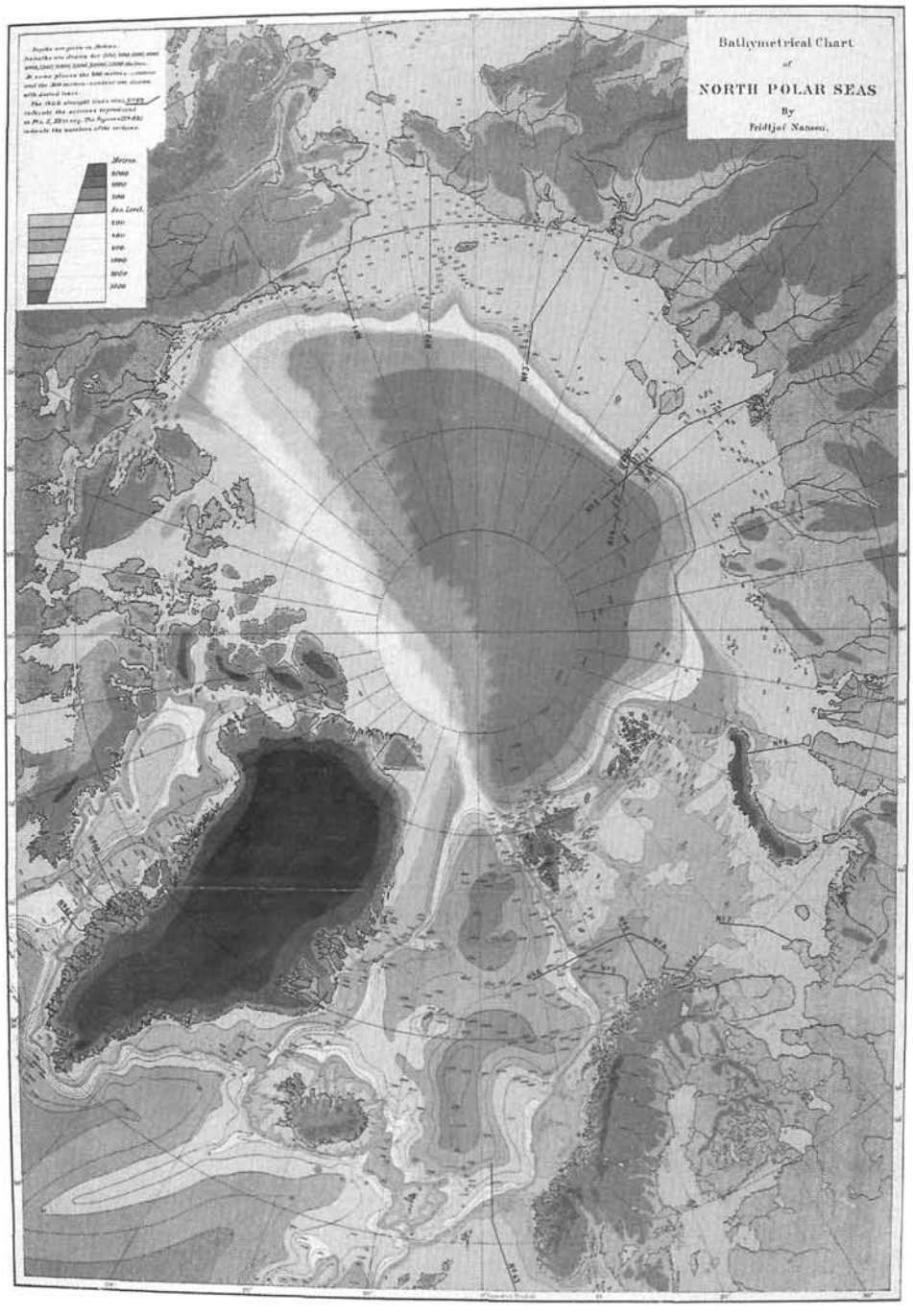
