

PROCEEDINGS OF THE OCEAN DRILLING PROGRAM

VOLUME 116 INITIAL REPORTS DISTAL BENGAL FAN

Covering Leg 116 of the cruises of the Drilling Vessel *JOIDES Resolution*,
Colombo, Sri Lanka, to Colombo, Sri Lanka, Sites 717-719,
2 July 1987-19 August 1987

James R. Cochran, Dorrik A. V. Stow, Christian Auroux, Kazuo Amano,
Peter S. Balson, Jacques J. Boulegue, Garrett W. Brass, Jeffrey Corrigan,
Stefan Gartner, Stuart Hall, Silvia Iaccarino, Toshio Ishizuka,
Irena Kaczmarek, Heidemarie Kassens, Gregory Leger,
Franca Proto Decima, Challagundla Venkata Raman, William W. Sager,
Kozo Takahashi, Thomas L. Thompson, Jean-Jaques Tiercelin,
Mark R. Townsend, Andreas Wetzel, N. P. Wijayananda, Colin Williams
Participating Scientists

Christian Auroux
Shipboard Staff Scientist

William W. Sager
Shore-based Staff Scientist

Prepared by the
OCEAN DRILLING PROGRAM
Texas A&M University

William R. Winkler
Volume Editor

in cooperation with the
NATIONAL SCIENCE FOUNDATION
and
JOINT OCEANOGRAPHIC INSTITUTIONS, INC.

This publication was prepared by the Ocean Drilling Program, Texas A&M University, as an account of work performed under the international Ocean Drilling Program, which is managed by Joint Oceanographic Institutions, Inc., under contract with the National Science Foundation. Funding for the program was provided by the following agencies at the time of this cruise:

Department of Energy, Mines and Resources (Canada)

Deutsche Forschungsgemeinschaft (Federal Republic of Germany)

Institut Français de Recherche pour l'Exploitation de la Mer (France)

National Science Foundation (United States)

Natural Environment Research Council (United Kingdom)

University of Tokyo, Ocean Research Institute (Japan)

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, the participating agencies, Joint Oceanographic Institutions, Inc., Texas A&M University, or Texas A&M Research Foundation.

It is recommended that reference to the whole or to part of this volume be made in one of the following forms, as appropriate:

Cochran, J. R., Stow, D.A.V., et al., 1989. *Proc. ODP, Init. Repts.*, 116: College Station, TX (Ocean Drilling Program).

Shipboard Scientific Party, 1989. Site 717: Bengal Fan. In Cochran, J. R., Stow, D.A.V., et al., 1988. *Proc. ODP, Init. Repts.*, 116: College Station, TX (Ocean Drilling Program),

Effective Publication Dates of ODP *Proceedings*

According to the International Code of Zoological Nomenclature, the date of publication of a work and of a contained name or statement affecting nomenclature is the date on which the publication was mailed to subscribers, placed on sale, or when the whole edition is distributed free of charge, mailed to institutions and individuals to whom free copies are distributed. The mailing date, *not the printed date*, is the correct one.

The mailing dates of recent *Proceedings of the Ocean Drilling Program* are as follows:

Volume 108 (*Initial Reports*): March 1988

Volumes 106/109/111 (*Initial Reports*): March 1988

Volume 110 (*Initial Reports*): April 1988

Volume 112 (*Initial Reports*): August 1988

Volume 113 (*Initial Reports*): September 1988

Volume 114 (*Initial Reports*): November 1988

Distribution

Copies of this publication may be obtained from Publications Distribution Center, Ocean Drilling Program, 1000 Discovery Drive, College Station, Texas 77840. Orders for copies will require advance payment. See current ODP publication list for price and availability of this publication.

Printed January 1989

ISSN 0884-5883

Foreword

By the National Science Foundation

The scientists of the Ocean Drilling Program (ODP) have embarked on what could prove to be one of the most important earth science initiatives of the decade—an initiative rivaling in scope and impact the exploration of the frontiers of outer space. The program explores our planet's last frontier—the Earth's structure and history as it is revealed beneath the oceans. The scope of the program's scientific goals excites the imagination, challenges the intellect, and enhances the spirit of cooperation among peoples in countries around the world.

