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The Ocean Drilling Program I: Overview and Science Plans

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ABSTRACT

The Ocean Drilling Program (ODP) commenced its field operations in January 1985. Texas A&M University (TAMU), as Science Operator, has as its ultimate task to collect cores from the floor of the oceans and to ensure that adequate scientific analyses are performed on those samples. The Science Operator implements the science plans, provides logistical and technical support for the shipboard science team, manages post-cruise activities and the long term curation and distribution of core samples, and coordinates, edits, and publishes the final research product. The scientific program uses a dynamically positioned commercial drillship, the JOIDES RESOLUTION, which has a much more expansive research and drilling facility than previously employed for scientific ocean drilling. TAMU receives scientific guidance from an international scientific organization called the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES).

The primary scientific objectives of the ODP lie in studying the origin and evolution of the oceanic crust, the tectonic evolution of the continental margins, the origin and evolution of marine sedimentary sequences, studies of long term changes in the atmosphere, oceans, cryosphere, biosphere, and magnetic field, and in the development of new tools and technology for deep ocean exploration and drilling. This paper describes the future science plans and an overview of the Ocean Drilling Program.

INTRODUCTION

The Ocean Drilling Program (ODP) is a basic research program primarily directed to studying the evolution of the solid earth and its environment through the recovery of samples from beneath the floors of the world's oceans. The ODP, with Texas A&M University (TAMU) as the Science Operator, is the successor program to the Deep Sea Drilling Project (DSDP) operated by Scripps Institution of Oceanography (SIO) of the University of California at San Diego. Between 1968 and 1983, the scientific drillship used by DSDP, the D/V GLOMAR CHALLENGER, logged 375,000 miles, drilled 1092 holes at 624 sites and recovered 96 km of core.

Since its inception, scientific ocean drilling as developed by DSDP, produced spectacular advances in the understanding of fundamental earth processes as well as in ocean technology[1-3]. Nevertheless, important questions remain to be answered which require facilities to examine, measure, and analyze basic earth processes more precisely than ever before. One of the principal tasks of TAMU during the start up period was the procurement and conversion of a drilling vessel with more expanded facilities than existed on the CHALLENGER. This includes more laboratory space and scientific/technical quarters, a longer drill string, and riser and high latitude capabilities.

THE DRILLSHIP

The SEDCO/BP 471 (commonly referred to as the JOIDES RESOLUTION) was chartered in March 1984 from Underseas Drilling, Inc., Dallas, Texas. This 470 ft. dynamically positioned drillship (Figure 1) was constructed in 1978 and was engaged in oil and gas exploration. The principal characteristics of the drillship are described in Table 1.

Table 1
Characteristics of the drillship

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

In order to accommodate the needs of a scientific and technical party of 50 persons, a seven story main laboratory structure was constructed on the starboard side of the vessel (Figure 2). In addition, a library and study area was installed on the main deck forward of the bridge, and an underway geophysics laboratory was constructed on the fantail under the helicopter deck. Additional scientific, office and storage space was also provided for a total of approximately 12,000 sq. ft. of science space.

The science laboratories in the lab stack contain a complete array of state-of-the-art seagoing scientific research equipment. Included are laboratories for sedimentology, physical properties, paleomagnetics, chemistry and gas, paleontology, petrology and thin section, X-ray diffraction and fluorescence (XRD/XRF), scanning electron microscope, and downhole measurements. In addition, facilities for photography, electronics, and refrigerated core storage are available. While the ship is in transit between drill sites, digital single channel seismics are recorded and processed in the underway geophysics laboratory. The JOIDES RESOLUTION is also equipped with a research oriented computer system which is designed to perform as many routine clerical and arithmetical tasks as possible. A pair of VAX computers serve as a central processor and data library for 50 microcomputers distributed throughout the laboratories.