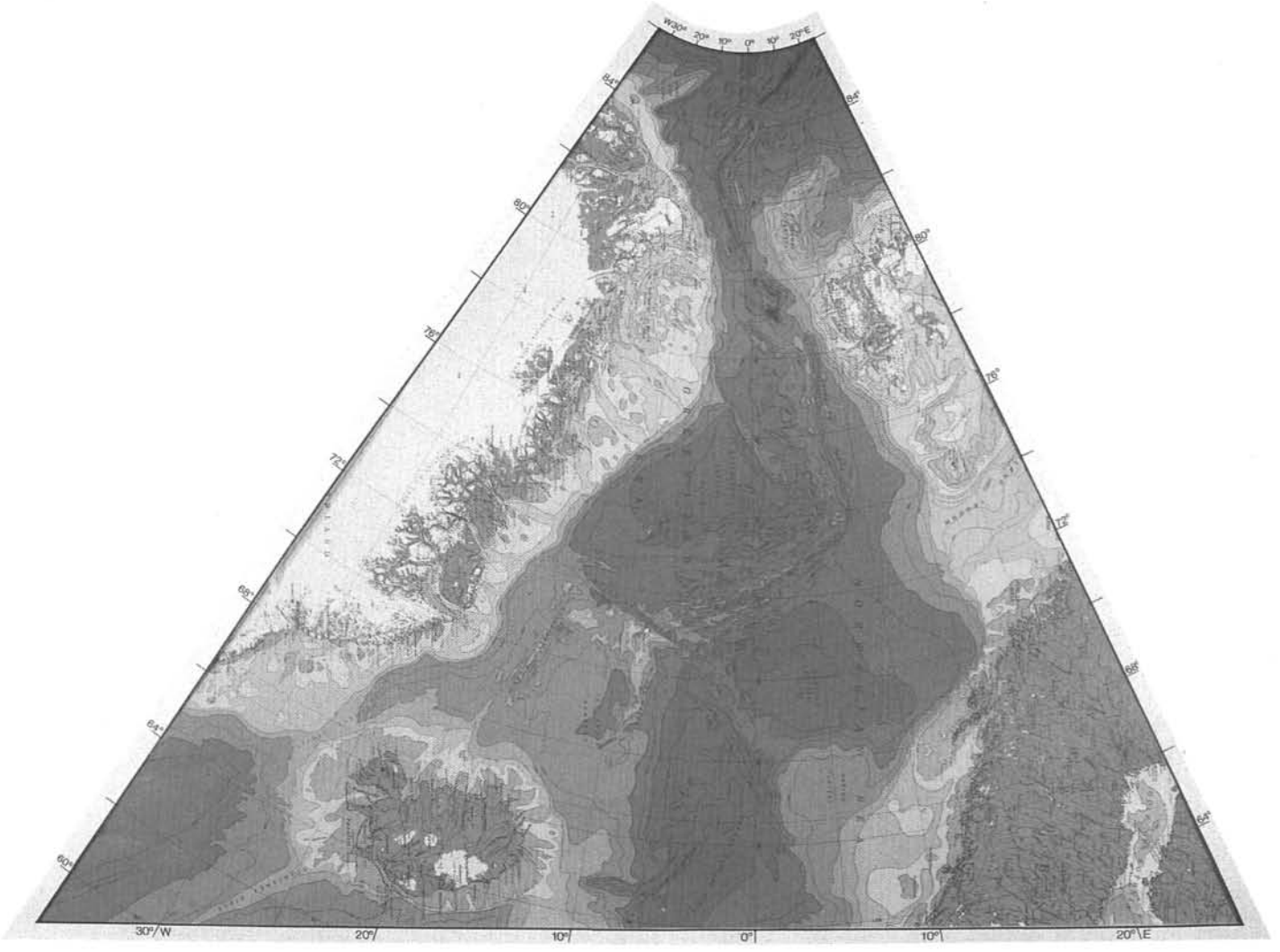