Between 1872 and 1876, HMS *Challenger* undertook the world's first major oceanographic expedition. That expedition greatly expanded man's knowledge of the world's oceans and revolutionized our ideas about planet Earth. From 1968 to 1983, another ship named *Challenger* logged more than 375,000 miles on 96 voyages across every ocean for the Deep Sea Drilling Project (DSDP), operated by Scripps Institution of Oceanography. Among the project's many remarkable discoveries were the confirmation of seafloor spreading and the establishment of the relative youth of the seafloor, thus verifying the dynamic and changing nature of the Earth's crust.

Today, the Ocean Drilling Program, which began in 1983, brings new resources to bear on scientific ocean drilling. A new drillship is in operation—the *JOIDES Resolution*—one of the world's most modern and best equipped drillships with enhanced capability for drilling and coring in polar areas and rough weather, expanded laboratory space, facilities for more scientists, and a major drill-hole logging program. The name of the ship was derived from the international scientific partnership that directs the program—the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES)—and from the flagship of Captain Cook's second voyage to the Pacific Ocean in the late 18th century. Texas A&M University is responsible for science operations in the program, and Lamont-Doherty Geological Observatory is responsible for the logging program.

The Ocean Drilling Program truly has international participation. In 1975, the International Phase of Ocean Drilling began with member nations—the U.S.A., U.S.S.R., the Federal Republic of Germany, Japan, the United Kingdom, and France—all providing funds and scientific guidance for the project. Today, ODP partners include the U.S.A., Canada, France, the Federal Republic of Germany, Japan, the United Kingdom, and the European Science Foundation, which represents Sweden, Finland, Norway, Iceland, Denmark, Belgium, the Netherlands, Spain, Switzerland, Italy, Greece, and Turkey.

The National Science Foundation, with funds contributed by the United States and international partners, supports the scientific operations and planning for the ODP through a contract with Joint Oceanographic Institutions, Inc. (JOI).

The information gained by the program leads to a better understanding of the Earth and its dynamic processes. Drilled sediment cores and logs reveal clues to past climatic history and tie into parallel studies of paleoclimates from glacial ice cores drilled on the continents. Understanding these sediment cores will enable scientists to complete the map of major geologically active regions of the Earth, and to identify processes that lead to dynamic change such as earthquakes, volcanic eruptions, and mountain and continental growth. We are far from being able to predict such changes accurately now; but with the new tools and understanding, the accuracy of such predictions can be improved. This better understanding of the Earth's system(s) will allow us to identify regions of potential mineral and energy resource development, an issue of worldwide human interest. The Ocean Drilling Program is not in itself aimed at finding resources, but the knowledge of the Earth's processes that is gained through such a basic research program will inevitably provide pieces of information required for such resource discovery and exploitation.

The program is fully under way in its aim to further the understanding of the Earth's dynamic systems. People of our planet will benefit directly and indirectly from this research in both their daily living and work activities. This multinational endeavor will perhaps foster other cooperative efforts in science or among societies. The Ocean Drilling Program has distinguished ancestors in the original *Resolution* and *Challenger* expeditions and the Deep Sea Drilling Project. The National Science Foundation is proud to be playing a leading role in this program, and we are looking forward to significant and innovative science for many years to come.



Erich Bloch
Director
National Science Foundation

Washington, D.C.

Foreword

By Joint Oceanographic Institutions, Inc.

This volume presents results from the Ocean Drilling Program (ODP), where scientists use a specially equipped ocean drilling ship to sample and measure the properties of the submerged part of the Earth's crust. These data are then synthesized with other information to yield new insights into earth processes.

These results address the scientific goals of the program, which include providing a global description of geological and geophysical structures and materials, studying in detail areas of major geophysical activity such as mid-ocean ridges and the associated hydrothermal circulations, and studying passive and active continental margins. In addition, the ODP data support the study of sea-level and ocean-circulation changes, the effects of the Earth's orbital variations on climate, and the study of processes and mechanisms of evolution from the biological records in the cores which are recovered from drilling.

The Ocean Drilling Program is a partnership of scientists and governments. Overall scientific policy and management guidance is provided by Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), which consists of committees and panels made up of representatives of the participating institutions and other scientific and engineering experts. The JOIDES Executive Committee (EXCOM) provides general oversight; the JOIDES Planning Committee (PCOM) is the focal point for all scientific planning for the ODP and is key to the scientific success of the program.

