by Philip D. Rabinowitz

The Ocean Drilling Program

The Ocean Drilling Program is responsible for the collection, management, and distribution of more than 46 kilometers of cored material obtained during the past 5 years. In its quest for information about how the Earth has evolved with time, the program has explored the ocean floor at 175 sites throughout the world. Nearly 700 scientists have participated on 29 cruises of JOIDES Resolution and have taken more than 250,000 core samples for further study.

Using the remarkable research vessel, participants have drilled beneath the ocean floor deeper than ever before and have gained insights into the evolution of the ocean crust. They also have developed new technology for deep ocean exploration and drilling.

The science operator for the program, Texas A&M University, manages three repositories for more than 125 kilometers of cores collected in over 20 years of scientific ocean drilling, as well as manages and distributes the collection of data. The program, funded by a total of 19 countries, serves as a successful example of international cooperation in science research. (Ed.)

cruise 128 (November 1989), has operated at 175 sites in the North Atlantic Ocean, in the eastern and northwestern Pacific Ocean, in the Weddell Sea and Prydz Bay off Antarctica, and in the Indian Ocean. We anticipate that the vessel will continue research in the western Pacific Ocean before it commences a major expedition bordering western North and South America in the spring of 1991. Thus far, approximately 700 scientists from around the world have participated in the cruises (fig. 2) and have brought over 250,000 individual core samples home to their respective institutions for further study.

The scientific equipment aboard *JOIDES Resolution* is located in a seven-story, 12,000-ft² laboratory stack. This laboratory contains equipment necessary to analyze the physical and chemical properties of the rocks (fig. 3) and is probably one of the most complete earth science laboratories in the world (Kidd and others, 1985; Rabinowitz, 1986). The 50-member science and technical team, which remains aboard the vessel for 2-month durations, has available for its research studies laboratories for sedimentology, physical property, paleomagnetism, chemistry and gas paleontology, petrology, thin section, X-ray diffraction, X-ray fluorescence, and downhole measurements. In addition, facilities for photography, electronics, and refrigerated core storage are available. While the ship is approaching or leaving drill sites, digital single-channel seismic data are recorded and processed in the underway geophysics laboratory. The *JOIDES Resolution* is also equipped with a research-oriented computer system that is designed to perform as many routine chemical, arithmetic, and graphics tasks as possible. Two computers serve as a central processor and data library for 50 microcomputers that are distributed throughout the laboratories.

Table 1.—JOIDES member countries

UNITED STATES	
FRANCE	
JAPAN	
UNITED KINGDOM	
CANADA AND AUSTRALIA	
FEDERAL REPUBLIC OF GERMANY	
EUROPEAN SCIENCE FOUNDATION	
Belgium	The Netherlands
Denmark	Norway
Finland	Spain
Iceland	Sweden
Italy	Switzerland
Greece	Turkey

The Ocean Drilling Program (ODP), which is the successor program to the Deep Sea Drilling Project (DSDP), is an international basic research program of scientific ocean drilling that has Texas A&M University of College Station, Texas, USA, as the science operator. The mission of ODP is to learn how the Earth has evolved with time. To do this, sediment and hard rock samples are retrieved from beneath the deep sea floor in order to study the evolution of ocean basins, evolution of prehistoric life, evolution of past ocean currents, and paleoclimates. ODP is funded by the U.S. National Science Foundation and major contributions from 18 other countries (table 1). This international partnership is called the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES).

ODP commenced its field operations with a shakedown and sea trials cruise in January 1985 in the Gulf of Mexico (Rabinowitz and others, 1985). About every 2 months since that time, an internationally staffed expedition of our drilling research vessel, the *SEDCO/BP 471*, better known to the scientific community as the *JOIDES Resolution*, has taken place in very remote but geologically important areas of the world's oceans (fig. 1). Each expedition carries a scientific and technical complement of 50 persons, as well as the ship's crew and drilling complement of about 60 persons. The ship, as of

Ship operations

The 470-ft, dynamically positioned drillship *JOIDES Resolution* was constructed in 1978 and was engaged in oil and gas exploration prior to its conversion to scientific ocean drilling. Its main characteristics are listed in table 2.