North Atlantic–Arctic Gateways

When Fridtjof Nansen, the famous Norwegian scientist and explorer, set course for the Arctic in 1893, exactly 100 years before Ocean Drilling Program Leg 151, on the then-modern polar research vessel *Fram*, he thought the Arctic Ocean was not deeper than shelf depths. Later he described Fram Strait as a shallow sill between the Arctic Ocean and the Norwegian-Greenland Sea. Based on the results of his expedition and the data of others, however, he was able to publish the first bathymetric map of these areas (Nansen, 1904) and showed both North Atlantic–Arctic Gateways: the Fram Strait and the Greenland-Scotland Ridge. The modern bathymetry (Perry et al., 1986) is given on the opposite page to provide a physiographic framework of the Leg 151 drill sites and for comparison with the Nansen map.


30°W
20°
10°
0°
10°
20°E
85°
80°
75°
70°
65°
60°

PROCEEDINGS OF THE OCEAN DRILLING PROGRAM

VOLUME 151

INITIAL REPORTS

NORTH ATLANTIC–ARCTIC GATEWAYS I

Covering Leg 151 of the cruises of the Drilling Vessel *JOIDES Resolution*,
St. John's Harbor, Newfoundland, to Reykjavik, Iceland, Sites 907–913,
24 July–24 September 1993

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Foreword

By the National Science Foundation

The National Science Foundation is proud to play a leading role in partnership with the U.S. oceanographic community in the operation and management of the Ocean Drilling Program (ODP). We are equally proud of the cooperation and commitment of our international partners, who contribute both financial and intellectual resources required to maintain the high quality of this unique program. The Ocean Drilling Program, like its predecessor, the Deep Sea Drilling Project (DSDP), is a model for the organization and planning of research to address global scientific problems that are of high priority internationally and of long-term interest to the scientific community and general public.

Major scientific themes guiding the development of specific drilling cruises range from determining the causes and effects of oceanic and climatic variability to understanding the circulation of fluids in the ocean crust and the resultant formation of mineral deposits. Although such studies are at the forefront of basic scientific inquiry into the processes that control and modify the global environment, they are equally important in providing the background for assessing man's impact on the global environment or for projecting resource availability for future generations.

The transition from the DSDP to the ODP was marked by a number of changes. The 471-foot *JOIDES Resolution,* which replaced the *Glomar Challenger,* has allowed larger scientific parties and the participation of more graduate students, a larger laboratory and technical capability, and operations in more hostile ocean regions. The *JOIDES Resolution* has drilled in all of the world's oceans, from the marginal ice regions of the Arctic to within sight of the Antarctic continent. Over 1,200 scientists and students from 26 nations have participated on project cruises. Cores recovered from the cruises and stored in ODP repositories in the United States and Europe have provided samples to an additional 1,000 scientists for longer term post-cruise research investigations. The downhole geochemical and geophysical logging program, unsurpassed in either academia or industry, is providing remarkable new data with which to study the Earth.

In 1994, NSF and our international partners renewed our commitment to the program for its final phase. Of the 20 countries that supported ODP initially, only one, Russia, has been unable to continue for financial reasons. As the reputation and scientific impact of the program continue to grow internationally, we hope to add additional members and new scientific constituencies. This global scientific participation continues to assure the program's scientific excellence by focusing and integrating the combined scientific knowledge and capabilities of its member nations.

We wish the program smooth sailing and good drilling!

Neal Lane
Director
National Science Foundation

Arlington, Virginia

Foreword

By Joint Oceanographic Institutions, Inc.

This volume presents scientific and engineering results from the Ocean Drilling Program (ODP). The papers presented here address the scientific and technical goals of the program, which include providing a global description of geological and geophysical structures including passive and active margins and sediment history, and studying in detail areas of major geophysical activity such as mid-ocean ridges and the associated hydrothermal circulations.

The Ocean Drilling Program, an international activity, operates a specially equipped deep-sea drilling ship, the *JOIDES Resolution* (Sedco/BP 471), which contains state-of-the-art laboratories, equipment, and computers. The ship is 471 feet (144 meters) long, is 70 feet (21 meters) wide, and has a displacement of 18,600 short tons. Her derrick towers 211 feet (64 meters) above the waterline, and a computer-controlled dynamic-positioning system stabilizes the ship over a specific location while drilling in water depths up to 27,000 feet (8230 meters). The drilling system collects cores from beneath the seafloor with a derrick and drawworks that can handle 30,000 feet (9144 meters) of drill pipe. More than 12,000 square feet (1115 square meters) of space distributed throughout the ship is devoted to scientific laboratories and equipment. The ship sails with a scientific and technical crew of 51 and a ship's crew (including the drill crew) of 62. The size and ice-strengthening of the ship allow drilling in high seas and ice-infested areas as well as permit a large group of multidisciplinary scientists to interact as part of the scientific party.

Logging, or measurements in the drilled holes, is an important part of the program. ODP provides a full suite of geochemical and geophysical measurements for every hole deeper than 1300 feet (400 meters). For each such hole, there are lowerings of basic oil-industry tools: nuclear, sonic, and electrical. In addition, a borehole televiewer is available for imaging the wall of the hole, a 12-channel logging tool provides accurate velocity and elastic property measurements as well as sonic waveforms for spectral analysis of energy propagation near the wall of the hole, and a vertical seismic profiler can record reflectors from below the total depth of the hole.