The ship's dynamic positioning system underwent major modification to include capability for station keeping using long-base line and short-base line systems as well as the original ultra-short base line system. It is supported by 12 powerful 800 hp retractable thrusters, as well as by two main propellers, each driven by six 750 hp motors. In the operational mode, the station keeping system can hold the ship to ± 2% of water depths, with wind limits of 45 kts., gusts to 60 kts., significant wave height of 15 ft., maximum wave height of 27 ft., and surface currents of 2.5 kt., provided the prevailing environment is within 30° of the bow or stern.

TABLE 2
Drilling Equipment

Derrick Capacity (dynamic), lb	1,200,000
Swivel capacity (static), t	650
Bearing load rating, t	450
Heave Compensator (active), t	400
Drawworks, 2 Electric Brakes, hp	2,800
Electric Top Drive:	
Max. continuous torque, ft-lb	31,000
Max. intermittent torque, ft-lb	41,300
Iron Roughneck, hydraulic:	
Make-up torque, ft-lb	63,000
Break-out torque, ft-lb	75,000
Dual Elevator System, t	500
Double Drum Coring Winch, electric:	
Capacity each drum, 9/16 wire, ft	36,000
Hoisting speed, ft/min	500
Mud Pumps, two triplex, each, hp	9,700
Pipe Racker, total capacity, ft	30,000
Logging Winch (electro hydraulic) capacity, ft	36,000
Crown block:	
Rating, t	600
Number sheaves (66 in. diameter)	7
Drilling Line Size, in.	1 3/4
Spring Connector Rating, t	600

The drilling systems described in Table 2 were designed to accommodate high speed wireline coring and to operate with a 30,000 ft. drill-string. The traveling block, connector, heave compensator, swivel, and power sub were designed with a 4 1/8" axial bore. This permits running the coring line and overshot assembly over a permanently mounted crown block sheave and into the drillpipe for efficient operation.

SCIENTIFIC AND TECHNICAL OBJECTIVES

Science Planning and Objectives

In a continuous series of cruises, each approximately 8 weeks long, a team of about 25 scientists from the international scientific community, plus 25 highly trained TAMU/ODP marine technicians, and a ship's crew of 65 circle the globe to retrieve core samples from beneath the floors of the world's oceans in some of the most remote but geologically important areas of the earth. In its capacity as Science Operator, TAMU/ODP ensures that adequate scientific analyses are performed on the retrieved cores by providing and maintaining shipboard science laboratories, providing logistical and technical support for shipboard scientific teams, managing post-cruise activities, curating and distributing core samples, and coordinating the editing and publishing of the scientific results. Lamont-Doherty Geological Observatory of Columbia University is the prime logging contractor for ODP, and supplies a full suite of geophysical and geochemical services, including the acquisition and processing of in situ logging measurements.

The Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) provides scientific planning and advice to the program. The present membership of JOIDES includes 10 U.S. institutions [Lamont- Doherty Geological Observatory (L-DGO) of Columbia University; Scripps Institution of Oceanography at the University of California; Woods Hole Oceanographic Institution; the Rosenstiel School of Marine and Atmospheric Science of the University of Miami; the University of Washington; Hawaii Institute of Geophysics; the University of Rhode Island; the University of Texas; Texas A&M University; and Oregon State University], plus the Deutsche Forschungsgmeinschaft in the Federal Republic of Germany, the Ocean Research Institute of the University of Tokyo in Japan, the Centre National pour l'Exploitation des Oceans in France, and the Department of Energy, Mines and Resources in Canada. The JOIDES organizational structure includes an Executive Committee which sets the general policies and a Planning Committee (PCOM) which, based on the recommendations of its various panels, formulates the scientific objectives and drilling targets for the program. The panels which advise the PCOM include: thematic panels, which are responsible for determining the scientific drilling objectives and for directing proposals received from the community at large; regional panels, which review proposals for drilling specific regions around the world; and service panels, which advise on information handling, safety and pollution problems, downhole measurements, and pre-drilling site survey. The people who make up the JOIDES structure serve on a voluntary basis and are drawn from the international scientific and technical communities at large.

