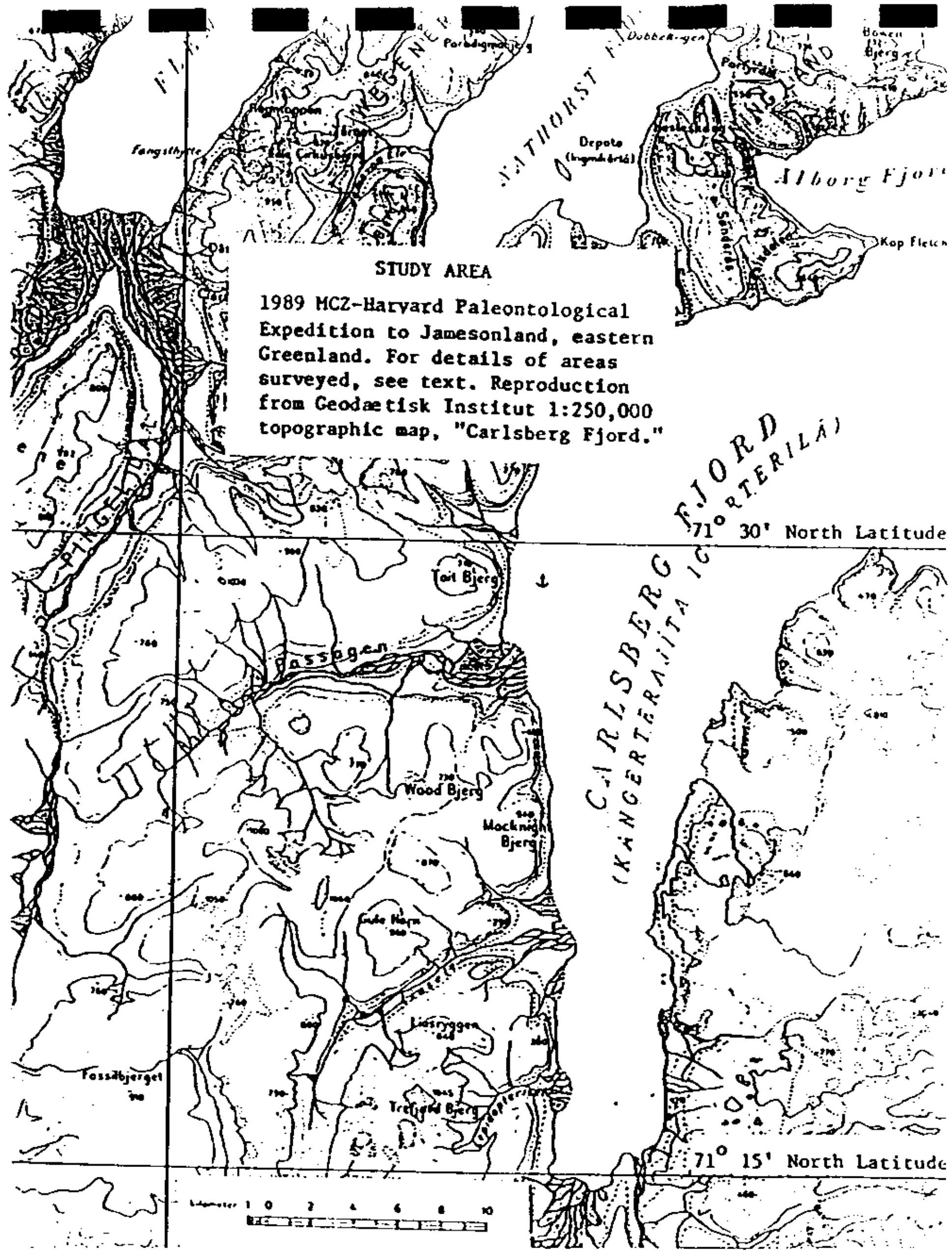
F. Acknowledgments

We are grateful to the Division of Polar Programs (NSF) and its Director, Dr. Herman B. Zimmerman, and The Commission for Scientific Research in Greenland and its Secretary, Mr. Gregers L. Andersen, for their support of this project. In addition we received useful advice from Dr. Lars Clemmensen (Geologisk Centralinstitut, University of Copenhagen), and during the process of the Commission's review from Dr. T. C. R. Pulvertaft (GGU), Dr. S. E. Bendix-Almgreen (Geological Museum, University of Copenhagen) and other (anonymous) reviewers. The logistical arrangements and support of the Polar Ice Coring Office and its Field Operations Manager, Mr. Kent Swanson, were essential to our operation. We also wish to express our appreciation for the courteous cooperation of GLACE (Mr. Ole Romer and Mr. Paol Lasson) and AFIS in providing excellent transportation and communication services, and to Master Chief Petty Officer Curtis W. Sattler (U. S. Naval Air Station, Keflavik) for assistance in transferring personnel and cargo through Iceland.

1989 MCZ-Harvard Expedition to Eastern Greenland

FIELD NO./PRELIMINARY IDENTIFICATION LIST

FIELD NO.	PRELIM. I.D.	COLLECTOR(S)	DATE
22/88/G	[G/7/17/88] Additional fragments of turtle	Party	7/2-3/89
4/88/G	Prosauropod dinosaur	Party	7/4-9/89
7/88/G	?Juvenile prosauropod, skull & limb frags.	Party	7/9/89
G/1/89	Amphibian trackway	SMG	7/1/89
G/3/89	Triangular, flattened, partial skull	WWA	7/13/89
G/4/89	Amphibian skull, flattened	WWA	7/13/89
G/5/89	Small vertebrate with ?skull	NS	7/15/89
G/6/89	Small bone association, possible skull	NS	7/15/89
G/7/89	Fish maxillary fragment	HEJ	7/15/89
G/8/89	2 dinosaur tracks	SMG	7/15/89
G/9/89	Large labyrinthodont skull	WWA	7/16/89
G/10/89	Lungfish tooth and skull roof	NS	7/16/89
G/11/89	Small jaw in bone bed	SMG	7/16/89
G/12/89	Samples for acid processing, "Quarry 1"	WWA & Party	7/16/89
G/13/89	6 lungfish toothplates	SMG	7/19/89
G/14/89	Vert. bone association, ?fish skull	FAJJr & Party	7/20/89
G/15/89	?phytosaur, weathered & fragmented	NS & Party	7/20/89
G/16/89	Bone bed sample for acid prep.	FAJJr	7/22/89
G/17/89	Vertebrate with scutes (skree stone)	WWA, NS, HEJ	7/22/89
G/18/89	?Complete skeleton, tuberculated scutes	SMG	7/23/89
G/19/89	Small ?fish skull	SMG	7/23/89
G/20/89	Small bone association, ?partial fish skull	HEJ	7/23/89
G/21/89	Limestone block w/bone for acid prep.	FAJJr	7/24/89
G/22/89	Bone with struts & plates, ?partial skull	SMG	7/24/89
G/23/89	Partial jaw with conical teeth, assoc. bone	WWA	7/26/89
G/24/89	Small disarticulated skull, partial	WWA	7/24/89
G/25/89	Partial skeleton, ?skull, tuberculated	WWA & NS	7/26/89
G/26/89	Small jaw with closely set, pointed teeth	WWA	7/27/89
G/27/89	Skeleton in many blocks, tuberculated	SMG & NS	7/29/89
G/28/89	Partial jaw, weathered teeth, ?skull parts	NS	7/29/89
G/29/89	Coprolitic association of small bone	HEJ	7/29/89
G/30/89	Bone association, partial lower jaw	NS & Party	7/31/89
G/31/89	Skree block w/finely tuberculated scutes, ?amphibian	WWA	7/31/89
G/32/89	Partial amphibian skull	NS & FAJJr	8/1/89
G/33/89	Small jaw, partial, weathered	SMG	8/1/89
G/34/89	Samples of bone bed for acid prep. & exam.	NS & FAJJr	8/1/89
G/35/89	Jaw fragment, (some teeth covered by matrix)	NS & FAJJr	8/1/89
G/36/89	Samples of bone bed for acid prep. & exam.	FAJJr	8/1/89



STUDY AREA

1989 MCZ-Harvard Paleontological Expedition to Jamesonland, eastern Greenland. For details of areas surveyed, see text. Reproduction from Geodætisk Institut 1:250,000 topographic map, "Carlsberg Fjord."

9. Crustal Reflection Profiling Across Oldest Archean Crust and Crustal Satures in West Greenland
Deparment of Geology and Geophysics
University of Wyoming
Principal Investigator: Dr. Scott Smithson

Field Personnel: Scott Smithson
Chris Humphreys
Allen Tanner
Richard Blenkner
Reid Fletcher
Mark Skelton
Lawrence Shengold
James Fowler
Marvin Speece
Peter Skjellerup

Dates in Field: September 10 - October 3

Location: Nuuk (Godthaab)

Summary:
Attached: After Operations Report by Dr. Scott Smithson.

**Crustal Reflection Profiling Across
Oldest Archean Crust and Crustal Satures
In West Greenland**

Dr. Scott Smithson
University of Wyoming
Department of Geology and Geophysics

Our project is to record seismic profiles over some of the earth's oldest Precambrian rocks. We relied on a combination of helicopters, a small (25 foot) motor boat and a Zodiak from the big research vessel to deploy seismographs along the coast line, along fjord and at Isua by the ice sheet. Traverses had to be switched to place us in fjords during high winds and due to inclement weather.

The PASSCAL seismic recording instruments were extremely flexible in operation which greatly facilitated the survey in the face of bad weather and difficult logistics.

During the survey, the following abstract was faxed for the December 1989 AGU Meeting in San Francisco:

Geophysical Studies of Earth's Oldest Crust
in West Greenland Using the New PASSCAL Instruments

M.A. Speece, M.C. Humphreys and S.B. Smithson
Department of Geology and Geophysics
University of Wyoming

Y. Kristofferson
Jordskjelvstasjonen
University of Bergen
Bergen, Norway

V. McGregor
Atammik
Greenland, Denmark

J. Fowler
IRIS

A large cooperative project was mounted in September 1989 to carry out geophysical studies of the Earth's oldest crust in West Greenland. Targets include possible oceanic crust under oldest supracrustal rocks, granulite terranes, the ancient Moho and three crustal sutures. Geophysical studies consist of gravity, CDP reflection and wide-angle reflection studies that combine recording on land and sea using 6000 cu in airguns from the University of Bergen's research vessel. The new PASSCAL instruments were used for the first time with a controlled source for three-component recording in three different deployments on land. Deployment was by small boat and helicopter. Fjords were used for access of up to 100 km inland. PASSCAL 2-hz three-component seismometers were tested against 7.5 hz geophones and provided better results. The PASSCAL field computer was used to check data quality as the data was recorded and to provide real-time feedback into the experiment. The marine airguns were fired at one-minute intervals to generate 120-km-long common receiver gathers with trace spacing of 105m. P-waves and S-waves converted off the water bottom were recorded out to more than 100 km on the PASSCAL instruments. Combined land and marine recording, utilizing the great flexibility of the PASSCAL instruments, resulted in a relatively dense network consisting of hundreds of kilometers of fan CDP and wide-angle profiles parallel to both strike and dip as well. Strong Moho P- and S-wave reflections were recorded on many profiles at long offsets, and events at travel times greater than 70s were noted at offsets around 180 km.