The management of the Ocean Drilling Program involves a partnership of scientists and governments. International oversight and coordination are provided by the ODP Council, a governmental consultative body of the partner countries, which is chaired by a representative from the United States National Science Foundation. The ODP Council periodically reviews the general progress of the program and discusses financial plans and other management issues. Overall scientific and management guidance is provided to the operators of the program by representatives from the group of institutions involved in the program, called the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES).

The Executive Committee (EXCOM), made up of the administrative heads of the JOIDES institutions, provides general oversight for ODP. The Planning Committee (PCOM), with its advisory structure, is made up of working scientists and provides scientific advice and detailed planning. PCOM has a network of panels and working groups that screen drilling proposals, evaluate instrumentation and measurement techniques, and assess geophysical-survey data and other safety and siting information. PCOM uses the recommendations of the panels and committees to select drilling targets, to specify the location and major scientific objectives of each two-month drilling segment or leg, and to provide the science operator with nominations for co-chief scientists.

Joint Oceanographic Institutions, Inc. (JOI), a nonprofit consortium of U.S. oceanographic institutions, serves as the National Science Foundation's prime contractor for ODP. JOI is responsible for seeing that the scientific objectives, plans, and recommendations of the JOIDES committees are translated into scientific operations consistent with scientific advice and budgetary constraints. JOI subcontracts the operations of the program to two universities: Texas A&M University and Lamont-Doherty Earth Observatory of Columbia University. JOI is also responsible for managing the U.S. contribution to ODP.

Texas A&M University (TAMU) serves as science operator for ODP. In this capacity, TAMU is responsible for planning the specific ship operations, actual drilling schedules, and final scientific rosters, which are developed in close cooperation with PCOM and the relevant panels. The science operator also ensures that adequate scientific analyses are performed on the cores by maintaining the shipboard scientific laboratories and computers and by providing logistical and technical support for shipboard scientific teams. Onshore, TAMU manages scientific activities after each leg, is curator for the cores, distributes samples, and coordinates the editing and publication of scientific results.

Lamont-Doherty Earth Observatory (LDEO) of Columbia University is responsible for the program's logging operation, including processing the data and providing assistance to scientists for data analysis. The ODP Data Bank, a repository for geophysical data, is also managed by LDEO.

Core samples from ODP and the previous Deep Sea Drilling Project are stored for future investigation at four sites: ODP Pacific and Indian Ocean cores at TAMU, DSDP Pacific and Indian Ocean cores at the Scripps Institution of Oceanography, ODP and DSDP Atlantic and Antarctic cores through Leg 150 at LDEO, and ODP Atlantic and Antarctic cores since Leg 151 at the University of Bremen, Federal Republic of Germany.

Scientific achievements of ODP include new information on early seafloor spreading and how continents separate and the margins evolve. The oldest Pacific crust has been drilled and sampled. We have new insights into glacial cycles and the fluctuations of ocean currents throughout geological time. Many of the scientific goals can be met only with new technology; thus the program has focused on engineering as well as science. To date, ODP engineers have demonstrated the capability to drill on bare rock at mid-ocean-ridge sites and have developed techniques for drilling in high-temperature and corrosive regions typical of hydrothermal vent areas. A new diamond coring system promises better core recovery in difficult areas.

In addition, ODP is cooperating closely with other geological and geophysical programs; for example, in 1991 the first hole was drilled by ODP for emplacement of a seismometer near Hawaii for the Ocean Seismic Network. JOI is pleased to have been able to play a facilitating role in the Ocean Drilling Program and its cooperative activities, and we are looking forward to many new results to come.

D. James Baker
President
Joint Oceanographic Institutions, Inc.

Washington, D.C.

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France, Institut Français de Recherche pour l'Exploitation de la Mer

Japan, University of Tokyo, Ocean Research Institute

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VOLUME 151—INITIAL REPORTS

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CD-ROMs

This volume contains two CD-ROMs. The first, "*Initial Reports,* Vol. 151," includes an electronic version of the volume in Adobe Acrobat, as well as data files. The Acrobat Reader is included for installation on the following: a (386-based or higher) personal computer running Windows 3.1 or a Macintosh computer (68020 or later processor). Also on this CD is a data directory with ASCII copies of data tables too large to print in the volume.

You are strongly urged to refer to the READ.ME file for more information.