Scientific ocean drilling provides access to the sediments and hard rocks beneath the deep ocean floor and thus provides information required to understand the phenomena of sea floor spreading and continental drift and its effects on our very mobile planet earth. The major questions to be addressed by scientific ocean drilling were outlined by the JOIDES community in "The Report of the Conference on Scientific Ocean Drilling," (COSOD)[4] and include:

1. Processes of magma generation and crustal construction at mid-ocean ridges.
What is the character and composition of the deep portion of the oceanic crust?
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 chaging ocean boundaries, e.g., 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 do gravitational interactions with other planets, especially Jupiter, affect paleocirculation in the atmosphere and hydrosphere?
11. Patterns of evolution of microorganisms.
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.?

Coring Systems

Although similar principles of drilling practice apply for both industrial and scientific drilling, there are important differences in equipment and procedures. The prime objective in oilfield drilling is to reach the target depth as efficiently as possible with coring done only as appropriate. In scientific drilling, the primary objectives are to understand the composition and properties of the strata in the earth's crust. This objective requires continuous coring and, the recovered cores must remain undisturbed for analysis; in addition, drilling and coring of the hard rock basaltic oceanic basement are also required. Hence, scientific drilling may take considerably longer than commerical drilling to achieve the same penetration depth[5].

Scientific ocean drilling thus requires techniques that allow relatively undisturbed samples of the rocks beneath the sea floor to be retrieved. Specialized wireline coring tools have been developed at DSDP and are being continued in development at ODP[6]. These include the the Advanced Hydraulic Piston Corer[7] (APC), developed to overcome problems related to core disturbances resulting from rotary drilling the soft sea floor sediments (Figure 3). With APC, pressurized water drives the core barrel (which acts as a high speed hydraulic arm) ~ 30 ft. ahead of the bit at a rate of 10 - 20 ft./sec. With the rotary wireline coring system, the very soft sediments generally found in the upper parts of the column could be virtually pumped into the core barrel as the drillstring heaves in response to the ship's motion. The hydraulic piston coring effectively separates the coring process from the ship's heave and allows a relatively undisturbed 2 1/2 in. diameter core to be recovered. Using this method, cores have been taken to depths ~1,000 ft. below the sea floor. The increased core quality obtained by piston coring is essential for scientific studies involving the origin and evolution of marine sedimentary sequences and causes of long term changes in the atmosphere, oceans, cryosphere, biosphere, and magnetic field.

The Extended Core Barrel[8] (XCB; Figure 3) has been developed for areas where lithologies alternate between hard and soft beds. The high circulation rate (and weight) necessary to penetrate a hard sedimentary layer would wash away any underlying soft layer once the bit punched through so that only the hard layers were recovered. With the XCB, the core barrel extends in ~6 in. below the bit in soft formations to protect the sediment from circulating fluids; in harder formations, the core barrel is retracted to the bit allowing the sediment to be cut primarily by the roller cones. The XCB is interchangeable with the APC so that both can be used without tripping the drillstring.

The number one priority for development at the present time is a hard rock spudding coring system which will allow scientists to sample rocks from beneath the sea floor in areas of highly fractured rocks with little or no sediment cover. This system, designed to operate in 4300 m of water will be tested in November 1985 on the Mid-Atlantic Ridge. Present plans call for a gravity base to be lowered to the sea floor from the drillship. Cement will be pumped to build up the weight of the base and grout it to the sea floor. The initial hole will be drilled with downhole mud motors.

SCIENCE OPERATIONS

During the first two years of field operations of the project (between January 1985 and February 1987) a number of drilling objectives and potential drillsites were selected by the JOIDES community. Candidate drillsites for this time interval are shown in Figure 4. Upon completion of the initial two year drilling program, the JOIDES RESOLUTION is scheduled to begin scientific investigation in the Indian Ocean.

At the time of this writing, the JOIDES RESOLUTION has completed her Shakedown voyage (Leg 100) as well as the first three international cruises (Legs 101-103).