The ship's dynamic positioning system includes the capability for station keeping using long-base line, short-base line, and ultra-

Figure 1.—JOIDES Resolution (registered name SEDCO/BP 471) drilling on cruise 105 in Baffin Bay.

Table 2.—Characteristics of the drillship JOIDES Resolution

Principal dimensions	
Overall length, in ft	470
Molded beam, in ft	70
Draft, in ft	24
Total displacement, in short tons	18,636
Power systems	
Main: Five 16-cylinder turbo-charged diesels and two 16-cylinder diesels	
Total horsepower (hp)	18,757
Total main propulsion, in hp	9,000
Total thrusters, in hp	9,600

short-base line techniques. The system is supported by 12 powerful 800-horsepower (hp) retractable thrusters, as well as by 2 main propellers, each driven by 6 750-hp motors. In the operational mode, the station keeping system can hold the ship to ± 2 percent of the water depth with wind limits of 45 knots (kn), gusts to 60 kn, significant wave height of 4.5 m, maximum wave height of 8 m, and surface currents of 2.5 kn, provided the prevailing environment is within 30° of the bow or stern. In addition, the ship has the world's largest heave compensator, a device that acts as a hydraulic shock absorber in order to minimize the vertical motion of the drillship relative to the sea floor. This is essential for collecting high-quality, relatively undisturbed cores (Foss, 1985).

Because of its size and displacement, *JOIDES Resolution* has proven itself to be a remarkably stable drilling platform for work in high latitudes (Foss and others, 1988). We have collected samples beneath the deep sea floor (fig. 4) in the Norwegian Sea (Leg 104), Baffin Bay and Labrador Sea (Leg 105), Weddell Sea and sub-Antarctic South Atlantic Ocean (Legs 113 and 114), and Prydz Bay and sub-Antarctic Indian Ocean (Legs 119 and 120). The ship's drilling capabilities were put to severe tests during these cruises. For example, on Leg 120, operating in the southern high latitudes during

the months of March and April was a challenge. Nevertheless, the objectives of the cruise were met with less than a total of 2 days lost waiting on weather, despite high winds (average 20–40 kn and gusts of 50–70 kn) and heavy seas (fig. 5) while operating at relatively shallow water depths (about 1–2 km). In 5 years of drilling operations, the *JOIDES Resolution* has been unable to retrieve cores as a result of weather for only about 5 days—a remarkable achievement considering the areas of operation. Further, the excellent heave compensation aboard the vessel has allowed reasonable quality cores to be retrieved in hostile environments.

On three of the above voyages (Legs 105, 113, 119), ice was a factor and support vessels were used for ice management and escort duties. For the Baffin Bay drilling of Leg 105, the Canadian registered support vessel M/V *Chester* reported on ice conditions in the operating area. This vessel did not have capabilities for moving or deflecting icebergs or growlers. For our Antarctic research, we used the Danish vessel *Maersk Master* for ice management duties. This 83-m, 14,900-ton vessel not only reported ice conditions but had capabilities to tow or otherwise deflect icebergs (fig. 6). In addition when ice conditions were favorable, ancillary geophysical and biological studies were conducted from this vessel.

Scientific and technical objectives

The scientific objectives during ODP's first 5 years were formulated at the Conference on Scientific Ocean Drilling held in Austin, Texas (COSOD; see JOIDES, 1981). These objectives include studies of the long-term changes in the atmosphere, oceans, cryosphere, and magnetic field (paleoceanography); origin and evolution of marine sedimentary sequences; evolution of continental margins; and origin and evolution of the oceanic crust (table 3). ODP's technical objectives have been in support of the science, that is, development of new tools and technology for deep ocean exploration and drilling.

Paleoenvironmental studies have been major objectives on Legs 100 (Gulf of Mexico), 101 (Bahamas), 104 (Norwegian Sea), 105

Figure 2.—Shipboard participants on Legs 101–128 (January 1985–November 1989), not including scientists on Leg 100 (shakedown and sea trials cruise) or on Leg 124E (engineering cruise). Thus far, about 700 scientists from many countries around the world have participated on ODP cruises. Abbreviations: CAN/AUS, Canada and Australia; FRG, Federal Republic of Germany; UK, United Kingdom; ESF, European Science Foundation; USA, United States of America.