E. OTHER NSF-SPONSORED PROJECTS

10. Geological Sciences
State University of New York at Binghampton
Principal Investigator: Dr. H. R. Naslund

Field Personnel: Dr. H.R. Naslund
Jennifer Coats
James Greenwood
Robert Heiss
Rebecca Soble
John Tacinelli

Dates In Field:

Location:

Summary:
Attached: After Operations Report by Dr. H. R. Naslund.

Petrofabric Analysis of Igneous Lamination in Layered Mafic Intrusions

Dr. H. Richard Naslund
Department of Geological Sciences
State University of New York, Binghampton

Field Personnel: Dr. H. Richard Naslund, Associate Professor
Jennifer Coats, student
James Greenwood, student
Robert Heiss, student
Rebecca Soble, student
John Tacinelli, student

Travel logistics and deployment dates: We traveled to the airstrip in SØdalen, Greenland on July 16, 1989 from Isafjördur, Iceland by Twin Otter aircraft chartered from Flugfelag Nordurlands HF of Akureyri, Iceland. We returned from SØdalen to Isafjördur on August 19, 1989 also by Twin Otter. Travel from SØdalen to the Skaergaard intrusion was by foot and rubber boat. Our travel to, from and within the field area was coordinated with Platinova Resources Ltd., of Toronto, Canada. The assistance of Platinova Resources Ltd. was greatly appreciated.

Summary of field activities: The primary purpose of this field season was to collect oriented samples for petrofabric studies within the Skaergaard and Basistoppen intrusions and to map in detail preferred mineral alignments within these intrusions. Detailed maps of mineral alignments in the Skaergaard intrusion were made of exposures in the vicinity of picrite blocks in lower zone a; anorthsite blocks in lower zone c, middle zone and upper zone a; trough-band structures in upper zone a; pyroxene replacement bodies and perpendicular plagioclase structures in the Marginal Border Series; and layering features in the Layered, Marginal Border and Upper Border Series. Additional samples were collected along measured traverses in Lower zones b & c, the middle zone, the Marginal Border Series and the Upper Border Series.

Summary of post-season research plans: Samples collected during the 1989 field season will be examined petrographically and analyzed for their major element, trace element and isotopic compositions. We are attempting to determine the origin of preferred mineral fabrics in these intrusions and, therefore, will spend a great deal of effort in determining the mineral orientation in selected samples using U-stage microscopic techniques. We want to determine if the samples with the best preferred mineral orientation fabrics have distinctive chemical or isotopic compositions relative to samples with only poorly developed preferred mineral orientations.

Recent publications resulting from previous Greenland field research:

Parr, J.T., Birnie, R.W., Naslund, H.R., Nichols, J.D. and Turner, P.A., 1988, Lithologic mapping in East Greenland with Landsat thematic mapper imagery. Proceed., 6th Thematic Conf. on Remote Sensing for Exploration Geol., Environ. Res. Inst. of Mich., Ann Arbor, MI., 203-212.

Conrad, M.E., and Naslund, H.R., 1989, Modally-Graded Rhythmic layering in the Skaergaard intrusion, J. Petrol., 30, 251-269.

Naslund, H.R., 1989, Petrology of the Basistoppen sill, East Greenland: A calculated magma differentiation trend, J. Petrol., 30, 299-319.

Naslund, H.R. and Tacinelli, J.C., 1989, Grain size distributions within Skaergaard cumulates, Geol. Soc. Amer. Abst. with Prog., 21, A261.

Work in Progress:

Igneous Layering -- Work is continuing on the origin of layering features in the Skaergaard and Basistoppen intrusions. One paper was recently published (with M.E. Conrad, see above), a second has been submitted for publication (below), and a third with D. W. Keith on layering features in the Upper Border Series is planned:

Naslund, H.R., Turner, P.A., and Keith, D. W., ( ), Crystallization and Layer Formation in the Middle Zone of the Skaergaard intrusion, submitted to Bull. Geol. Soc. Denmark.

Basistoppen Intrusion -- Work is continuing on the differentiation history of the Basistoppen sill. A paper on the differentiation trend of the sill has been recently published (see above), and a second paper on the mineralogical variations observed within the sill is planned. Work on the composition of the intercululate material in the sill is continuing with Dr. Chris Chalokwu of Auburn University.

Sulfide distribution with the Skaergaard Intrusion -- Work is continuing with Patricia A. Turner of Platinova Resources Ltd. on the distribution of S, Cu, Zn, Co and Ni within the Skaergaard intrusion and on the texture and distribution of sulfides within the Pt-Pd-Au horizon in the middle zone of the intrusion. Several publications are planned.

Remote Sensing -- Work continues with R. W. Birnie and J. T. Parr on using LANDSAT thematic mapper images to map lithology within mafic intrusions in East Greenland. One paper was recently published (see above), one is in press (below) and a third comprehensive paper is planned.

Birnie, R.W., Parr, J.T., Naslund, H.R., Nichols, J.D. and Turner, P.A., ( ), Applications of LANDSAT thematic mapper and ground based spectrometer data to a study of the mafic intrusions of East Greenland, submitted to Remote Sensing of the Environment.

Kraemer Ø Macrodyke -- Work is continuing with D. E. Barnett on the Kraemer Ø Macrodyke. A publication of these results is planned.

Petrofabric studies -- The petrofabric study is just beginning and it is anticipated that it will last for several years. We plan to examine the relationship of preferred mineral alignments in the Skaergaard, Basistoppen and Vandfaldsdalen intrusions to their cooling surfaces, to layering features, to xenoliths and autoliths, and to post crystallization replacement structures. We also plan to compare the preferred mineral distributions within the intrusions to grain-size distribution. Several publications are planned.

Differentiation studies -- The differentiation trend of the Skaergaard intrusion is currently the subject of a debate with one group advocating an iron-enrichment trend and another group a silica-enrichment trend. Work currently underway on this problem includes experimental studies and analytical studies of previously collected samples. This work is being coordinated with similar work being done by A. R. McBirney, C. K. Brooks, and T. F. D. Nielsen. A paper has been submitted for publication (below); more are planned.

McBirney, A.R., and Naslund, H.R., IN PRESS, The differentiation of the Skaergaard Intrusion by R.H. Hunter and R.S.J. Sparks, a discussion, submitted to Contr. Mineral. Petrol.

11. Tertiary Magma-Hydrothermal Systems of East Greenland
Department of Geology
Stanford University
Principal Investigator: Dr. Dennis K. Bird

Field Personnel: Dennis Bird
Mark Brandriss
Kristen Flehaber
Richard Nevle
Nicholas Rose

Dates in Field: July 21 - September 16

Location: East Greenland

Summary:
Attached: After Operations Report by Dr. Dennis K. Bird

STANFORD UNIVERSITY EAST GREENLAND EXPEDITION
DEPARTMENT OF GEOLOGY
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

Dennis K. Bird
Nicholas M. Rose
Mark E. Brandriss
Richard J. Nevle

TELEX: 348402 STANFRD STNU
TELEPHONE: (415) 723 1664
FAX: (415) 725-2199

October 12, 1989

Ms. Dorothy Dahl, Administrative Assistant
Polar Ice Coring Office
203 O'Neil Building
Fairbanks, Alaska
99775-1710

Dear Dorothy,

Enclosed is a copy of our After Operations Report for our geological field studies in East Greenland this summer. We had a very successful field season and were able to complete all of our proposed research objectives.

Best Regards,

Dr. Dennis K. Bird
Associate Professor of Geology

907-474-5585

STANFORD UNIVERSITY EAST GREENLAND EXPEDITION
DEPARTMENT OF GEOLOGY
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

Dr. Dennis K. Bird
Associate Professor, Geology

TELEX: 348402 STANFRD STNU
TELEPHONE: (415) 723-1664

REPORT TO THE

UNITED STATES DEPARTMENT OF STATE
Bureau of Oceans and International Environmental and Scientific Affairs

THE COMMISSION FOR SCIENTIFIC RESEARCH IN GREENLAND
Copenhagen, Denmark

POLAR ICE CORING OFFICE
University of Alaska, Fairbanks

**Research Conducted by the
Stanford University East Greenland Expedition
to the Kangerdlugssuaq Region (67°-69°N),
21 July - 16 September, 1989**

In Conjunction With:

Petrology Institute, University of Copenhagen, Denmark
Platinova Resources Ltd., Toronto, Canada

October 10, 1989

CONTENTS

TERTIARY MAGMA-HYDROTHERMAL SYSTEMS OF EAST GREENLAND

Dennis K. Bird, Mark E. Brandriss, Kristen Fehlhaber,
Richard J. Nevle and Nicholas M. Rose
Stanford University

Research Sponsored by National Science Foundation NSF-EAR 8803754
Division of Earth Sciences: Petrogenesis and Mineral Resources
Division of Polar Programs

I. Summary

Our research focuses on the physical and chemical aspects of the deep portions of hydrothermal systems formed during continental rifting and the development of new ocean basins. Field observations of early Tertiary igneous lithologies in East Greenland, including their deformation and alteration are combined with microchemical and stable isotopic analyses of assemblages of minerals and theoretical analysis of fluid-rock interaction in order to evaluate the relationships between fluid flow, hydrothermal metasomatism and rock permeability. The results will provide a better understanding of the importance of groundwaters, both meteoric and seawater, in the physical and chemical processes that characterize crustal rifting. In addition, this research will provide information required to develop heuristic models of large-scale hydrothermal processes in regions of continental and oceanic rifting worldwide. Our land-based data set will assist in the interpretation of petrological and geophysical observations of the ocean basins and their margins, and it will have an impact on other earth science disciplines including tectonics, ore deposits and hydrology.

We are investigating the relationships of magmatic and hydrothermal processes in nine gabbro complexes and in the basaltic rocks that they intrude in East Greenland. The study area is ~175 km by 50 km which includes the region between Nugalik and Jacobsen Fjord. Here we have conducted field and laboratory research on the Skaergaard intrusion, Kap Edvard Holm complex, Miki Fjord Macrodike and its inland extension, Nordre Aputiteq, Igtutarajik, Patulajivit, the skerries located between Nordre Aputiteq and Igtutarajik, Søndre Aputiteq and Kruuse Fjord complex. Exposures within the study area record the spatial and temporal relations of multiple intrusions, hydrothermal metasomatism, fracturing and fracture infilling with secondary minerals that occurred at crustal depths of 4-8 km. The research cited on pages 3 to 6 has established that these fractures and other permeable structures controlled the flow of reactive groundwater-derived hydrothermal solutions during the cooling of the layered gabbro complexes; that the permeability of these hydrothermal systems changed in space and time as new fractures were formed and as older fracture systems were sealed by secondary minerals; and that there is an increase in the complexity of the interrelated processes of multiple intrusion, fracturing and hydrothermal mineralization from the gabbros located in the coastal mountains to those located in the offshore islands.