LEG 100 - SHAKEDOWN CRUISE (JANUARY 11-29, 1985)

This first cruise departed Pascagoula, Mississippi, on 11 January 1985 and arrived in Miami, Florida, on 29 January 1985 after 18 days of testing all of the drilling systems and scientific laboratories and giving the drilling and scientific/technical crew an opportunity to train on their respective equipment. During this inaugural cruise, three holes were drilled at Site 625 near De Soto Canyon, west Florida Shelf, in order to correlate alternating sedimentary and erosive sequences to world-wide sea level changes over the last several million years.

The capabilities of the ship and the dynamic positioning system were tested in hostile sea conditions with winds between 45 and 55 kts. and 18- to 20-ft. seas. The ship remained stable and held station to within 50 ft. (water depth 3,000 ft.). Even in these adverse conditions, high quality cores were retrieved. In general, all systems performed up to or exceeded expectations. Some adjustments or rearrangements of equipment were required, but the minor nature of these is best illustrated by the fact that the vessel departed on its first international scientific mission (Leg 101) after only two days in port[9].

LEG 101 - BAHAMAS (JANUARY 31 - MARCH 14, 1985)

The scientific objectives of this first international cruise were to study the evolution of the Bahamas carbonate platform, a large area of coral reefs and sediments east of Florida. In particular, two fundamentally different hypotheses for the long term crustal evolution of the Bahamas were tested by drilling 19 holes at 11 sites. The "megabank" hypothesis holds that the modern archipelago is underlain by a drowned shallow platform, while the "graben" hypothesis suggests instead that the present topography reflects the underlying horst and graben related to Mesozoic rifting of North America and Africa. The result of the analysis of the samples collected should aid in resolving the above hypotheses[10].

Co-Chief Scientists for the cruise were Dr. James Austin of the University of Texas and Dr. Wolfgang Schlager of the University of Miami. Dr. Amanda Palmer was the Texas A&M Staff Scientist representative.

LEG 102 - SITE 418 REVISITED (MARCH 19 - APRIL 25, 1985)

The JOIDES RESOLUTION revisited DSDP site 418 during Leg 102, in 5500 m deep water, at the southern edge of the Bermuda Rise in the western North Atlantic Ocean. The purpose of the cruise was to obtain a baseline suite of borehole geophysical measurements in Hole 418A and to conduct seismic studies in the vicinity of the site to characterize the physical properties and structural features of 110 m of crust. The original hole penetrated 324 m sediment and 544 m oceanic basaltic basement rocks beneath the sea floor. When the data from Leg 102 is fully analyzed, it should allow scientists to better understand the evolution and aging of the earth's crust as it spreads from the mid-ocean ridges[11].

The Co-Chief Scientists for the cruise were Dr. Matthew Salisbury of Scripps Institution of Oceanography, University of California, and Mr. James Scott from the U.S. Geological Survey, Denver, Colorado. Dr. Christian Auroux was the Texas A&M University Staff Scientist representative.

LEG 103 - GALICIA BANK (APRIL 26 - JUNE 19, 1985)

The scientific objectives of this cruise were to study the evolution of a passive continental margin by obtaining reasonably complete sequences of the post-, syn-, and pre-rift strata. On this cruise, 14 holes were drilled at 5 sites on the Galicia continental margin, northwest of the Iberian Peninsula[12]. By examining the samples obtained from drilling there, the shipboard scientific party hopes to learn more about the processes that relate to the earliest rifting history and separation of the continents.

The Co-Chief Scientists for the cruise were Dr. Gilbert Boillot of the University Pierre et Marie Curie in France, and Dr. Edward L. Winterer of the Scripps Institution of Oceanography, University of California. Dr. Audrey Meyer was the Texas A&M University Staff Scientist representative.

LEG 104 - NORWEGIAN SEA (JUNE 25 - AUGUST 12, 1985)

Leg 104 is in progress at this writing. The scientific objectives are primarily to sample the dipping reflector sequence found under portions of the Voring Plateau of the Norwegian continental margin and believed to be associated with early seafloor spreading and/or rifting. Drilling is projected to penetrate the dipping reflectors and into material forming an acoustically opaque basement defined by a sharp upper contact, Horizon K. In addition, problems to be addressed include paleoceanography of the Norwegian current and northern hemisphere, glaciation, and evolution of polar flora and fauna.