***Initial Reports,* Vol. 151, Directory Structure:**

- Acrobat
  - Mac
  - Win
- Chapters (Acrobat viewing files linked for viewing)
  - Figures
  - Index
- Data (ASCII data files of tables within the volume)
  - Index (index properties)
  - Shear (shear strength)
  - Thermal (thermal conductivity)
  - Velocity
- VCD (Acrobat viewing files of visual core description forms by site, with core photographs)

A second CD-ROM, entitled "Log and Core Data," contains dept-shifted and processed logging data, as well as shipboard gamma-ray attenuation porosity evaluator (GRAPE), index property, magnetic susceptibility, and natural gamma data of cores collected on board *JOIDES Resolution* during Leg 151. This CD was produced by the Borehole Research Group at Lamont-Doherty Earth Observatory, the wireline logging operator for ODP.

Log and Core Data Directory Structure:

- GENERAL INFORMATION directory
  - Format documentation file
  - INDEX file
  - Software documentation file
- LOGGING DATA directory
  - README document
  - HOLE NUMBER subdirectory
    - Conventional logging subdirectory
      - General information subdirectory
        - Acronyms and units file
        - Processing history of logging data file (info.doc and/or infoswf.doc, geochem.doc)
      - Logging data subdirectory
        - Individual tool data files
      - Geochemical logs subdirectory
        - Geochemical data in ASCII format files
      - FMS and dipmeter data subdirectory
        - Dipmeter file(s) in ASCII format
        - FMS images in portable bit map (PBM–8 bit binary) format subdirectory
        - 1:1 ratio image raster files (every 10 m) subdirectory
          - Data files
          - Raster documentation file
        - 1:10 ratio image raster files (every 100 m) subdirectory
          - Data files
          - Raster documentation file
- CORE DATA directory
  - README document
  - LEG directory
    - GRAPE documentation file
    - Index property documentation file
    - Magnetic susceptibility documentation file
    - Natural gamma documentation file
    - SITE NUMBER subdirectory
      - GRAPE data file
      - INDEX PROPERTY data file
      - MAGSUS data file
      - NATURAL GAMMA data file

The above structure is identical for each site and/or hole.

The INDEX file contains a summary of all the files loaded on the CD-ROM. The software documentation file in the GENERAL INFORMATION directory contains information about which software packages work best to import portable bit map (PBM–8 bit binary) raster files. It also includes network sources for the graphics software and data compression information. The README file gives information on whom to contact with any questions about the production of or data on the CD-ROM.

All of the ASCII files (basic log, dipmeter, sonic waveforms, GRAPE, index property, magnetic susceptibility, and natural gamma files) are TAB delimited for compatibility with most spreadsheet and database programs. Holes that have more than one logging pass with the

same tools are labeled Pass 1, Pass 2, etc. Holes that have long logging runs are often divided into TOP, MIDDLE, and BOTTOM sections. This is noted by adding "top," "mid," or "bot" to the data file names where space permits or a "t," "m," or "b" where there is room for only one character.

In the FMS-PBM format subdirectory are two subdirectories: 1:1 ratio with maximum 10-m-long image raster files and 1:10 ratio with maximum 100-m-long image raster files. The image raster files are named according to their depth intervals. The raster documentation files contain image file parameter information necessary for use with most graphic software packages.

Summary of Log Data, Leg 151
- Hole 907A:
  - Conventional logs
  - FMS data
  - Geochemical logs (element and oxide weight %)
- Hole 908A:
  - Conventional logs
  - FMS data
- Hole 909C:
  - Conventional logs
  - FMS data
- Hole 910C
  - Conventional logs
- Hole 911A:
  - Conventional logs
  - FMS data
  - Geochemical logs (element and oxide weight %)

Summary of Core Data, Leg 151
- Hole 907A:
  - GRAPE data
    - grape_1.dat: cores 1–18
    - grape_2.dat: cores 19–26
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 908A:
  - GRAPE data
    - grape_1.dat: cores 1–18
    - grape_2.dat: cores 19–32
    - grape_3.dat: cores 33–37
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 908B:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 909A:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 909B:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 909C:
  - GRAPE data
    - grape_1.dat: cores 1–29
    - grape_2.dat: cores 31–50
    - grape_3.dat: cores 51–73
    - grape_4.dat: cores 74–103
  - Index property data
  - MAGSUS data
    - magsus_1.dat: cores 1–60
    - magsus_2.dat: cores 61–103
  - Natural gamma data
- Hole 910A:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 910B:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 910C:
  - GRAPE data
    - grape_1.dat: cores 1–35
    - grape_2.dat: cores 36–53
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 910D:
  - GRAPE data
  - MAGSUS data
  - Natural gamma data
- Hole 911A:
  - GRAPE data
    - grape_1.dat: cores 1–17
    - grape_2.dat: cores 18–35
    - grape_3.dat: cores 36–53
  - Index property data
  - MAGSUS data
  - Natural gamma data
- Hole 911B:
  - GRAPE data
  - Index property data
  - MAGSUS data
- Hole 911C:
  - GRAPE data
  - MAGSUS data
- Hole 912A:
  - GRAPE data
  - Index property data
  - MAGSUS data
  - Natural gamma data