(Labrador Sea and Baffin Bay), 107 (Tyrrhenian Sea), 108 (north-west Africa), 112 (Peru margin), 113 and 114 (Weddell Sea and sub-Antarctic South Atlantic), 115 (Mascarene Basin), 117 (Oman margin), 119–120 (Prydz Bay and sub-Antarctic Indian Ocean), 122 (Exmouth Plateau), and 127–128 (Sea of Japan).

On Leg 108 (Ruddiman and others, 1988), over 3,800 m of core collected off northwest Africa demonstrated a broad-scale linkage—at least for the last 3 million years (m.y.)—between the polar components of the climate system (ice sheets, sea ice, and polar oceans) and the low-latitude ocean atmosphere components (surface oceans, upwelling regions, wind circulation, and land climate). On Leg 117 (Prell and others, 1989), over 4,300 m of core was retrieved in order to decipher the record of the Indian Ocean south-western monsoon and the evolution of the Himalayas and their impact on global climate. On Leg 105 (Arthur and others, 1987), the cores collected determined that the onset of glaciation occurred at

about 2.5 Mega-annum (Ma, 10^6 years) in the Norwegian Sea and as early as 3.4 Ma in Baffin Bay. The sub-Antarctic cruises, Leg 113 (Barker and others, 1988) and Leg 119 (Barron and others, 1989), demonstrated that glaciation at sea level first occurred between 5 and 10 Ma on west Antarctica and that the ice sheet has been a stable and permanent feature since about 4.8 Ma. These cruises also provided evidence that the east Antarctic ice sheet may be possibly as old as 42 Ma and perhaps was much larger during its early history than it is at present. These results, amongst many others, will greatly enhance our knowledge of the evolution of global climate.

For paleoenvironmental studies, cores must be continuous and of high quality in order to determine information about environmental responses that occurred during earth orbital changes of 20,000–100,000 years. ODP engineers have developed and continuously are improving the techniques for collecting high-quality, continuous, and undisturbed cores. One important development that allows us to

A

D

B

E

C

F

Figure 3.—Shipboard laboratory spaces aboard JOIDES Resolution. A, 9.5-m core being sectioned on catwalk; B, paleomagnetism laboratory; C, chemistry laboratory; D, preparing samples in core laboratory; E, scientists analyzing XRF measurements (right) and XRD data (left); and F, preparing water guns for underway geophysics.

Figure 4.—ODP operations areas (darkened boxes) showing nearly 5 years of expeditions from January 1985 to November 1989 (Legs 100–128). Open boxes indicate future areas of scientific exploration.

retrieve undisturbed cores from the upper 200–300 m of soft sediment is the advanced piston corer (APC; Storms and others, 1983 a, b; Huey, 1984). Here, the nonrotary, direct insertion of a core barrel that shoots out ahead of the drill bit (fig. 7) eliminates the severe disturbances on un lithified sediments that are caused by rotary drilling.

Studies relating to marine sedimentary sequences also require techniques for high-quality core collection of the more lithified sediments. The development of the extended core barrel (XCB) system (fig. 8; Cameron, 1984) offers important advantages over the standard rotary core barrel (RCB) system (Huey and Storms, 1985). One advantage is that the XCB can be deployed in the same bottom hole assembly as the APC after reaching piston coring refusal. In this way, coring ahead can be accomplished without tripping the pipe to change to a different bit. Another advantage afforded by XCB over standard rotary coring is that the core barrel cutting shoe extends about 7 in. beyond the face of the core bit. In the extended position, the cutting shoe shields the incoming core from the disturbance caused by the jet hydraulics of the bit. When the deposits become very hard, the coil spring compresses and the cutting shoe retracts. This is especially useful in coring deposits of interbedded hard and soft lithologies.