The Co-Chief Scientists for Leg 104 are Dr. Olav Eldholm, of the University of Oslo, Norway; and Dr. Jorn Thiede of Christian-Albrechts University, Kiel, Federal Republic of Germany. Dr. Elliott Taylor is the Texas A&M University Staff Scientist representative.

LEG 105 - BAFFIN BAY AND LABRADOR SEA (AUGUST 24 - OCTOBER 26, 1985)

The scientific objectives of Leg 105 are to document the climatic history, paloceanographic history, age calibration of magnetic anomalies, and timing of the opening of the Labrador Sea and Baffin Bay. A first priority is the re-entry site located on the lower rise of Baffin Bay. The Eocene to Quaternary sedimentary sequence that is expected to be recovered should represent the first complete sediment record for this period from this latitude and will enhance studies of climatic and paleoceanographic relationships between middle and high latitudes.

The second site proposed for Leg 105 is located southwest of Eirik Ridge, a sediment drift in the east-central Labrador Sea. The scientific objectives at this site are to document the the Eocene to Holocene paleoceanographic and paleoclimatic history of this region.

The Co-Chief Scientist designates are Dr. Shiri Srivastava of the Bedford Institute of Oceanography in Dartmouth, Canada; and Dr. Michael Arthur of the University of Rhode Island. Dr. Brad Clement will be the Texas A&M University Staff Scientist representative.

LEG 106 (NOVEMBER 1 - DECEMBER 27, 1985) AND LEG 109 (APRIL - JUNE 1986) - BARE ROCK DRILLING AT THE MID-ATLANTIC RIDGE

Legs 106 and 109 will drill either one or two holes in zero age crust in the median valley of the Mid-Atlantic Ridge to the south of the Kane Fracture Zone (KFZ). The scientific objectives of the legs are to investigate the processes of magma generation and crustal accretion.

Three primary sites were identified during the recent SeaMARC site survey of this area and are described below (not in order of preference).

Site 1 is located at 23°15.10'N, 44°53.20'W in approximately 3800 m of water. The site is situated on a lobate basalt flow some 200 m in thickness which has ponded against the eastern rift valley wall. The major rift fault presumably acted as a conduit for magma to reach the surface. The site is approximately 2 km across, almost flat, and has a few centimeters of sediment cover.

Site 2 is located at 22°55.45'N, 44°56.80'W in approximately 3300 m of water. The site is situated on a flat topped volcano located to the west of the ridge axis. The volcano's distance from the spreading axis would suggest an age of around 15,000 years. The site is approximately 1 km in diameter and has a slope of a few degrees. Bottom photographs show a relief in the order of a few tens of centimeters with areas of ripple flows, recent extensional fractures along one edge, and a patchy sedimentary cover 10 to 20 cms in thickness.

Site 3 is located at 23°22.15'N, 44°57.15'W in approximately 3400 m of water. The site is situated in a shallow depression on the apex of the active spreading ridge. Bottom photographs show a covering to the area of yellowish-colored sediments, possibly a meter or more in thickness, and associated colonies of worms and crabs. These are indicative of the presence of a locally active hydrothermal vent. The site is approximately 750 m across.

All three sites will require the use of a specially designed bare rock guide base. Should drilling at the prime targets be unsuccessful, back-up sites are located in the eastern nodal basin of the KFZ (23.6°N, 44.9°W), and in sediment ponded areas along the eastern non-transform section of the fracture zone valley (23.4°N, 43.4°W). These sites have sufficient sediment cover to allow the use of conventional drilling and re-entry techniques.

The Co-Chief Scientists for Leg 106 will be Dr. Jose Honnorez of the University of Miami and Dr. Robert S. Detrick of the University of Rhode Island. Dr. Andrew Adamson is the designated Texas A&M University Staff Scientist representative.