The PCOM has a network of panels and working groups which screen drilling proposals, evaluate instrumentation and measurement techniques, and assess geophysical survey data and other safety and siting information. PCOM uses the recommendations of these panels and committees to select drilling targets, to specify the major scientific objectives of each two-month drilling segment or leg, and to provide the science operator with nominations for co-chief scientists. The science operator, Texas A&M University, in turn is responsible for planning the detailed ship's operations, actual drilling schedules, and final scientific rosters, which are developed in close cooperation with PCOM and the cognizant panels.

Many of the scientific goals can be met only with new technology. Thus the program has identified engineering goals, which include the ability to start a hole and to core on bare rock at mid-ocean ridge sites, to drill in high-temperature and corrosive regions typical of hydrothermal areas, and to core in high latitudes with minimum interference from high seas and sea ice. To meet these needs, the program operates a specially equipped drillship, the *JOIDES Resolution*, which contains laboratories and equipment that are state-of-the-art, and carries a major new logging program.

The ship, registered as SEDCO/BP 471 after her owners and her length in feet (144 meters), is 70 feet (21 meters) wide, and has a displacement of 16,595 long tons. Her derrick towers 200 feet (61 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 50 and a ship's crew of 65.

Logging is a major part of the overall operation. The program 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 televiwer is available for imaging the well-bore wall, 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 well bore, and a vertical seismic profiler records reflectors from below the total depth of the hole.

Texas A&M University serves as science operator for the Ocean Drilling Program. In this capacity, they operate and staff the drillship to collect cores from JOIDES-designated sites from around the world. The science operator also ensures that adequate scientific analyses are performed on the cores by maintaining the shipboard scientific laboratories and by providing logistical and technical support for shipboard scientific teams. Onshore, Texas A&M manages scientific activities after each leg, is curator for the cores, distributes samples, and coordinates the editing and publication of the scientific results. Lamont-Doherty Geological Observatory (LDGO) of Columbia University manages the program's logging operations, which include processing the data and provision of assistance to scientists in data analysis. The ODP Data Bank, a repository for geophysical data, is also managed by LDGO. Core samples from ODP and the previous Deep Sea Drilling Project are stored for future investigation at three sites: ODP Pacific and Indian Ocean cores at Texas A&M University, ODP and DSDP Atlantic and Antarctic cores at Lamont-Doherty Geological Observatory, and DSDP Pacific and Indian Ocean cores at Scripps Institution of Oceanography.

International oversight and coordination are provided by the ODP Council, a governmental consultative body of partner country representatives, chaired by the United States, which periodically reviews the general progress of the program and discusses financial plans and other management issues. Joint Oceanographic Institutions, Inc., a nonprofit consortium of U.S. oceanographic institutions, serves as the National Science Foundation's prime contractor and manages the ODP. JOI is responsible for seeing that the scientific objectives and plans are translated into scientific operations consistent with JOIDES recommendations and budgetary constraints.

Scientific achievements of the ODP already include new data on early seafloor spreading and how continents separate and their margins evolve. We have new insight into glacial cycles and the fluctuations of currents throughout geological time. Technical achievements include the first bare-rock coring, and logging data more accurate and complete than ever before. JOI is pleased to have played a facilitating role in the Ocean Drilling Program.



D. James Baker
President
Joint Oceanographic Institutions, Inc.

Washington, D.C.

OCEAN DRILLING PROGRAM

MEMBER ORGANIZATIONS OF THE JOINT OCEANOGRAPHIC INSTITUTIONS FOR DEEP EARTH SAMPLING (JOIDES):

University of California at San Diego, Scripps Institution of Oceanography

Columbia University, Lamont-Doherty Geological Observatory

University of Hawaii, Hawaii Institute of Geophysics

University of Miami, Rosenstiel School of Marine and Atmospheric Science

Oregon State University, College of Oceanography

University of Rhode Island, Graduate School of Oceanography

Texas A&M University, Department of Oceanography

University of Texas at Austin, Institute for Geophysics

University of Washington, College of Ocean and Fishery Sciences

Woods Hole Oceanographic Institution

Canada/Australia Consortium for the Ocean Drilling Program, Department of Energy, Mines and Resources (Canada) and Department of Primary Industries and Energy (Australia)

European Science Foundation Consortium for Ocean Drilling (ECOD), Belgium, Denmark, Finland, Iceland, Italy, Greece, the Netherlands, Norway, Spain, Sweden, Switzerland, and Turkey

Federal Republic of Germany, Bundesanstalt für Geowissenschaften und Rohstoffe

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

Japan, University of Tokyo, Ocean Research Institute

United Kingdom, Natural Environment Research Council

PRIME CONTRACTOR

Joint Oceanographic Institutions, Inc.
Washington, D.C.