ODP has studied the tectonic evolution of passive continental margins—those margins believed to have formed by processes associated with the rifting of continental crust and the emplacement of oceanic crust during the early formation of ocean basins—by retrieving cores from the Bahamas region (Leg 101) and the Galicia (Leg 103), Norwegian (Leg 104), Sardinian (Leg 107), northwest Africa (Leg 108), Oman (Leg 117), east Antarctic (Leg 119), and northwest Australia (Legs 122 and 123) margins. These cruises also addressed problems relating to the Earth's paleoenvironment, as well as the origin and evolution of marine sedimentary sequences.

The Galicia margin off the Iberian Peninsula is typical of many of the world's passive continental margins, that is, the present-day morphology is controlled primarily by elongate, tilted, broken continental crustal blocks interpreted as rift structures. Drilling here at five sites on Leg 103 recovered a nearly complete sequence of post-rift, synrift, and prerift sediment (Boillot and others, 1987). In contrast, the continental margin off Norway is characterized by a broad structural high, the Voring Plateau, believed to represent a stage in the evolution of one type of passive margin formed either during the latest period of rifting or during the earliest period of sea-floor spreading. We drilled here approximately 900 m into a dipping seismic reflector sequence (Eldholm and others, 1987). This sequence

consists of tholeiitic basalt flows and interbedded volcanoclastic sediments. Prior to drilling, the sequence was thought to be either predominantly volcanic in nature or sedimentary beds lying unconformably beneath a lower Eocene unit. These results demonstrate that volcanism can play a larger role than anticipated in the evolution of passive margins. Off northwest Australia, five sites were drilled to study the post-Permian rifting of the Exmouth Plateau (Leg 122; Haq and others, 1989), and two sites were drilled to ad-

dress problems relating to the final stages of rifting, formation of early oceanic basement, and sediment accumulation in the adjacent Argo and Gascoyne abyssal plains (Leg 123; Gradstein and others, 1989). The oldest sediments ever recovered from beneath the deep ocean floor were encountered on Leg 122. These sediments extended the record of marine sediments to basal Late Triassic (Carnian/No-rrian, 231–215 Ma). The most surprising result of Leg 123 was that the Indian Ocean here may be as much as 20 m.y. younger than

Figure 5.—Sea conditions during drilling operations in high latitudes on Leg 120.

Figure 6.—Maersk Master, ice support vessel used by ODP for ice management duties, shown here towing large icebergs. This iceberg is probably the largest object ever moved by man.

previously thought. The later opening of the Indian Ocean (Valanginian) has important consequences for the plate tectonic model of the Southern Hemisphere and the demise of Tethys.

Active continental margin regions have been drilled on Legs 107 (Tyrrhenian Sea), 110 (Barbados), 112 (Peru), 124 (Sulu and Celebes Seas), 125 and 126 (Mariana and Izu-Bonin forearcs), and 127 and 128 (Sea of Japan).

On Leg 110 on the Barbados Ridge, *JOIDES Resolution* achieved a first-ever penetration of a décollement zone by drilling

Table 3.—Major scientific questions to be addressed by scientific ocean drilling, as outlined by the first Conference on Scientific Ocean Drilling (COSOD)