Leg 109 will continue operations started on Leg 106. Co-Chief Scientists will be Dr. Wilfred B. Bryan of Woods Hole Oceanographic Institution; and Dr. Thierry Juteau of Universite Strasbourg, France. Dr. Andrew Adamson will be the designated Texas A&M University Staff Scientist representative.

LEG 107 - TYRRHENIAN SEA (JANUARY - FEBRUARY 1986)

A Tyrrhenian Sea transect of 5 sites is planned for this cruise in the Mediterranean. The scientific objectives consist of:

- establishing the plio-quaternary magnetic stratigraphy and tephrachronology of Western Mediterranean Sea;
- clarifying the relationships between the distensive evolution of the Tyrrhenian basin and the different phases of the Apenninic collision and Calabrian Arc subduction;
- deciphering the multirifting evolution and multispreading history of this marginal basin;
- documenting plio-quaternary sequences of the starved Sardenian passive margin in order to model continental crust stretching and subsequent subsidence.

Dr. Kim Kastens of the Lamont-Doherty Geological Observatory, Palisades, USA, and Dr. Jean Mascle of the Laboratoire de Geodynamique Sous-Marine de Villefranche sur Mer, Universite Pierre et Marie Curie, France, are the Co-Chief Scientists designates for Leg 107. The Texas A&M University Staff Scientist representative will be Dr. Christian Auroux.

LEG 108 - NORTHWEST AFRICA (FEBRUARY - APRIL 1986)

Leg 108 will drill a transect of eleven sites across a number of oceanic and atmospheric regimes and boundaries. When completed, these sites will connect with six sites drilled in DSDP Leg 94 to provide a paleoenvironmental transect from 54°N to around 2°S, spanning nearly 60° of latitude. It will yield new and important paleoclimatic data on oceanic and atmospheric circulation patterns, on ice volume and sea level changes, and provide detailed studies of Neogene biostratigraphy. The eleven sites proposed are for shallow penetration, high resolution biostratigraphy.

The Co-Chief Scientist designates for Leg 108 are Dr. Michael Sarnthein, University of Kiel, Federal Republic of Germany, and Dr. Bill Ruddiman, Lamont-Doherty Geological Observatory. The Texas A&M University Staff Scientist representative will be Dr. Jack Baldauf.

LEG 109 (See Leg 106)

LEG 110 - BARBADOS (JUNE - AUGUST 1986)

During Leg 110, studies will be conducted across the northern Barbados Forearc. Objectives of this cruise are to sample a complete sequence of the accretionary prism, the decollement surface, and the underlying sediments and ocean basement. In addition, a transect of sites across the forearc will be drilled to test the lateral variability of convergence and accretionary processes.

Three holes are proposed for drilling on Leg 110. At one site, coring will be done to completely recover the lithologic columnn at the toe of the accretionary front. This site will require a re-entry cone and drill-in casing to sustain hole conditions through the decollement zone. During drilling operations, an extensive program of downhole measurements and logging will be carried out.

The other two candidate sites are single bit sites located upslope from the deformational front. The two sites will address questions regarding the lateral variations in structural features, physical properties, fluid pressures, and composition of offscraped material in the decollement zone.

The Co-Chief Scientists for Leg 110 will be Dr. Casey Moore, University of California at Santa Cruz, and Dr. Alain Mascle, Institute Francais du Petrole, France. The Texas A&M University Staff Scientist representative will be Dr. Elliott Taylor.

LEGS 111 TO 113

Legs 111 through 113 will be carried out between September 1986 and February 1987. They tentatively include deepening of the deep crustal hole drilled at DSDP hole 504B (Leg 111); an investigation of the accretionary wedge sediments at the margin of the Peru trench (Leg 112); and paleoceanographic studies in the Weddell Sea (Leg 113).

CONCLUDING REMARKS

The Ocean Drilling Program is off to an excellent start. The state-of-the-art onboard scientific, drilling, and operational equipment has been tested under varying sea conditions. The JOIDES RESOLUTION is an extremely stable vessel that should meet the needs of the international scientific community over the next decade.