Thomas E. Pyle
Director, Ocean Drilling Programs

OPERATING INSTITUTION

College of Geosciences
Texas A&M University
College Station, Texas

Melvin Friedman, Principal Investigator

OCEAN DRILLING PROGRAM

Philip D. Rabinowitz
Director

Louis E. Garrison
Deputy Director

Sylvia Cecile DeVoge
Administrator

Audrey W. Meyer, Manager
Science Operations

Barry Harding, Manager
Engineering and Drilling Operations

Russell B. Merrill, Curator and Manager
Science Services

Robert E. Olivas, Manager
Technical and Logistics Support

LOGGING OPERATOR

Borehole Research Group
Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York

Roger N. Anderson, Head

PARTICIPANTS ABOARD JOIDES RESOLUTION FOR LEG 116

James R. Cochran
Co-Chief Scientist
*Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964*

Dorrik A. V. Stow
Co-Chief Scientist
*Department of Geology
University of Nottingham
University Park
Nottingham NG7 2RD
United Kingdom*

Christian Auroux
ODP Staff Scientist/Physical Properties Specialist
*Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, Texas 77840*

William W. Sager
ODP Staff Scientist/Paleomagnetist
*Department of Oceanography
Texas A&M University
College Station, Texas 77843*

Kazuo Amano
Sedimentologist
*Department of Earth Sciences
Ibaraki University
Bunkyo 2-1-1
Mito 310
Japan*

Peter S. Balson
Sedimentologist
*British Geological Survey
Keyworth
Nottingham NG12 5GG
United Kingdom*

Jacques J. Boulegue
Inorganic Geochemist
*Laboratoire de Géochimie
Université Pierre et Marie Curie
4 Place Jussieu
75252 Paris Cedex 05
France*

Garrett W. Brass
Sedimentologist
*Division of Marine Geology and Geophysics
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098*

Jeffrey Corrigan
Sedimentologist
*Department of Geological Sciences
University of Texas at Austin
Austin, Texas 78713-7909*

Stefan Gartner
Paleontologist (nannofossils)
*Department of Oceanography
Texas A&M University
College Station, Texas 77843*

Stuart Hall
Paleomagnetist
*Department of Geosciences
University of Houston
Houston, Texas 77004*

Silvia M. Iaccarino
Paleontologist (foraminifers)
*Istituto di Géologia
Università degli Studi di Parma
Via delle Scienze
43100 Parma
Italy*

Toshio Ishizuka
Organic Geochemist
*Ocean Research Institute
University of Tokyo
1-15-1 Minami-dai, Nakano-Ku
Tokyo 164
Japan*

Irena Kaczmarzka
Paleontologist (diatoms)
*Department of Geology
Mount Allison University
Sackville, New Brunswick E0A 3C0
Canada*

Heidemarie Kassens
Physical Properties Specialist
*Geologisches-Paläontologisches Institut und Museum
Universität Kiel
Olshausenstrasse 40
D-2300 Kiel
Federal Republic of Germany*

Gregory Leger
Logging Scientist
*Department of Oceanography
Dalhousie University
Halifax, Nova Scotia B3H 4J1
Canada*

Franca Proto-Decima
Paleontologist (foraminifers)
*Istituto di Géologia
Università di Padova
via Giotto, 1
35137 Padova
Italy*

C. V. Raman
Sedimentologist
*Department of Geology
Andhra University
Visakhapatnam 530003
India*

Kozo Takahashi
Paleontologist (radiolarians)
*Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543*

Thomas L. Thompson
Petroleum Geologist
*Colorado School of Mines
Golden, Colorado 80401*

Jean-Jacques Tiercelin
Sedimentologist
*GIS Océanologie et Géodynamique
Université de Bretagne Occidentale
29287 Brest Cedex
France*

Mark R. Townsend
Sedimentologist
*Department of Geology
University of Nottingham
University Park
Nottingham NG7 2RD
United Kingdom*

Andreas Wetzel
Physical Properties Specialist
*Geologisches Institut der Universität Tübingen
Sigwartstrasse 10
D-7400 Tübingen
Federal Republic of Germany*