1. **Processes of magma generation and crustal construction at midocean ridges.**
2. **Configuration, chemistry, and dynamics of hydrothermal systems.**
What are the dimensions and characteristics of hydrothermal systems at ridge crests versus those on ridge flanks?
How does overlying sediment cover, or the lack of it, affect these hydrothermal systems?
3. **Early rifting history of passive continental margins.**
What is the shallow and deep structure of stretched and normal faulted margins versus those characterized by excessive volcanism?
4. **Dynamics of forearc evolution.**
What are the relative motion, deformation, and pore water characteristics of sediments at accreting and erosional margins?
5. **Structure and volcanic history of island arcs.**
What are the space and time relationships of forearc subduction, accretion, and erosion, and of backarc spreading, compression, and volcanism at island arcs?
6. **Response of marine sedimentation to fluctuations in sea level.**
Which stratigraphic sequences and intervening unconformities represent fluctuations of sea level, and which represent vertical tectonic motion?
7. **Sedimentation in oxygen-deficient oceans.**
What are the ocean circulation, paleoclimate, and potential hydrocarbon characteristics associated with black shale deposits?
8. **Global mass balancing of sediments.**
What are the best estimates of the world sediment mass and composition balances in space and time?
9. **History of ocean circulation.**
How do patterns of ocean circulation respond to changing ocean boundaries, that is, changing ocean size, the extent of shallow continental seas, and the opening and closing of oceanic passages, especially the Drake passage, the Isthmus of Panama, and the Tethys seaway?
What is the history of abyssal circulation?
10. **Response of the atmosphere and oceans to variations of the planetary orbits.**
How did gravitational interactions with other planets, especially Jupiter, affect paleocirculation in the atmosphere and hydrosphere?
11. **Patterns of evolution of micro-organisms.**
How has the process of evolutionary change proceeded in marine organisms?
12. **History of the Earth's magnetic field.**
What is the nature of the magnetic field during a magnetic reversal?
What is the detailed history of magnetic reversals and changes in the intensity of the magnetic field during the past 200 m.y.?

ADVANCED PISTON CORER (APC)

Figure 7.—Schematic diagram of advanced piston corer (APC) used in ODP operations. A piston shoots out ahead of the drill bit to retrieve undisturbed sections (right). This system has been used to depths as great as 300 m below the sea floor. Abbreviations: I.D., inner diameter; BHA, bottom hole assembly.

EXTENDED CORE BARREL (XCB)

Figure 8.—Schematic diagram of extended core barrel (XCB) used in ODP operations.

through an accretionary complex and into subducted sediments. This resulted in the discovery of distinct hydrogeologic systems through which the Barbados accretionary prism dewateres (Masle and others, 1988). (See also article by Xavier Le Pichon in *Episodes*, v. 12, no. 4, p. 263–266, 1989—Ed.) Drilling on Legs 125 and 126 in the Mariana and Izu-Bonin forearcs has addressed problems relating to the origin and evolution of forearc terranes and to dewatering of subducted lithosphere (Fryer and others, 1989; Fujioka and others, 1989). Drilling in the Yamato Basin on Legs 127 (Pisciotta and others, 1989) and 128 (Ingle and others, 1990) has confirmed that the southeastern Sea of Japan formed by rifting of a continental arc in early Miocene time (~19 Ma). Drilling on the Okushiri Ridge in the Japan Basin has shown conclusively that compressional tectonics began to collapse the northeast margin of the Sea of Japan at approximately 1.8 Ma, which possibly represents the initiation of a new subduction zone. Thus, drilling on these cruises has documented both the initiation of formation of the Sea of Japan and the initiation of its possible destruction. A borehole seismometer was emplaced in the basement rocks in the Sea of Japan in order to allow for seismic investigation of crustal structure and for long-term data accumulation on natural earthquakes.

Ocean crust objectives have been addressed by drilling and (or) performing downhole experiments on Legs 102 (110-Ma Atlantic crust), 106 and 109 (zero-age crust, Mid-Atlantic Ridge), 111 (Costa Rica rift), 115 (hot spot trace, Indian Ocean), 118 (Atlantis II transform), and 121 (Ninetyeast Ridge), amongst others. ODP's major technical challenge has been in drilling hard rock, in particular to initiate, drill, and core holes in bare rock near midocean ridges. A major problem has been to initiate or spud a hole that has no sediment cover and is in water depths of several kilometers. To accomplish this task, a guide base and reentry cone system was designed to confine the drill bit and allow initiation of the hole (Harding, 1987). The base (fig. 9) is ~6 m × 6 m × 3 m, weighs approximately 20,000 kilograms (kg), and is designed to land on an ocean floor sloped up to 20°. Once landed, the base can be anchored further by pumping ~50,000 kg of cement into it. A television camera attached to the outside of the drill string and lowered to the sea floor allows scientists to view the rugged sea floor of the midocean ridge environment and enables them to lower the guide base accurately to its desired location. The base confines the drill bit in order to initiate a surface hole into which a secondary reentry cone and string of casing can be landed and cemented.