Our ongoing research addresses the geochemical and transport characteristics of the source regions for hydrothermal solutions marginal to these gabbro intrusions, the interaction of altered basalts with the gabbroic intrusions, and the structural and hydrothermal characteristics associated with magma chambers that have experienced multiple pulses of magma emplacement. These continuing studies allow the East Greenland hydrothermal systems to be used as type examples for comparative analysis with other, less well exposed gabbro-hosted magma-hydrothermal systems in both continental and oceanic environments.

II. Summary of Field Logistics

Field operations in summer 1989 were conducted from 21 July to 16 September. Participating personnel in the research described here included Professor Dennis Bird, Mark Brandriss, Richard Nevle and Dr. Nicholas M. Rose. We worked in close association with geologists from Platinova Resources, Ltd. (Toronto, Canada) and the University of Copenhagen. A base camp at the Sødalen airstrip and helicopter transport was provided by Platinova Resources. Base camp was supported by Twin Otter flights from Flugfleg Nordurlands, Iceland. Fly camps were established at Willow Ridge and Junction Nunatak on the Kap Edvard Holm Complex, near Eskimonaes on the Miki Fjord Macrodike, and on the islands of Patulajivit and Nordre Aputiteq. Helicopter reconnaissance was conducted on the island of Igtutarajik, on the archipelago of islands north of Patulajivit, and on the small islands located between Igtutarajik and Nordre Aputiteq. The Kruuse Fjord complex was visited on three separate occasions. HF-SSB communication was maintained between the fly camps and the Sødalen airstrip on a regular basis. Ice remained heavy south of Kangerdlugssuaq Fjord through late August and unsettled weather was experienced throughout the field season.

Seven layered gabbro complexes were sampled and mapped. These include the Kap Edvard Holm and Kruuse Fjord complexes, the gabbros and basalts located on Nordre Aputiteq, Igtutarajik, Patulajivit, the skerries south of Nordre Aputiteq, and the Eskimonaes Macrodike (see Figure 1).

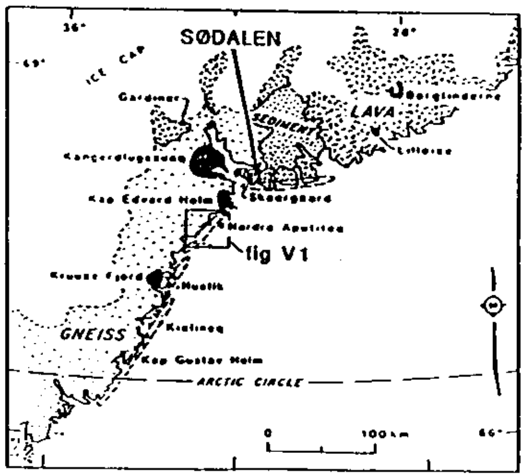


Figure 1 Generalized geologic map of the East Greenland Tertiary igneous province.

III. Publications on Greenland Geology and Geochemistry

JOURNAL ARTICLES

Rosing, M. T., Lesher, C. E., and Bird, D. K., 1989, Chemical modification of east Greenland Tertiary magmas by two-liquid interdiffusion, Geology, v. 17, no. 7, p 626-629.

Bird, D. K., Manning, C. E., and Rose, N. M., 1988, Hydrothermal alteration of Tertiary layered gabbros, East Greenland. American Journal of Science, v. 288, p. 405-457.

Rose, N. M. and Bird, D. K., 1987, Prehnite-epidote phase relations in the Nordre Aputiteq and Kruuse Fjord intrusions, East Greenland. Journal of Petrology, v. 28, p. 1193-1218.

Rogers, R. D. and Bird, D. K., 1987, Fracture propagation associated with dike emplacement at the Skaergaard intrusion, East Greenland. Journal of Structural Geology, v. 9, p. 71-86.

Rosing, M. T., Bird, D. K. and Dymek, R. F., 1987, Hydration of corundum-bearing xenoliths in the Qorqut granite complex, Godthabsfjord, West Greenland. American Mineralogist, v. 72, p. 29-38.

Bird, D. K., Rogers, R. D. and Manning, C. E., 1986, Mineralized fracture systems of the Skaergaard intrusion. Meddelelser om Grønland, Geoscience, v. 16, 68 pp.

Manning, C. E. and Bird, D. K., 1986, Hydrothermal clinopyroxenes of the Skaergaard intrusion. Contributions to Mineralogy and Petrology, v. 92, pp. 437-447.

Bird, D. K., Rosing, M. T., Manning, C. E. and Rose, N. M., 1985, Geologic field studies of the Miki Fjord area, East Greenland. Bulletin of the Geological Society of Denmark, vol. 34, pp. 219-236.

Norton, D., Taylor, H. P., Jr., and Bird, D. K., 1984, The geometry and high-temperature brittle deformation of the Skaergaard intrusion. Journal of Geophysical Research, v. 89, p. 10,178-10,192.

JOURNAL ARTICLES IN PRESS

Manning, C. E. and Bird, D. K., 1989, Fluorian calcic garnets in the basalt host rocks of the Skaergaard intrusion, American Mineralogist, in press.

ABSTRACTS

Manning, C. E. and Bird, D. K., 1989, Fluid flow during contact metamorphism, Geol. Soc. Am. Abstracts with Programs, v. 21, no. 7.

Bird, D. K., Manning, C. E. and Rose, N. M., 1988, Mineralogic and isotopic constraints on the regional hydrology of the Skaergaard magma-hydrothermal system, East Greenland: Geol. Soc. Am. Abstracts with Programs, v. 20, no. 7, p. A344.

Rose, N. M., Liou, J. G. and Bird, D. K., 1988, Experimental investigation of reactions between albite, prehnite, quartz and an aqueous solution at 300°C, 300 bars: Implications for Ca metasomatism in mafic intrusions: Geol. Soc. Am. Abstracts with Programs, v. 20, no. 7, A41-A42.

Manning, C. E. and Bird, D. K., 1988, Evolution of porosity and fluid flow during contact metamorphism of the Skaergaard host basalts, E. Greenland: Geol. Soc. Am. Abstracts with Programs, v. 20, no. 7, p. A 344.

Rose, N. M. and Bird, D. K., 1988, Metasomatic alteration of Tertiary dolerite dikes during continental rifting in East Greenland: EOS, v. 69, p. 468.

Bird, D. K., Manning, C. E., and Rose, N. M., 1987, Metamorphic and structural evolution of hydrothermal systems associated with Tertiary gabbros, East Greenland. Geological Society of America Abstracts with Program, v. 19, no. 7, p. 589.

Manning, C. E. and Bird, D. K., 1987a, Wollastonite + fluorite in metabasalt host rocks of the Skaergaard intrusion: implications for metamorphic fluid composition. Geological Society of America Abstracts with Program, v. 19, no. 7, p. 759.

Manning, C. E. and Bird, D. K., 1987b, Contact metamorphism of basalts marginal to the Skaergaard intrusion. Eos, v. 68, p. 467.

Bird, D. K., Rose, N. M. and Manning, C. E., 1986, Hydrothermal alteration in layered gabbros of the East Greenland Tertiary Province. Mineralogical Society of America, Fourteenth International Mineralogical Association Meeting Abstracts with Program, p. 57.

Rose, N. M., and Bird, D. K., 1986, Hydrothermal mineralogy of the Nordre Aputiteq and Kruuse Fjord intrusions; evidence for multistage hydrothermal alteration in two East Greenland gabbros. International Association of Geochemistry and Cosmochemistry, Fifth International Symposium on Water-Rock Interaction, p. 475.

Rogers, R. D. and Bird, D.K., 1984, Fracture distributions near dike margins in the Skaergard intrusion East Greenland. Eos, v. 65, p. 283.

Bird, D. K., and Manning, C. E., 1984, Mineralogic record of hydrothermal fluid-flow in the Layered Series of the Skaergaard intrusion. Geological Society of America Abstracts with Programs, v. 16, p. 445.

Manning, C. E., and Bird, D. K., 1983, Hydrothermal clinopyroxenes of the Skaergaard intrusion, East Greenland. Eos, v. 64, p. 904.

Bird, D. K., and Rodgers, R. D., 1983, Fracture controlled hydrothermal alterations of the Skaergaard intrusion, Kangerdlugssuaq, East Greenland. Geological Society of America Abstracts with Programs, v. 15, p. 526.

Rogers, R. D. and Bird, D.K., 1983, Deformation associated with emplacement of tholeiitic dikes in the Kangerdlugssuak region of East Greenland. Geological Society of America Abstracts with Programs, v. 15, p. 673.

THESES

Manning, C. E., 1989, Porosity evolution, contact metamorphism, and fluid flow in the host basalts of the Skaergaard magma-hydrothermal system, Ph. D. Dissertation, Stanford University, Stanford, Ca., 190 p.

Manning, C. E., 1985, Hydrothermal clinopyroxenes of the Skaergaard intrusion, East Greenland. M. S. Thesis, Stanford University, Stanford, Ca., 38 p.

Rose, N. M., 1989, Experimental and field studies of metasomatic mass-transfer in the system Na_2O - Al_2O_3 - CaO - SiO_2 - H_2O - HCl. Ph. D. dissertation, Stanford University, Stanford Ca., 200 p.

Rose, N. M., 1985, Prehnite-epidote phase relations in the Nordre Aputiteq and Kruuse Fjord intrusions, East Greenland. M. S. Thesis, Stanford University, Stanford, Ca., 57 p.

THESES IN PROGRESS

Fehlhaber, K., The mineralogy and chemistry of hydrothermally altered gabbro pegmatites: Implications for fluid and magma genesis in the Kap Edvard Holm complex, East Greenland. Senior Thesis, to be completed December 1989.

Brandriss, M. E., High temperature metamorphism and partial assimilation of basaltic host rocks by gabbroic magmas, Ph. D. Dissertation, Stanford University, to be completed, 1991.

Nevle, R.J., Metasomatism in the contact zone of the Hutchinson Gletscher Syenite II: Dike and fracture controlled hydrothermal mass transfer in the Kap Edvard Holm gabbro, east Greenland, Ph. D. Dissertation, Stanford University, to be completed, 1992.

PAPERS IN PROGRESS

Mineralogic and isotopic characteristics of the volcanic aquifer marginal to the Skaergaard intrusion.

Olivine hydrolysis: a mechanism for fracture sealing in cooling gabbroic intrusions.

Contact metamorphism and water-rock interaction of the Skaergaard intrusion host basalts.

Evolution of porosity and fluid flow in the Skaergaard intrusion host basalts.

Dissolution rates of prehnite, epidote and albite.

Constraints on hydrothermal calcium-metasomatism: evidence from prehnite-mineralized dikes in the Miki Fjord region, east Greenland.

Crystallization of the marginal gabbros, and pegmatite evolution in the Nordre Aputiteq layered gabbro, east Greenland.