Hole 912B:
- GRAPE data
- Index property data
- MAGSUS data
- Natural gamma data

Hole 913A:
- GRAPE data
- Index property data
- MAGSUS data
- Natural gamma data

Hole 913B:
- GRAPE data
  - grape_1.dat: cores 1–34
  - grape_2.dat: cores 35–48
  - grape_3.dat: cores 49–50
- Index property data
- MAGSUS data
- Natural gamma data

ACKNOWLEDGMENTS

The quest to understand the evolution of the modern global environment and the modes of global change is presently attracting the efforts of many scientific disciplines and nations. Few areas of the globe have greater influence on our modern natural environment than the polar and subpolar deep-sea basins of the Northern Hemisphere. In preparing and executing Leg 151 of the Ocean Drilling Program (ODP), we therefore were able to draw upon a large number of individuals and institutions.

The drill sites planned in the Norwegian-Greenland Sea and in the Arctic Ocean required scientific research licenses, which were granted from Danish, Icelandic, and Norwegian authorities. The Ocean Drilling Program and JOIDES advisory structure, with their scientific and technical committees—in particular the Detailed Planning Group (DPG) for the "North Atlantic-Arctic Gateways" (NAAG) under the chairmanship of W. Ruddiman—as well as the ODP Data Bank, were of great help in selecting the sites for solving the various scientific objectives of this cruise and in assisting us to assemble the necessary scientific documentation for the drill sites. Drill site proposals had been submitted by Scandinavian, German, English, and North American researchers.

We were particularly grateful that the Finnish ice escort vessel *Fennica* was made available to assist the *JOIDES Resolution* during drilling close to the ice margin. The collaboration with the *Fennica*, under the command of Captain Jukka Kyröhonka of the National Board of Navigation of Finland, was very good and provided for sufficient on-site information about the ice situation to guarantee safe drilling. We also were supplied with specific ice forecasts and observations by the Nansen Environmental Remote Sensing Center (NERSC) in Bergen, the ice observers on board the *Fennica* from the Scott Polar Research Institute, and the German Marine Weather Service.

The geophysical and geological database necessary for the drilling was made available by colleagues from a number of American (LDEO–Lamont-Doherty Earth Observatory), Danish (GGU–Geological Survey of Greenland), German (BGR–Geological Survey of the Federal Republic; Department of Geophysics of Kiel University; AWI–Alfred Wegner Institute for Polar and Marine Research; GEOMAR–Research Center for Marine Geosciences), and Norwegian (Institute of Solid Earth Physics, University of Bergen; NPI–Norwegian Polar Institute; Department of Geology, University of Oslo) institutions.

The harsh working conditions of the Arctic and subarctic regions were, despite the Arctic summer, a particular challenge to the technicians of the Ocean Drilling Program and to the crew of the *JOIDES Resolution*. Both groups—under the able leadership of Captain Tom Ribbens of the *JOIDES Resolution*, Bob Caldow of SEDCO-Schlumberger, and Gene Pollard of ODP—made every effort to guarantee the scientific success of this expedition.

The scientific party of Leg 151 expresses its gratitude and appreciation for the efforts of all who supported us in preparing and conducting this expedition. Leg 151 brought a scientific drilling vessel into higher latitudes than ever before and there-

fore was considered a particularly challenging venture. In 1993, DSDP/ODP also celebrated its 25th anniversary.

We dedicate this volume to the memory of Fridtjof Nansen, the famous Norwegian polar explorer and scientist who in 1893, 100 years before ODP Leg 151, departed on his epic expedition on the *Fram* to study the Transpolar Drift of the Arctic sea ice cover and who published the first reasonably well documented bathymetric map of the North Atlantic-Arctic Gateways (see Frontispiece). Leg 151 was the first serious effort toward realization of the Nansen Arctic Drilling (NAD) program, which has the aim to decipher the tectonic and paleoenvironmental history of the Arctic abyss by means of deep-sea drilling techniques.

Fridtjof Nansen as a young man.