Thus far, we have deployed the guide base successfully twice: once near the axis of the Mid-Atlantic Ridge south of the Kane Fracture Zone (Legs 106 and 109; Detrick and others, 1988; Bryan and others, 1988) and once on the Atlantis II transform on the Southwest Indian Ridge (Leg 118; Robinson and others, 1989). On Legs 106 and 109, only about 50 m of rock was penetrated owing to considerable hole-stability problems. On the Atlantis II transform of Leg 118, however, we continuously cored a 500-m-deep section and had a very high recovery rate of 89 percent. The gabbroic rocks recovered were the first coherent in-place section of lower crustal rocks ever obtained from the ocean basins. The core from these cruises has provided important constraints on the evolution of oceanic crusts along slowly accreting plate boundaries.

The deepest hole ever drilled into ocean crust is hole 504B, which penetrated 1,562.3 m of Nazca plate crust that formed at 5.9 Ma in the Costa Rica rift (Becker and others, 1988). This hole, which was drilled during several DSDP expeditions and was continued on ODP Leg 111, extends over twice as deep into oceanic basement as any other hole and penetrates 274.5 m of sediment and 1,287.8 m of underlying basaltic rocks. It provides the only in-place samples of oceanic sheeted dikes, the transition between extrusive and intrusive basalts, and the transition between layers 2B and 2C.

Figure 9.—Schematic diagram showing major elements of hard rock spud system for use at sites having little or no sediment cover. This system has been deployed at the Mid-Atlantic Ridge (Leg 106) and Atlantis II transform southeast of Madagascar (Leg 118).

Hole 504B, whose layer 2C–layer 3 boundary may be within reach of the next drilling expedition, thus provides us with our best set of observations of the nature of in-place oceanic crust.

ODP also has returned to previously drilled DSDP deep crustal holes, cleaned the holes, and performed further logging and down-hole measurements. This has been accomplished on young ocean crust in the Atlantic on ODP Leg 109 (DSDP site 395; ~9 Ma; Detrick and others, 1988; Bryan and others, 1988) and on old ocean crust in the Atlantic on Leg 102 (DSDP site 410; ~110 Ma; Salisbury and others, 1986). In particular on ODP Leg 102, borehole seismometers were clamped in the hole, and a seismic ship shot to the seismometers in concentric circles in order to test for anisotropy of the ocean crust.

Hot spot traces in the Indian Ocean have been drilled on Leg 115 (Reunion-Chagos-Laccadive-Maldives hot spots) and Leg 121 (Ninetyeast Ridge hot spot) that support the concept that hot spots are stationary features in the mantle over long periods. However, evidence has surfaced from these cruises that indicates that the axis of the Earth's rotation may have moved with respect to the true figure of the Earth.

Scientific drilling with ODP certainly has made an impact on our understanding the evolution of ocean crust. However, we have only drilled a small part of the Earth's crustal column. If we are ever going to understand the processes responsible for our dynamic Earth, then we must obtain deeper samples in order to examine the chemistry of the rocks and how the rocks change with time. The success achieved with the gabbros of the Atlantis II transform during Leg 118 in the Indian Ocean leads us to believe that continued drilling in

hole 504B of Leg 111 may become even more successful as the hole is deepened into the transition zone between the sheeted dikes and the gabbros.

Future ODP science and technology

In July 1987, a second international Conference on Scientific Ocean Drilling (COSOD II; see JOIDES, 1987) was held in Strasbourg, France, in order to review and redefine future scientific objectives (table 4). The new science themes generally call for deeper penetration drilling and drilling into and recovering rocks from complex formations (that is, highly fractured crustal rocks and alternating chert and soft sediment layers). ODP's most promising new technology to meet these demands is the diamond coring system (DCS, fig. 10), a system that attempts to adapt land-based mining technology to the deep ocean environment. In this system, a small-diameter ($3\frac{1}{2}$ -in.) drill rod string is run inside the normal ODP $5\frac{1}{2}$ -in. drill pipe to beneath the sea floor. The $3\frac{1}{2}$ -in. drill pipe is less stable structurally than the normal ODP $5\frac{1}{2}$ -in. drill pipe, so the latter thus acts as a drill rod stabilizer between the ship and the sea floor. The $3\frac{1}{2}$ -in. drill pipe is rotated at 400–600 revolutions per minute (r/min) from a hydraulically driven top drive unit, as compared to ~ 70 r/min for normal ODP $5\frac{1}{2}$ -in. drill pipe rotations, and has a much smaller weight on the bit ($\sim 4,000$ lb compared to up to 35,000 lb for normal ODP drilling). A secondary heave compensator is used to maintain precise control of weight on the bit when using the thin kerf diamond core bits. We anticipate that the DCS will revolutionize our abilities to obtain high-quality samples of hard rock beneath the deep ocean floor and perhaps accomplish for hard rock drilling what piston coring has done for soft rock drilling.