Experimental investigation of mass transfer between minerals and aqueous solutions in the system Na_2O-CaO-Al_2O_3-SiO_2-H_2O-HCl.

IV. Kap Edvard Holm Complex

The Kap Edvard Holm Complex (Figure IV-1) has an outcrop area of approximately 360 km² of gabbros with a cumulative thickness exceeding 7 km, and 60 km² of later syenite and breccias (Deer and Abbot, 1965; Brooks and Nielsen, 1982). It is believed that the complex consists of at least three separate gabbroic intrusions, termed the Lower (LLS), Middle (MLS), and Upper Layered Series (ULS) (Elsdon, 1969). Contact and age relations between these intrusive units are unknown at present. However, our research suggests that the MLS was intruded after the LLS, causing the dramatic ^{18}O depletion measured in plagioclases of the LLS (see Figure IV-2).

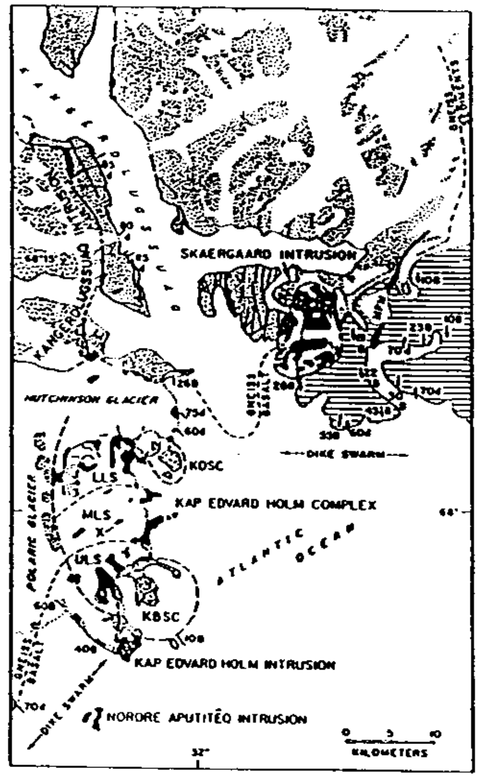
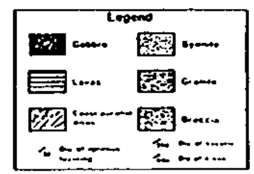


Figure IV-1.
Geologic map of the Kangerdlugssuaq region. Map shows exposures of mafic dikes and gabbroic intrusions (solid black lines and areas, respectively), Tertiary sedimentary rocks and lavas, and the Precambrian basement. KDSC is Kap Deichmann syenite complex, KBSC is the Kap Boswell syenite complex. The Kap Edvard Holm complex, which is distinct from the smaller Kap Edvard Holm intrusion to the south, is divided into three units as shown: Lower Layered Series (LLS), Middle Layered Series (MLS), and Upper Layered Series (ULS).



In 1987 and 1988, field studies at Kap Edvard Holm were conducted by Dennis K. Bird of Stanford University and C.K. Brooks and Stefan Bernstein of Copenhagen University. These studies posed two intriguing questions regarding the role of mafic dikes as natural aqueducts during hydrothermal circulation in the Kap Edvard Holm Complex: 1) Does the increase in the extent of secondary alteration of the gabbroic pegmatites near the dikes indicate that hydrothermal alteration of the pegmatites resulted from dike-channelized circulating fluids? 2) Do the extensively fractured and altered pre-syenite dikes represent high-permeability channels for metasomatic fluids during hydrothermal circulation associated with syenite emplacement? This year we addressed these questions in the field. In addition, we began a new study addressing the dehydration of basaltic xenoliths as a possible mechanism for introducing water into the gabbros.

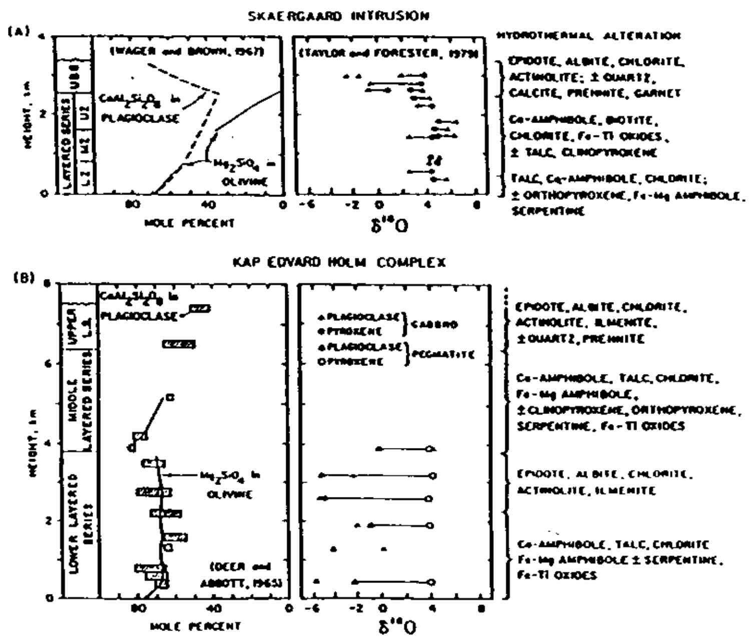


Figure IV-2. Stratigraphy, magmatic plagioclase and olivine compositions, $\delta^{18}O$ values for plagioclase and pyroxene in the pegmatites and gabbros, and the dominant hydrothermal alteration mineralogy, of the Skaergaard (A) and Kap Edvard Holm complex (B) gabbros. $\delta^{18}O$ values for Kap Edvard Holm are from Fehlhaber (1989, Senior Thesis, Stanford University).

Stable Isotope Studies of Gabbros and Gabbro Pegmatites

Our research focuses on pegmatite petrogenesis within the layered gabbros, the more extensive hydrothermal alteration of pegmatites relative to their host gabbros, and the sources of the hydrothermal fluids which produced the observed alteration. Field observations indicate a spatial association of pegmatites and xenoliths; similar observations have been made in the Skaergaard and on Nordre Aputiteq, where dehydration of the xenoliths may have provided volatiles which caused pegmatites to form (Taylor and Forester, 1979; Rose, 1989).

In order to characterize the origin of hydrothermal fluids and the extent of hydrothermal alteration of the pegmatites, we have undertaken a study of oxygen and hydrogen stable isotopes in the gabbros and pegmatites. Preliminary results are presented in Figure IV-2B. Relative to the Skaergaard Intrusion, plagioclases from the LLS gabbro and pegmatites are significantly more depleted in ^{18}O. The trend of increased depletion of ^{18}O in plagioclase with depletion of ^{18}O in pyroxene observed in the Skaergaard is absent in the LLS. Pyroxenes from the LLS all have $\delta^{18}O_{px}$ near +4‰. Thus, the greater difference between the $\delta^{18}O$ values of plagioclase and pyroxene in the LLS is thought to reflect greater disequilibrium (faster subsolidus exchange), and the larger overall ^{18}O depletion in plagioclase reflects higher water-rock ratios than experienced by the Skaergaard. These differences can be explained by repeated activation of meteoric hydrothermal systems by multiple intrusions of gabbroic and syenitic magmas at Kap Edvard Holm, in contrast to a single episode of hydrothermal circulation around the Skaergaard intrusion.

The low $\delta^{18}O$ values at the base of the LLS may result from hydrothermal systems established during the emplacement of the Hutchinson Gletscher Syenites. Preliminary data suggest that plagioclase becomes less depleted with distance from the gabbro-syenite contact, which is consistent with decreasing intensity of hydrothermal activity. At the top of the LLS, plagioclase shows strong depletion; we interpret this to be a result of hydrothermal activity driven by intrusion of the MLS.

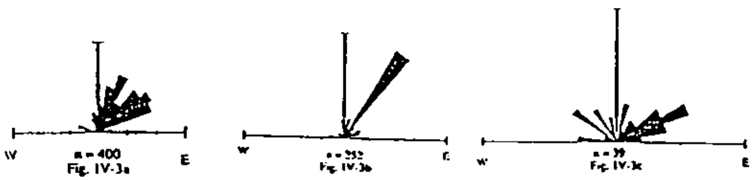
Forthcoming analyses of $\delta^{18}O$ will clarify the relationship between host rock and pegmatite alteration, while δD analyses of pegmatitic amphiboles will establish whether the hydrothermal fluids were magmatic or meteoric in origin.

Structural Control of Hydrothermal Alteration

We conducted an extensive field study of the fracture systems in gabbros near the contact zone of the Hutchinson Gletscher Syenite II in order to evaluate structural controls on hydrothermal alteration in the Kap Edvard Holm complex. In this area, hydrothermal alteration is concentrated near mafic dikes that intruded the LLS prior to the emplacement of the syenites. Characterization of these fracture systems included: 1) detailed mapping of fracture systems, 2) vein orientation and abundance measurements, and 3) sampling of gabbro, syenite, and mafic dikes for petrographic, geochemical, and light stable isotope analyses.

A preliminary analysis of the structural data shows: 1) fracture abundances in the dikes exceed those in the gabbro by a factor of three; 2) mafic dikes in the LLS gabbros have a broad range of orientations, with many trending between 050° and 080° (Figure IV-3a); 3) mineralized fractures in the contact zone gabbros < 100 m from the gabbro-syenite contact dominantly trend 030° to 040°, approximately perpendicular to the contact (Figure IV-3b); 4) mineralized fractures in the gabbros > 100 m from the contact have a broad range of orientations (Figure IV-3c).

The higher density of mineralized fractures in the mafic dikes relative to the gabbros suggests that these dikes acted as channels for the circulating fluids. Fracturing in the mafic dikes may have occured in response to emplacement and cooling of the dikes. The data in Figure IV-3b suggests that fractures in the contact zone gabbros may result from stresses imposed by emplacement and cooling of the Hutchinson Glacier Syenite II.



Figures IV-3. Rose diagrams of: a) mineralized fractures in the LLS > 100 m from the syenite-gabbro contact; b) mineralized fractures in LLS < 100 m from the contact; c) mafic dikes in the LLS. The letter "n" represents the number of features measured.

Analysis of the structural data and vein filling mineral assemblages permits an interpretation of the relative changes in permeability and stress conditions within the system. In addition, thermodynamic analysis of secondary mineral assemblages will allow us to constrain: 1) the temperature conditions during hydrothermal alteration, 2) the extent to which metasomatic fluids reacted with their host rocks, and 3) the compositions of these metasomatic fluids. Analysis of phase relations and mass transfer in the extensive metasomatic reaction zones surrounding veins in the contact zone gabbros will clarify the role that small scale transport processes play in metasomatizing these rocks. Combining these studies with light stable isotopic analyses of secondary and primary minerals will help to evaluate: 1) the sources of water responsible for producing the relatively extensive alteration of the Lower Layered Series relative to other East Greenland gabbros; 2) the amount of water involved in this process; and 3) the hypothesis that mafic dikes channelized hydrothermal fluids. These combined studies will contribute to the understanding of mass transfer in geologic systems characterized by fracture-controlled permeability and large gradients in chemical potential.