N. P. Wijayananda
Sedimentologist
*Oceanography Unit
National Aquatic Resources Agency
Crow Island, Mattakkuliya
Colombo 15
Sri Lanka*

Colin Williams
Logging Scientist
*Lamont-Doherty Geological Observatory
Columbia University
Palisades, New York 10964*

SEDCO OFFICIALS

Captain Edwin G. Oonk
Master of the Drilling Vessel
*Underseas Drilling, Inc.
707 Texas Avenue South
Suite 103D
College Station, Texas 77840-1917*

Kenneth D. Horne
Drilling Superintendent
*Underseas Drilling, Inc.
707 Texas Avenue South
Suite 103D
College Station, Texas 77840-1917*

ODP ENGINEERING AND OPERATIONS PERSONNEL

Charles Hanson	Operations Superintendent
Patrick Thompson	Special Tools Engineer

ODP TECHNICAL AND LOGISTICS PERSONNEL

Wendy J. Autio	Marine Technician
Gain P. Clement	Curatorial Representative
John R. Eastlund	Computer System Manager
Chris Galida	Photographer
Jenny Glasser	Marine Technician
Ted Gustafson	Marine Technician
Michiko Hitchcox	Yeoperson
Kazushi ("Kuro") Kuroki	Marine Technician
John Leonard	Marine Technician
Matt Mefferd	Chemistry Technician
William G. Mills	Laboratory Officer
Joe Powers	Chemistry Technician
Mike Reitmeyer	Electronics Technician
Vernon L. Rockwell	Weather Observer
Kevin Rogers	Marine Technician
Christian Segade	X-ray Technician
Don Sims	Marine Technician
Barry Weber	Electronics Technician

Ocean Drilling Program Publications Staff

Publications Supervisor
William D. Rose

Chief Editor
Norman J. Stewart

Editors
Eva M. Barbu
Elsa Kapitan Mazzullo
Sondra K. Stewart
William R. Winkler

Chief Production Editor
Raymond F. Silk

Publications Coordinator
Gail P. Clement

Hole Summary Coordinator
Debra Williams

Publications Distribution Specialist
Fabiola Muñoz Byrne

Senior Photographer
John W. Beck

Photographer
Roy T. Davis

Chief Illustrator
Karen O. Benson

Illustrators
Garnet D. Gaither
Larry R. Lewis
Pamela C. Vesterby
Christine L. Yokley

Compositor
Mary E. Betz

Production Assistants
Susan Collinsworth
Gigi Delgado
Jaime A. Gracia
Melynda Poët

TABLE OF CONTENTS

VOLUME 116—INITIAL REPORTS

SECTION 1: INTRODUCTION

1. INTRAPLATE DEFORMATION AND BENGAL FAN SEDIMENTATION: BACKGROUND AND OBJECTIVES	3
Shipboard Scientific Party	
2. ODP LEG 116 (BENGAL FAN): EXPLANATORY NOTES	13
Shipboard Scientific Party	
3. UNDERWAY GEOPHYSICS	29
Dean L. Merrill and Shipboard Scientific Party	

SECTION 2: SITE REPORTS

4. SITE 717: BENGAL FAN	45
Shipboard Scientific Party	
5. SITE 718: BENGAL FAN	91
Shipboard Scientific Party	
6. SITE 719: BENGAL FAN	155
Shipboard Scientific Party	
7. ODP LEG 116 SITE SURVEY	197
Shipboard Scientific Party	

SECTION 3: CORES

Core description forms and core photographs for:

Site 717	213
Site 718	289
Site 719	347

SECTION 4: POLICY

JOIDES ADVISORY GROUPS	381
SAMPLE-DISTRIBUTION POLICY	387

BACK-POCKET FOLDOUTS

INITIAL REPORTS, VOLUME 116: CHAPTER 7: FIGURE 9. SINGLE-CHANNEL SEISMIC REFLECTION RECORDS FROM THE VICINITY OF LEG 116 AVAILABLE PRIOR TO THE SITE SURVEY

INITIAL REPORTS, VOLUME 116: CHAPTER 7: FIGURE 10. SINGLE-CHANNEL SEISMIC REFLECTION LINE ACQUIRED ON R/V ROBERT D. CONRAD DURING THE APPROACH TO AND DEPARTURE FROM THE SITE SURVEY