Table 4.—Scientific objectives established at the second Conference on Scientific Ocean Drilling (COSOD II)

SCIENTIFIC THRUSTS	
Changes in the global environment	
Mantle-crust interactions	
Fluid circulation in the crust and the global geochemical budget	
Stress and deformation of the lithosphere	
Evolutionary processes in oceanic communities	
TECHNICAL THRUSTS	
Objectives	Technology demand
A series of crustal holes to 5,000 meters below sea floor.	Drill deep into igneous crust, improved bit life.
Drill accretionary prisms.	Deep drilling into unstable and unconsolidated sediments.
Drill sedimented ridges and prisms to study fluid processes.	Fluid sampling technique to recover hot corrosive fluids up to 300 °C.
Drill hot spot traces and old ocean crust to study plate motion.	Improved recovery in fractured crust, magnetic orientation undisturbed.

Science services

Texas A&M University (TAMU), as science operator for ODP, provides services for the management and distribution of cored material and data, as well as for the production of ODP publications.

Figure 10.—Schematic diagram of diamond coring system used by ODP.

A series of formal and informal published scientific reports is issued over the period extending from shortly before each cruise to about 3 years following the cruise. These publications include: (1) a precruise scientific prospectus that comes out about 3 months before each cruise; (2) a postcruise preliminary report that is published approximately 1 month after each cruise; (3) technical notes; and (4) our principal, formal, hardbound publication, "Proceedings of the Ocean Drilling Program." The proceedings is divided into two parts: "Initial Reports," which contains descriptions of drilling sites, including core photographs, and is distributed 12 to 15 months after the cruise; and "Scientific Results," which contains peer-reviewed specialty papers and is distributed about 36 months after the cruise.

Three repositories for cores are managed by TAMU/ODP. One is located at Scripps Institution of Oceanography, which houses the Indian and Pacific Ocean cores collected by the predecessor program, the Deep Sea Drilling Project; one at Lamont-Doherty Geological Observatory of Columbia University, which houses all Atlantic Ocean cores; and one at TAMU, which houses the ODP-collected Indian and Pacific Ocean cores. These repositories contain the most extensive collection of deep-sea sediment and hard rock samples in the world, more than 125 km of core collected over the last 20 years. Scientists throughout the world may request samples from the Curator of the Ocean Drilling Program at TAMU, who maintains records of all the investigations that have been proposed to study the

DSDP and ODP samples. The JOIDES Sample Distribution Policy and Sample Request Forms may be obtained from the Curator.

The ODP Database Group archives, processes, and edits the program's data collection (table 5) and distributes it to the scientific community (Brown and others, 1988). Included in the collection are the following:

- All geological and geophysical data collected on *JOIDES Resolution* (Legs 101 to present)
- Electronically archived data from the Deep Sea Drilling Project (DSDP) (Legs 1-96)

- Any data generated from postcruise work on the cores collected by the DSDP and OD
- All photographs of cores taken by DSDP and ODP

Further information on ODP data bases can be obtained from the Database Librarian at the Ocean Drilling Program at TAMU. Wire-line logging data for ODP are acquired, processed, and distributed by the Borehole Research Group of the Lamont-Doherty Geological Observatory of Columbia University (L-DGO). Further information and data requests for wire logging data can be obtained from the Log Analyst at L-DGO.