Basaltic Xenoliths

During the 1989 season we conducted a field study of basaltic xenoliths in the Kap Edvard Holm Layered Gabbro Complex, including extensive sampling at three localities. Xenoliths of basalt were found only in the westernmost nunataks of the Lower, Middle and Upper Layered Series (Figure IV-4). In accordance with the earlier work of Deer and Abbot (1972), most of the Lower Layered Series is nearly devoid of xenoliths, while the remainders of the Middle and Upper Layered Series contain xenoliths predominantly of gabbro and anorthosite. Within the Lower Layered Series, we observed abundant xenoliths of quartzofeldspathic gneiss near the western contact of the intrusion and on a nunatak located near the foot of Hutchinson Glacier. These observations suggest that xenoliths of the basaltic and gneissic country rocks are present only near the margins of the complex, although the original southern and eastern contacts of the complex are not exposed.

Within the Lower Layered Series, gneissic xenoliths contain basaltic dikes truncated at the xenolith margins, indicating that these dikes predate the emplacement of the gabbros. Also, we observed one tabular basaltic xenolith (5m x >50m) with patches of quartzofeldspathic gneiss along its upper and lower contacts; these gneiss patches were partially melted, and backveined the basalt xenoliths and host gabbro. These relationships indicate that many of the basalt xenoliths may represent fragments of basaltic dikes and sills which intruded the gneisses prior to emplacement of the gabbro, and were then incorporated into the gabbro as the less refractory gneisses melted away after stoping.

On the westernmost nunatak in the Middle Layered Series, the layered gabbros contain up to 20% by volume of granular hornfelsed basalt xenoliths over tens of meters of section. The xenoliths are lenticular, and conformable to layering. Many contain relict vesicles filled with plagioclase and flattened parallel to the long axes of the xenoliths. Xenoliths smaller than about 1m in thickness are devoid of hydrous minerals; larger xenoliths, however, contain abundant porphyroblasts of hornblende, phlogopite and plagioclase, with individual hornblende crystals up to 10 cm long. Within the xenoliths, wispy gabbroic and anorthositic stringers near the margins suggest that the blocks were partially melted. Together, these features indicate that the host gabbroic magma supplied enough heat to partially melt the larger xenoliths along their margins, but not enough to completely dehydrate their interiors.

Basalt xenoliths are common in the Upper Layered Series on the large nunatak on which the western contact is exposed. The xenoliths here are fine-grained granular hornfelses containing abundant relict vesicles. The vesicles are filled with plagioclase, and are greatly elongated approximately parallel to the xenolith contacts.

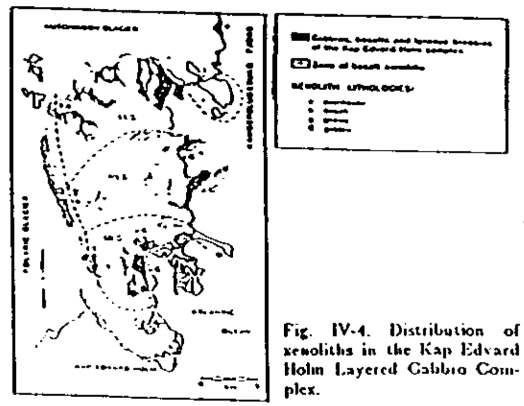


Fig. IV-4. Distribution of xenoliths in the Kap Edvard Holm Layered Gabbro Complex.

Our study of metabasalt xenoliths at Kap Edvard Holm will build upon our studies of xenoliths at Nordre Aputiteq, Patulajivit and the Miki Fjord Macrodike. We expect that the distributions, morphologies, compositions and mineralogies of basalt xenoliths within these intrusions will continue to yield information about the processes of gabbro emplacement and basaltic host rock assimilation.

V. The Island Gabbros

Our field studies over the past eight years in East Greenland have demonstrated that there is an increase in the complexity of the interrelated processes of multiple intrusion, fracturing, and hydrothermal mineralization from the gabbros located in the coastal mountains to those located in the offshore islands of Nordre Aputiteq, Igtutarajik, Patulajivit and the small skerries located between these islands (see Figure V-1). We believe that this change in the style of magmatic and tectonic activity was due to the transition from an incipient continental rift to an oceanic spreading axis. The objectives of our research program in the island gabbros are:

1. To establish in detail the relationships between fracturing and hydrothermal metasomatism in gabbro complexes that formed by multiple intrusions.

2. To determine when seawater became an important component of the hydrothermal fluids during the transition between continental and oceanic rifting.

The Stanford research team is working on this project in conjunction with Professor C. K. Brooks (Copenhagen University) and Dr. T. F. D. Nielsen (Greenland Geological Survey). It is our anticipation that this collaborative research will better our understanding of the magmatic, hydrothermal and structural evolution during the development of the East Greenland continental margin in the Kangerdlugssuaq region.

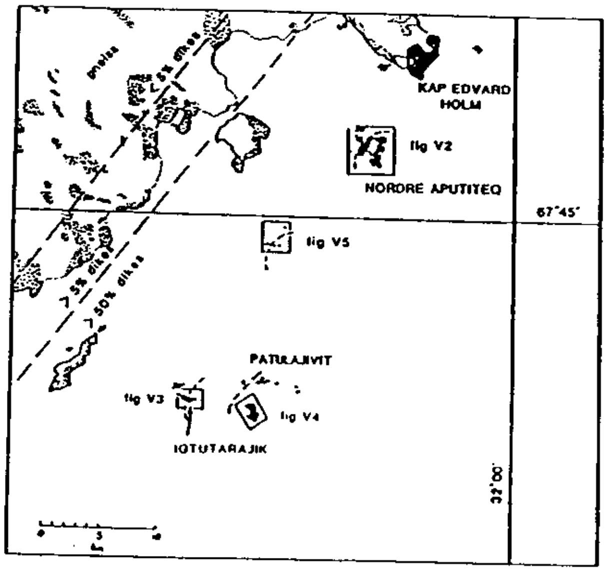


Figure V-1. Generalized geologic map of the island gabbros described in this report. Gabbros are shaded black, gneisses are stippled and the dashed lines are possible contact relations between the gabbros and the volcanics

Nordre Aputitêq

Two weeks of fieldwork were conducted by Bird and Rose in July 1989 in conjunction with Platinova Resources exploration program, an additional day was spent by Rose in late August finishing aspects of the earlier work. The main purpose of the present fieldwork was to define the extent of the Marginal Gabbros, investigate their contact relations with the basalts and central layered series, and map in detail their internal structure. All these aims were achieved, and detailed maps and four cross sections were completed through the Marginal Gabbros. A preliminary geological map of Nordre Aputitêq showing the location of 1989 cross-sections is given in Figure V-2.

The Marginal Gabbros constitute approximately 200 meters of stratigraphic thickness along the northwestern margin of the island (see Figure V-2). They are bounded to the northwest by a 45° dipping contact with basalts and tuffs, and to the southeast by a steeply dipping contact with rocks that are continuous with the Central Layered Series which comprise the central part of the island. The westernmost unit in the Marginal Gabbros is a pervasively pegmatitic gabbro which locally contains dendritic feldspars and crescumulate banding, features that are typical of the marginal zones in other East Greenland gabbros. Within the Marginal Gabbros there is abundant internal structure provided by: (1) contacts among megacyclic units dipping at 30° to 40° to the southeast and conformable with layering structures and deformed metabasalt xenoliths; (2) Steeply dipping linear belts of pegmatite together with metasomatic poikilitic pyroxene gabbro and mafic layers that dip at angles from 75° to 90° in both southeast and northwest directions and which strike parallel with layering in the gabbro; (3) Local zones of well developed inch-scale layering consisting of thin olivine-rich bands repeated for a distance of several meters, often developing into trough bands. Field relations indicate that the pegmatites and abundant zones of metasomatic poikilitic pyroxene gabbro are late stage steeply dipping sheet- or pipe-like features. Sample collections made with reference to the cross sections will be sufficient to trace bulk chemical and mineralogical variation across the Marginal Gabbros.

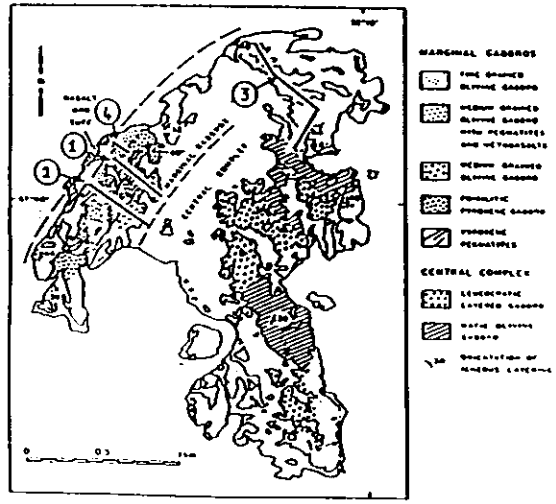


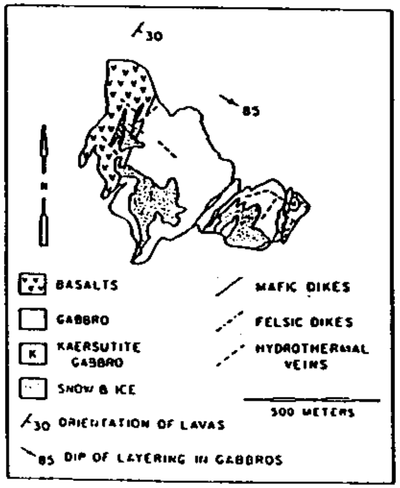
Figure V-2. Geological map of the Nordre Aputitêq Layered Gabbro, showing the major gabbro units and the location of four cross-sections through the marginal gabbros that were studied in 1989.

Igtutarajik

During our 1989, 1988 and 1987 field seasons in East Greenland we made short (< 1 hour) helicopter ground stops on the island of Igtutarajik. Brief accounts of the geology by Wager (1934), Bridgwater et al. (1978) and Myers et al. (1980) report that this island consists of metabasalts and gabbro with granitic material injected near the intrusive contacts.

The gabbros of Igtutarajik are medium- to coarse-grained, with poorly developed layering, and contain pegmatitic segregations. In general, the observed textural and lithologic features of the gabbros resemble the marginal gabbros of Nordre Aputiteq (Figure V-2). The gabbros range from leucocratic to melanocractic, with the former containing greater modal abundance of plagioclase and the latter containing greater modal abundance of opaques and kaersutite. Melanocratic karesutite gabbros are found at the eastern edge of the island, and appear to be intruded into the leucocratic gabbros. Complex metasomatic relations are apparent in the highly oxidized exposures of the contact zones. Sharp dike-like contacts trending 090° and dipping 85°S separates the two gabbros as well as gradational contacts associated with pegmatites and a increase in the median grain size. Olivine, discontinuously zoned plagioclase, and apatite are the cumulus phases in all samples, with plagioclase >> olivine > apatite. Textural relations suggest that olivine and apatite were on the liquidus before plagioclase. Intercumulus phases include augite, Fe-Ti oxide, kaersutite, biotite, and minor sulfide, with kaersutite and biotite the latest phases to form in all samples.

The contact between the gabbro and the volcanics is near vertical and is injected by granitic veins, dikes and breccias. Near vertical thin amphibole veins with densities of about 50 veins per meter occur near the contact. These veins are oriented 050° and 120°. The gabbros are partially altered and crosscut by 1 to 3 mm wide hydrothermal veins. The most prominent vein orientations are near vertical with trends of 025-035°, 120° and 150°. Most of these veins are filled by varying amounts of green hornblende, actinolite, albite and epidote. In the wall rock plagioclase is altered to sericite, epidote and albite; augite to hornblende, actinolite and/or secondary clinopyroxene; olivine to talc and magnetite; kaersutite to green hornblende and actinolite; and biotite to chlorite and epidote. The 025-035° vein set near the kaersutite-gabbro is filled with kaersutite and biotite.



The gabbros of Igtutarajik are crosscut by several NNE-trending mafic dikes. These dikes have subophitic to intersertal textures of plagioclase and augite and are highly altered to secondary mineral assemblages of actinolite, albite, epidote, chlorite, and sphene. Felsic (granitic) dikes trending 160° ranging from 5 to 20 cm wide are found in the leucocratic gabbros. Near vertical faults trending 060° are found on the eastern portion of the island.

Figure V-3. Generalized geologic map of Igtutarajik.

Patulajivit

Little is know at present about the gabbros at Patulajivit. Bridgwater et al. (1979) report that the intrusion forms an oval shaped body with inward dipping layers, and Brooks and Neilsen (1982) have noted complex layered structures that suggest instability and perhaps multiple intrusion during the formation of the gabbros.

Nineteen days were spent on this island during severe weather conditions. About 1000 m of stratigraphic section was mapped on a scale of 1:250 and samples were collected on 5 to 10 m intervals. This intrusive complex is unique relative to the other East Greenland gabbros we have studies in that it appears to have formed by numerous pulses of magma, similar to gabbros found in ophiolites. The dashed lines shown in the map below denote ultramafic-mafic basal units of these intrusive cycles that range from 0.5 to 2 m in thickness. The basal units transgress and deform the underlying layered gabbros and grade upward into layered gabbros. Well-developed modally graded layers are characteristic of the gabbros above the basal units. The individual intrusive cycles range from 10 to 80 m in thickness. Blocks of metabasalts and leucogabbro as well as pegmatites are common in the gabbros. The distribution of metabasalt xenoliths shown in the map suggest that stoping of the wall-rocks occurred periodically during the inflation of the magma-chamber.

In the north-central portions of the island there are a number of mafic plugs that were feeder conduits for the intrusive cycles shown on the map. Parallel to the east-west trend of these plugs are gabbroic and pegmatitic dikes (see map below). These dikes are associated with 10 to 40 cm horizontal left-laterial displacement of the layered gabbros.

The detailed mapping and sampling of the intrusive units, the metabasalt xenoliths and the vein and dike systems on this island will provide the data required to evaluate the interrelated processes of deformation and hydrothermal alteration associated with intrusive complexes formed by multiple pulses of magma.

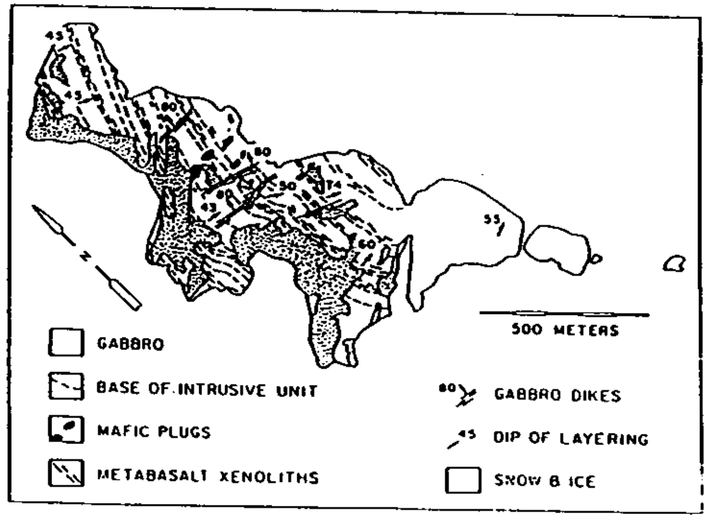


Figure V-4. Generalized geologic map of Patulajivit.

Islands between Nordre Aputiteq and Igtutarajik

A 15 minute heliocopter stop was made on the western most island of the group of skerries located midway between Nordre Aputiteq and Igtutarajik (Figure V-X). This island consists of medium to fine grained rust colored gabbros. No layered features or pegmatites were observed. However, irregular patches of rust colored, sulfide bearing gabbros occur throughout the portions of the island investigated. Two samples of the gabbro were obtained for geochemical and mineralogical analyses.

The map below summarizes our 1988 and 1989 field observations of this group of islands. In the gabbros thin felsic dikes 10 to 20 cm wide trending 110° were found in the northern most outcrops. No mafic dikes were observed in the gabbros. The volcanic skerries contained 40 to 50% mafic dikes and sills. These intrusions include aphanitic and plagioclase phyric mafic dikes usually <3 m wide and coarse grained dolerites up to 10 m wide. The lavas strike 020° and dip 30-40°E and exhibit textures and fabrics characteristic of high-grade contact metamorphism including irregular veins and patches of garnet and pyroxene. The earliest dikes trend 020° and 080° and are crosscut by dolerite dikes trending 040° and dipping 40° to 60°W. The younger set of dikes appear to be the most abundant intrusions in the volcanics. Faults trending 020° and dipping 80°W are common on the volcanic skerries. These faults are mineralized with quartz and epidote assemblages.

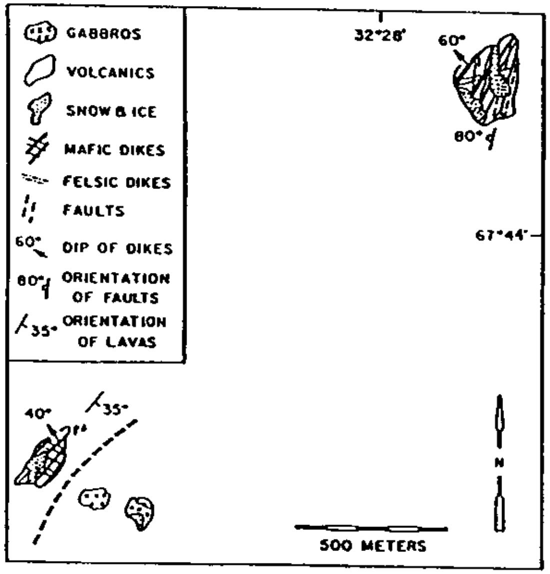


Figure V-5. Geologic sketch map of the islands located midway between Nordre Aputiteq and Igtutarajik. Scale and map orientation are only approximate.

VI. Miki Fjord Macrodike

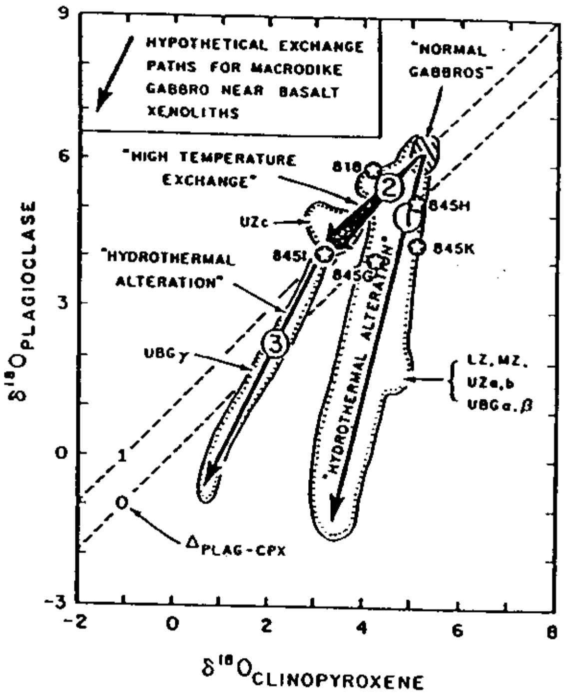
The Miki Fjord Macrodike is a NNW-trending dike-like gabbro >30km long and up to 1km wide, with the southernmost exposure outcropping 3km east of the Skaergaard intrusion. At least two distinct lithologic units have been distinguished within the Macrodike; a layered, olivine-rich unit with low initial $^{87}Sr/^{86}Sr$, and a later olivine-poor massive unit with higher initial $^{87}Sr/^{86}Sr$ (Deer, 1976; Bird et al., 1985; Charles Lesher, personal communication). Within the layered gabbros, metabasalt blocks locally constitute 10-50% of outcrop over tens of meters of section. These blocks display relict volcanic textures and structures, such as vesicles and chilled flow margins, and are metamorphosed to anhydrous granular assemblages of clinopyroxene, plagioclase, orthopyroxene, olivine and iron-titanium oxides. In places, the blocks are partially melted, forming gabbroic pods within the blocks. Therefore, at least part of the layered gabbro sequence may be composed of melted and recrystallized basaltic material.

Field work on the Miki Fjord Macrodike in 1989 concentrated on: a) determining the spatial, structural and temporal relationships between the layered and unlayered gabbros; and b) completing our sample collection of gabbros and basalt blocks for use in analytical studies. Fieldwork on the Macrodike was performed in conjunction with Dr. Chip Lesher and Miranda Fram of the Lamont-Doherty Geological Observatory, and Dr. Minik Rosing of the Geologic Museum of Copenhagen, Denmark.

Low snow levels provided excellent exposure of the Macrodike. We determined that the massive gabbro extends further westward than previously known, and that numerous dikes and sills of massive gabbro intrude the layered gabbro. These dikes and sills range from centimeters to tens of meters thick, including a 50m-thick sill which caps the layered gabbros at their highest exposures. This sill, along with the massive gabbro underlying the layered gabbro and scattered patches of massive gabbro along the western margin of the layered unit, indicate that the massive gabbro intruded along the top, bottom and western side of the layered sequence.

Our completed sample suite will help us characterize the flux of chemical components from basalt to gabbro magma via dehydration and partial melting of basaltic blocks. Recrystallization of the blocks took place at temperatures of 1050-1100°C, as calculated from measured distributions of elements between coexisting clino- and orthopyroxenes. This is well above the liquidus for typical hydrothermally altered metabasalts, indicating that partial assimilation of blocks by the magma probably took place. Because the metabasalts hosting the intrusion were hydrothermally altered prior to the emplacement of the Macrodike (due to earlier intrusion of the Skaergaard to the west; Bird et al, 1988b), their $\delta^{18}O$ values are typically several parts per thousand lower than those of fresh gabbroic rocks in the region. Partial assimilation of metabasalts by fresh gabbroic magmas might therefore be traced by localized depletion in ^{18}O in the vicinities of blocks . Preliminary results of oxygen isotope analyses suggest that ^{18}O depletion does occur in the layered gabbro immediately adjacent to basalt blocks (Figure VI-1). Our continuing work will include a detailed investigation not only of $\delta^{18}O$ variations, but also of variations in mineral compositions within the blocks and gabbros and across gabbro/block contacts. Twelve localities were sampled both by ourselves and by Dr. Chip Lesher, so that our analytical studies can be coupled with bulk compositional and radiogenic isotope studies by Dr. Lesher.