Table 5.—ODP data bases

1. LITHOLOGIC and STRATIGRAPHIC DATA

Visual Core Descriptions

-Sediment/sedimentary rock

-Igneous/metamorphic rock

Smear slide descriptions

Thin section descriptions

Paleontology

Screen

Lithology, core color, sedimentary structures, disturbance, large minerals and fossils

Lithology, texture, structure, mineralogy, alteration

Nature and abundance of sedimentary components

Petrographic descriptions of igneous and metamorphic rock. Includes mineralogy, texture, alteration, vesicles

Abundance, preservation and location of 26 fossil groups

Computer-generated lithologic classifications. Basic composition data, average density and age of layer

2. PHYSICAL PROPERTIES

G.R.A.P.E. (gamma ray attenuation porosity evaluator)

Grain size

Index properties: bulk and grain

density, water content, and porosity

Shear-strength measurements

Thermal conductivity

Velocity measurements

Downhole measurements

-Heatflow

-Pressure

Continuous whole-core density measurements

Sand-silt-clay content of a sample

Gravimetric and volumetric measurements

Measurements using motorized and Torvane instruments

Measurements of sediments using a thermal probe

Compressional and shear-wave velocity measurements

In-situ formation temperature measurements

In-situ formation hydrostatic pressure

3. SEDIMENT CHEMICAL ANALYSES

Carbon-carbonate

Interstitial water chemistry

Gas chromatography

Rock evaluation

Percent by weight of the total carbon, organic carbon and carbonate content of a sample

Quantitative ion, pH, salinity and alkalinity analyses

Hydrocarbon levels in core gases

Hydrocarbon content of a sample

4. IGNEOUS and METAMORPHIC CHEMICAL ANALYSES

Major and minor element analyses

Analyses of igneous, metamorphic, and some sedimentary rocks composed of volcanic material

5. X-RAY MINERALOGY

X-ray mineralogy

X-ray diffraction

6. PALEOMAGNETICS

Paleomagnetism

Susceptibility

Declination, inclination and intensity of magnetization

Discrete sample and continuous whole-core measurements

7. UNDERWAY GEOPHYSICS

Bathymetry

Magnetics

Navigation

Seismics

Analog records of water-depth profile

Analog records and digital data

Satellite fixes, course and speed changes that are merged with the depth and magnetic data

Analog records of sub-bottom profiles and unprocessed signal on magnetic tape

8. SPECIAL REFERENCE FILES

Leg, site, hole summaries

Initial Reports Bibliography

AGEPROFILE

COREDEPTH

General leg, site, and hole characteristics (cruise objectives, location, water depth, drilling statistics)

Titles and authors for all articles in the *Initial Reports*

Definition of age layers downhole

Depth of each core for determination of sample depth (in meters)

9. AIDS TO RESEARCH

ODASI

Keyword Index

Sample Records

Site Location Map

Thin Section inventory

A file of ODP-affiliated scientists and institutions

A computer-searchable bibliography of DSDP- and ODP-related papers and studies in progress

Inventory of all shipboard samples taken

DSDP and ODP site positions on a world map of ocean topography

Inventory of all shipboard thin sections

Concluding remarks

Over the past 5 years, about 700 scientists from around the world have participated in collecting over 46 km of cored material on 29 cruises of *JOIDES Resolution*. They have taken home to their respective laboratories over 250,000 samples for shore-based study. These scientists have sailed on a ship providing the most advanced laboratories and drilling facilities. In 5 years of drilling operations, we have experienced less than a total of 5 days of lost drilling time due to weather—a remarkable record, especially considering the hostile environments in which the ship has ventured.

Ocean-floor exploration through scientific ocean drilling has transformed the very way we think about our planet Earth. However, our research is still in its infancy. If we divide the Earth by the number of drill sites we have, it would be equivalent to having one or two holes in the State of California—and not very deep holes—and trying to decipher the geology of the State from them.

We believe that the *JOIDES Resolution* will continue to return results that will alter our perception of the Earth and that the international scientific community will continue to use the ship to examine and measure Earth processes more precisely than ever before.

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