Fig. VI-1. $\delta^{18}O_{PLAG}$ and $\delta^{18}O_{CPX}$ for gabbros of the Miki Fjord Macrodike (stars). Range of Skaergaard gabbros shown for comparison (fields with dotted outlines; after Taylor and Forester, 1979). Sample 818 is a massive gabbro; 845G, H, and K are layered gabbros sampled several meters from the nearest basalt blocks; 845I is a layered gabbro within 10cm of a basalt block.



VII. Kruuse Fjord Complex

The Kruuse Fjord complex, first discovered in 1978 (Bridgwater et al., 1978; Rex et al., 1979), is a large layered gabbroic and ultramafic complex (Figure VII-4). The only detailed geologic studies of this complex have been conducted on a few samples collected by the Edinburgh East Greenland Expedition in 1982 (Rose and Bird, 1987). In collaboration with geologists from Copenhagen University, our research group mapped and sampled the southeastern corner of the complex in August 1987, and during this summer's research DKB visited the ultramafic intrusion on three occasions to sample and investigate the mineralization near the intrusive contacts.

Our field observations are summarized in Figure VII-1. The gabbros experienced local and large-scale ductile deformation with layering dipping steeply toward the center of the complex. Near-vertical hydrothermal amphibole veins are found throughout the study area (rose diagrams, Figure VII-1). The layered gabbros are intruded by an arcuate ultramafic complex consisting of chromite- and sulfide-bearing peridodites, dunites, troctolites and olivine gabbros. The ultramafics contain minor amounts of Pd tellurides and antimonides and Pt arsenides in close association with chalcopyrite. The southern contacts of the ultramafic complex with the layered gabbros are associated with ductile folding and truncated layering, and field relations suggest intermingling of the various magmas. In contrast, in the north and east, the ultramafic intrusion caused brittle deformation of the layered gabbros. The layered gabbros in this area contain shallow-dipping calcic amphibole vein sets that are subparallel to the intrusive contact with the ultramafic body (Figure VII-1). These low-angle veins are 1 to 2 cm wide and crosscut the earlier 1 to 3 mm wide near vertical calcic amphibole veins (Figure VII-1, rose diagrams B & C). Our continuing research focuses on the igneous petrogenesis, deformation and alteration of the complex. We are working in close association with Thomas Nielsen and C. K. Brooks of Copenhagen University on the felsic-mafic pillow dikes found in this complex.

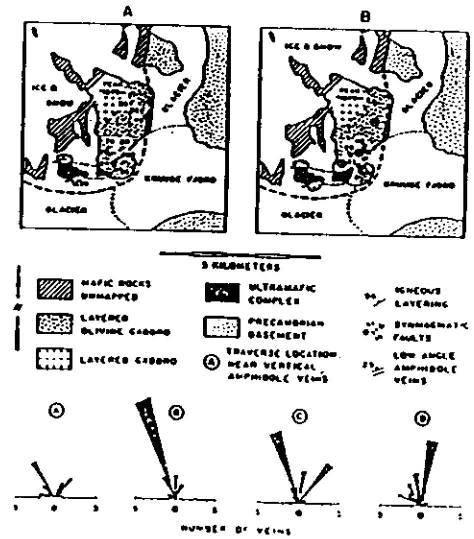


Figure VII-1 Generalized geologic map of the southeastern portion of the Kruuse Fjord Complex.

VIII. The volcanic aquifer marginal to gabbroic intrusions

The volcanic rocks intruded by the east Greenland gabbros were aquifers for groundwaters that circulated through and reacted with the cooling gabbros. Our objectives in studying the volcanic rocks marginal to these intrusions are to determine their paleohydrologic and geochemical characteristics by addressing the three questions: (1) What are the mineralogic and stable isotopic constraints on fluid compositions with the volcanic aquifer system? (2) What elements and stable isotopes were mobilized and/or fixed, how do these change with distance from the intrusion and what were the reactions responsible for this? (3) Can the relative permeability of different strata be characterized by the variations in mineralogy, stable isotopes and time integrated water-rock ratios?

During the 1989 field season we collected samples of metabasalts near the intrusive contacts of the gabbros at Kap Edvard Holm, Nordre Aputiteq and Patulajivit. This new research collection will build upon our detailed studies of the volcanic stratigraphy near the Skaergaard intrusion which is summarized below. Early Tertiary volcanic rocks (Lower Basalts) exposed east of the Skaergaard intrusion constitute a fluid source region for meteoric groundwaters that circulated through and reacted with the cooling gabbro. The Lower Basalts define a paleo-aquifer 3 to 5 km deep capped by 0.5 km of tuffs and underlain by sediments and gneisses (Figure VIII-1). This aquifer consists of a ~1.5 km succession of lavas, hyaloclastites, pillow breccias, aa flows and tuffaceous sediments that are crosscut by dikes, sills, and faults. At 3 to 6 km east of the Skaergaard the volcanics are intruded by the Miki Fjord Macrodike, a 0.4 to 1.5 km wide and >30 km long composite gabbroic dike complex which postdates the Skaergaard (Figure VIII-2). The Macrodike contains abundant blocks of metabasalt which had been metamorphosed previously by the Skaergaard hydrothermal system (Bird et al., 1988).

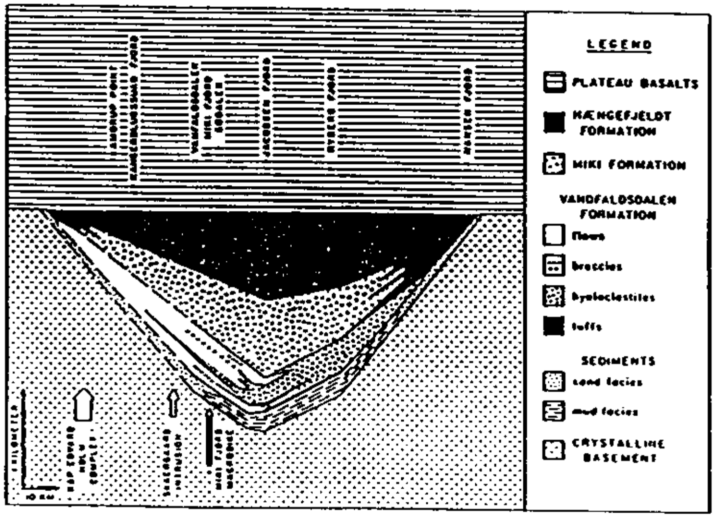


Figure VIII-1. Schematic stratigraphic reconstruction of the early Tertiary volcanic aquifer near the Kangerdlugssuaq-Blosseville Coast region of East Greenland

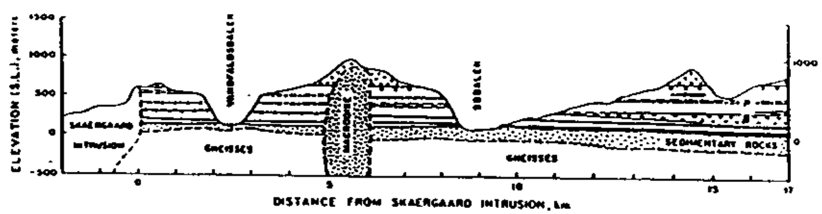


Figure VIII-2. Geology of the volcanic stratigraphy east of the Skaergaard intrusion. See Figure VIII-1 for legend.

At distances between 1.5 to 20 km east of the Skaergaard the lower portions of the aquifer are altered to low-grade mineral assemblages including groundmass chlorite + epidote + albite and drusy pore filling epidote + quartz + prehnite + microcline + calcite. In the lower portions of the aquifer epidote is absent at distances >20 km, and it occurs in the upper portions only where sills are abundant. Between 3 and 12 km from the Skaergaard $\delta^{18}O$ quartz is 8.3–10.5‰ and $\delta^{18}O$ epidote is 2.4–3.3‰, and at <2 km $\delta^{18}O$ quartz is 6.9–7.1‰ and $\delta^{18}O$ epidote is 0.7–1.1‰; the steep gradient in $\delta^{18}O$ between 2 to 3 km from the Skaergaard appears to correlate with increases in fluid inclusion temperatures from <250°C to 250-300°C near the intrusion (Figure VIII-4). Throughout the lower portions of the aquifer calculated values of $\delta^{18}O$ fluid in equilibrium with quartz are between 2 and -5‰, and freezing point depressions indicate that the aquifer fluids were <2 wt. % NaCl equivalent solutions (Figure VIII-3 & 4).

This investigation provides a basis for investigating the thermal and chemical consequences of stoping altered basaltic xenoliths into the gabbro magma chambers. For example, in the Miki Fjord Macrodike the lowest values of $\delta^{18}O$ plagioclase occur in centers of metabasalt xenoliths ($\delta^{18}O_{PLAG}$ = 3.1–4.2‰), whereas in gabbros without xenoliths $\delta^{18}O$ plagioclase is 5.5–5.8‰. Furthermore, in the xenolith-bearing layered gabbros of the Macrodike, samples taken several meters away from the nearest xenoliths have $\delta^{18}O_{PX}$= 4.4–5.1‰, whereas a sample taken from within 10 cm of a xenolith has $\delta^{18}O_{PX}$= 3.2‰. These observations, together with $\delta^{18}O$ basalt reported by Taylor and Forester (Jour. Pet. 1979), suggest that the Macrodike was intruded late relative to the regional mineralogic and isotopic alteration, and the altered basalts provided a lithologic reservoir of hydrated and ^{18}O depleted material that was locally stoped into and partially assimilated by the cooling macrodike magma.

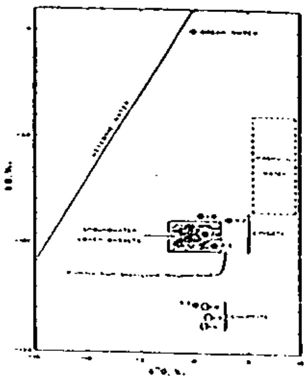
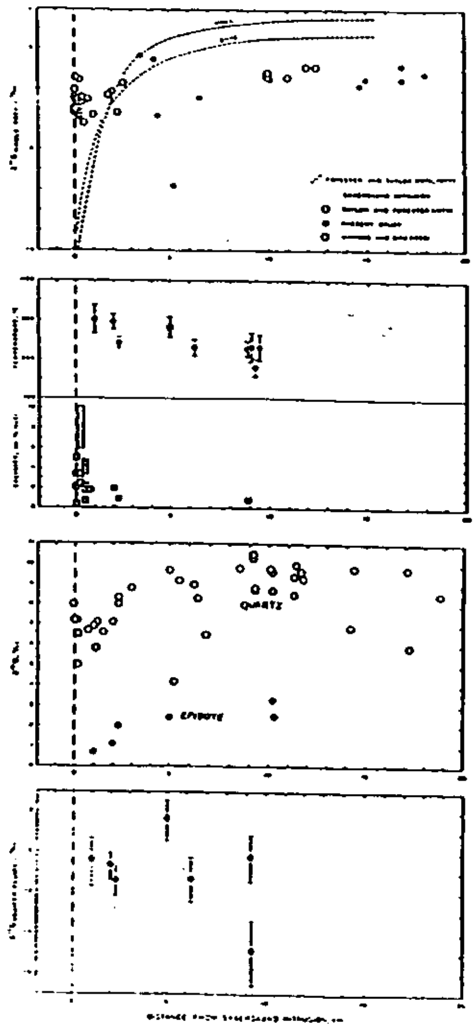


Figure VIII-3. Isotopic properties of epidote, chlorite and the groundwaters in the paleo-volcanic aquifer east of the Skaergaard intrusion.

Figure VIII-4. Oxygen isotope properties of the whole rock, quartz and epidote from the volcanic aquifer. Temperatures and fluid salinities are from fluid inclusion experiments on quartz crystals. The oxygen isotope properties of the aquifer fluids were determined from the isotopic fractionation of quartz and water.



IX. REFERENCES CITED

Abbott, D., and Deer, W.A., 1972, Geological investigations in East Greenland. Part 10 The gabbro cumulates of the Kap Edvard Holm Lower Layered Series: Medd. om Grønland, v. 190, 42 pp.

Bird, D. K., Rosing, M. T., Manning, C. E., and Rose, N. M, 1985, Geologic field studies of the Miki Fjord area, East Greenland: Geol. Soc. Denmark Bull., v. 34, p. 219-236.

Bird, D.K., Manning, C.E. and Rose, N.M., 1988, Hydrothermal alteration of Tertiary layered gabbros, East Greenland: Am. Jour. Sci., v. 288, p. 405–457.

Bird, D.K., Manning, C.E. and Rose, N.M., 1988b, Mineralogic and isotopic constraints on the regional hydrology of the Skaergaard magma-hydrothermal system, East Greenland: Geol.Soc.Am. Abstracts with Programs, v. 20, no. 7, p. A344.

Bridgwater, D., Davies, F. B., Gill, R. C. O., Gorman, B. E., Myers, J. S., Pedersen, S. and Taylor, P., 1979, Precambrian and Tertiary geology between Kangerdlugssuaq and Angmassalik, East Greenland: Rapp. Grønlands Geol. Unders., v. 83, 17 p.

Brooks, C. K., and Nielsen, T. F. D., 1982, The Phanerozoic development of the Kangerdlugssuaq area, East Greenland: Medd. om Grønland, Geosci., v. 9, 30 p.

Deer, W. A., 1976, Tertiary igneous rocks between Scoresby Sund and Kap Gustav Holm, East Greenland, in Escher, A. and Watt, W. S., eds., Geology of Greenland: Copenhagen, Geol. Survey of Greenland, p. 405–429.

Deer, W. A., and Abbott, D., 1965, Clinopyroxenes of gabbro cumulates of the Kap Edvard Holm complex, East Greenland: Mineralog. Mag., v. 34, p. 177–193

Elsdon, R., 1969, The structure and intrusive mechanism of the Kap Edvard Holm layered gabbro complex, East Greenland: Geol. Mag., v. 106, p. 45–56.

Forester, R.W. and Taylor, H.P., Jr., 1976, ^{18}O-depleted igneous rocks from the Tertiary complex of teh Isle of Mull, Scotland: Earth Planetary Sci. Letters, v. 32, p. 11-17.

Forester, R.W., and Taylor, H.P., Jr., 1977, $^{18}O/^{16}O$, D/H, and $^{13}C/^{12}C$ studies of the Tertiary igneous complex of Skye, Scotland: Am. Jour. Sci., v. 277, p. 136-177.

Myers, J.S., Bridgewater, D., and Gill, R.C.O, 1980, Mapping of Archaean, Mesozoic and Tertiary rocks between Watkins Bjerge and Angmagssalik (69° -65°50'N): Rapp. Grønlands Geol. Unders., v. 100, p. 86-90.

Rex, D.C., Gledhill, A.R., Brooks, C.K., and Steenfelt, A., 1979, A Rb-Sr whole rock age of 55 ± 7 m.y. from the Nualik plutonic centre, East Greenland: Rapp. Grønlands Geol. Unders., v. 95, p. 102-105.

Rose, N. M., 1989, Experimental and field studies of metasomatic mass-transfer in the system Na_2O - Al_2O_3 - CaO - SiO_2 - H_2O - HCl: Ph.D. dissertation, Stanford University, Stanford, Ca., 200 p.

Rose, N. M., and Bird, D. K., 1987, Prehnite-epidote phase relations in the Nordre Aputitêq and Krause Fjord intrusions, East Greenland: Jour. Petrology, v. 28, pp. 1193-1218.

Taylor, H. P., and Forester, R. W., 1979, An oxygen isotope study of the Skaergaard intrusion and its country rocks: A description of a 55-m.y. old fossil hydrothermal system: Jour. Petrology, 20, pp. 355-419.

Wager, L. R., 1934, Geological investigations in East Greenland. Part 1. General geology from Angmagssalik to Kap Dalton: Medd. om Grønland, v. 105, 46 p.

Wager, L.R., and Brown, G.M., 1967, Layered Igneous Rocks: San Francisco, W.H. Freeman, 588 p.

12. 1989 Lamont-Doherty Geological Observatory
Expedition to the Kangerdlugssuaq Area
Principal Investigator: Dr. Charles E. Lesher

Field Personnel: Charles E. Lesher
Miranda Fram
Minik Rosing
Janne Blichert-Toft

Dates In Field: August 5-September 6

Location: Mikl Fjord-Sodalen Region

Summary:
Attached: After Operations Report by Dr. Charles Lesher

1989 Lamont-Doherty Geological Observatory Expedition
to the Kangerdlugssuaq Area (68°15'N, 31°25'W)
East Greenland
Dr. Charles E. Lesher
Lamont-Doherty Geological Observatory
Columbia University

Field Personnel: Charles E. Lesher-PI/Expedition Leader (LDGO)
Miranda Fram (LDGO)
Minik Rosing (Geol. Mus., DK)
Janne Blichert-Toft (Univ. Copenhagen, DK)

Dates in field: August 5-September 6

Location: Mikl Fjord-Sodalen Region

Summary: Geological field investigations of the Miki Fjord and Vandfaldsdalen macrodykes were undertaken during August and early September of 1989. Fly camps were established at three locations in the Miki Fjord/Sodalen area and a fourth at Skaergaard. Helicopter positioning of these camps was provided (on a recharge bases) by Platinova Resources. Twin Otter flights between Iceland and Sodalen, East Greenland were provided by Flugfleg Nordurlands of Akureyri, Iceland. Daily communications via HF-SSB transceiver was maintained with the Platinova base camp located at the Sodalen airstrip.

From August 6 to August 24 a camp was established at 600m on the Eskimonaes segment of the Miki Fjord macrodyke. Members of this party included Miranda Fram (LDGO), Mark Brandriss (Stanford U.) and myself. We were joined there by Minik Rosing (Geol. Mus., DK) and Janne Blichert-Toft (U. Copenhagen) on August 20. Mark Brandriss departed on August 22. Detailed mapping and sampling of the intrusion and volcanic host rocks of the Miki Formation were undertaken during this period. Unusually low snow levels contributed to a more complete determination of the lateral and vertical extents of the gabbro body. Exposures in the vicinity of Peak 1010 demonstrate that portions of the banded gabbroic sequence are intruded by leucogabbro and may themselves represent metasomatized rafts of the volcanic host rock. Samples for petrographic, geochemical and isotopic study were collected to test this and competing hypotheses. Approximately 400m of the volcanic stratigraphy hosting the macrodyke was sampled.

A second fly camp was established at 580m on the west side of Vandfaldsdalen from August 24-August 28. From here we extended our sampling of the Lower Basalts to the base of the volcanic sequence. We also examined, but did not sample, outcrops of the Vandfaldsdalen macrodyke to the west of Sediment Ridge and along its northern and southern contacts at the head of Vandfaldsdalen.

A third fly camp was positioned on August 28 at Upper Issoeme. We remained at this location until September 3. Two Proterozoic mafic dikes cutting the macrodyke were mapped and sampled in detail. Leucogneiss and amphibolite of the basement were also sampled at a number of localities west of Issoeme for geochemical analysis. We returned to field check a number of macrodyke localities visited in 1987, and for which geochemical and isotopic data have been obtained. Traverses were made to the northeastern extension of the macrodyke and along the northeastern ridge leading to Peak 656m. A brief visit by Jorgen Taagholt (DK) and Kent Brooks (DK) was made on September 1. At that time we discussed with Kent Brooks opportunities for collaboration on proposed geochemical studies of the Lower basalts.

A short field excursion was made to Skaergaard from September 3-September 6. All primary field objectives were met; despite inclement weather experienced for most of the season. We wish to thank Platinova Resources for assisting us in our logistical operations.

Publications Resulting from L-DGO's East Greenland Studies:

The internal structure of the Mikl Fjord macrodyke. Rosing, M., Lesher, C.E. and Bird, D.K., 1987, Conference on East Greenland Tertiary Geology, Copenhagen (extended abstract, invited).

Experimental studies of the Tertiary macrodykes, Kangerdlugssuaq area, East Greenland. Lesher, C.E., Rosing M. and Bird, D.K., 1987, Conference on East Greenland Tertiary Geology, Copenhagen (extended abstract, invited).

Selective crustal contamination: An example from the Tertiary gabbroic macrodykes, Kangerdluggssuaq, East Greenland. Lesher, C.E., Blichert-Toft, J. and Rosing, M., 1988, EOS, 69, 521.

Kinetics of Sr and Nd isotope and chemical exchange between baslat and fusion products of continental crust. Lesher, C.E., 1988, Eos, 69, 1509.

Isotope and chemical exchange during dynamic mixing of magmas. Lesher, C.E., Blichert-Toft, J. and Rosing, M., 1989, EOS, 70, 499.

Physiochemistry of crustal contamination as exemplified by the Mikl Fjord macrodyke, central East Greenland. Blichert-Toft, J., Lesher, C.E. and Rosing, M., 1989 EOS, 70, 499.

Chemical modification of East Greenland Tertiary magmas by two-liquid interdiffusion. Rosing, M., Lesher, C.E., and Bird, D., 1989, Geology, 626-629.

Contrasting rates of chemical and isotopic exchange on mixing of magmas. Lesher, C.E., 1989 (submitted to Nature).

Emplacement, differentiation, and contamination of the Mikl Fjord macrodyke, Kangerdlugssuaq area, East Greenland. Lesher, C.E., Rosing, M., Bird, D. and Blichert-Toft, J. (in prep.).