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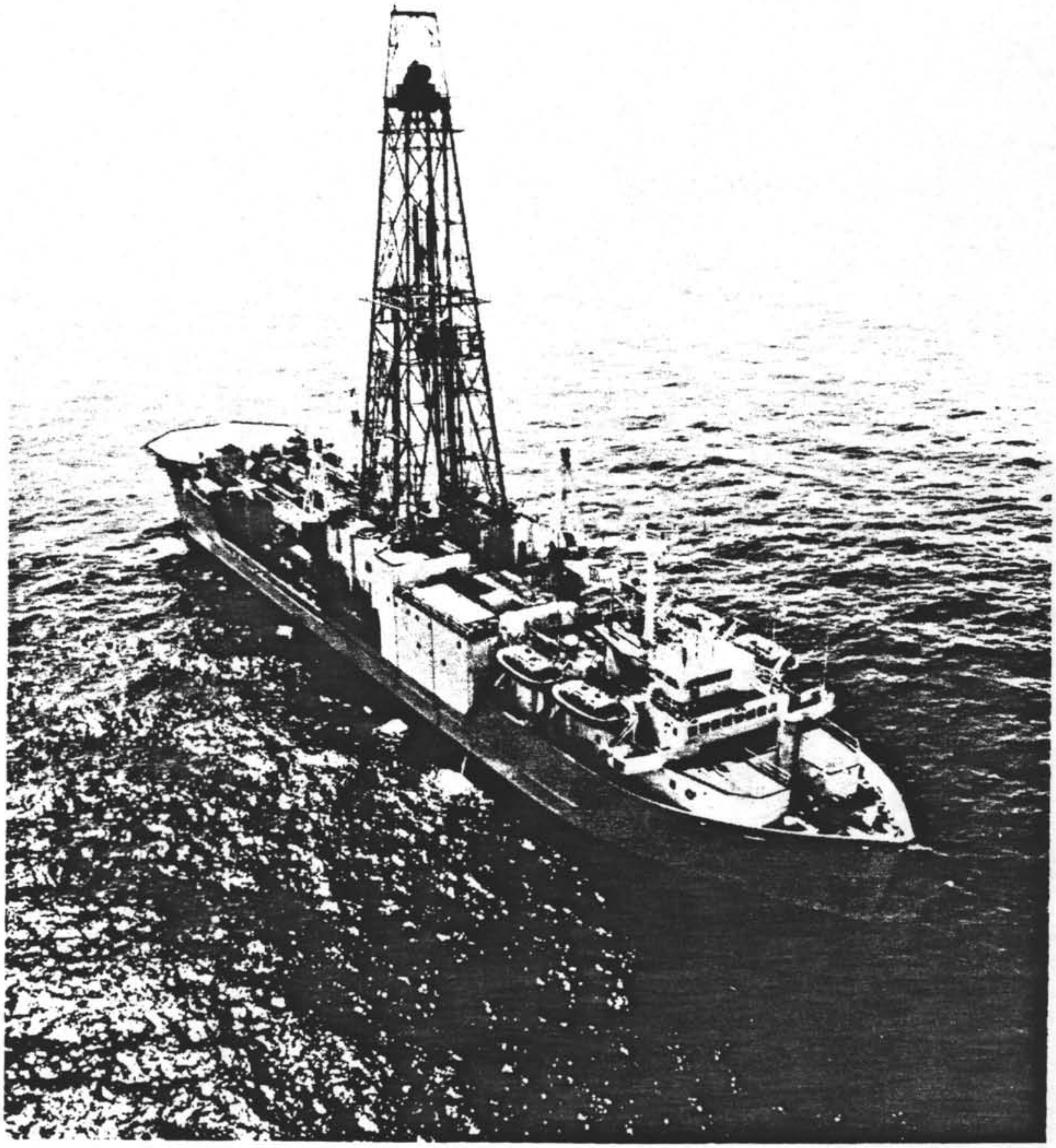
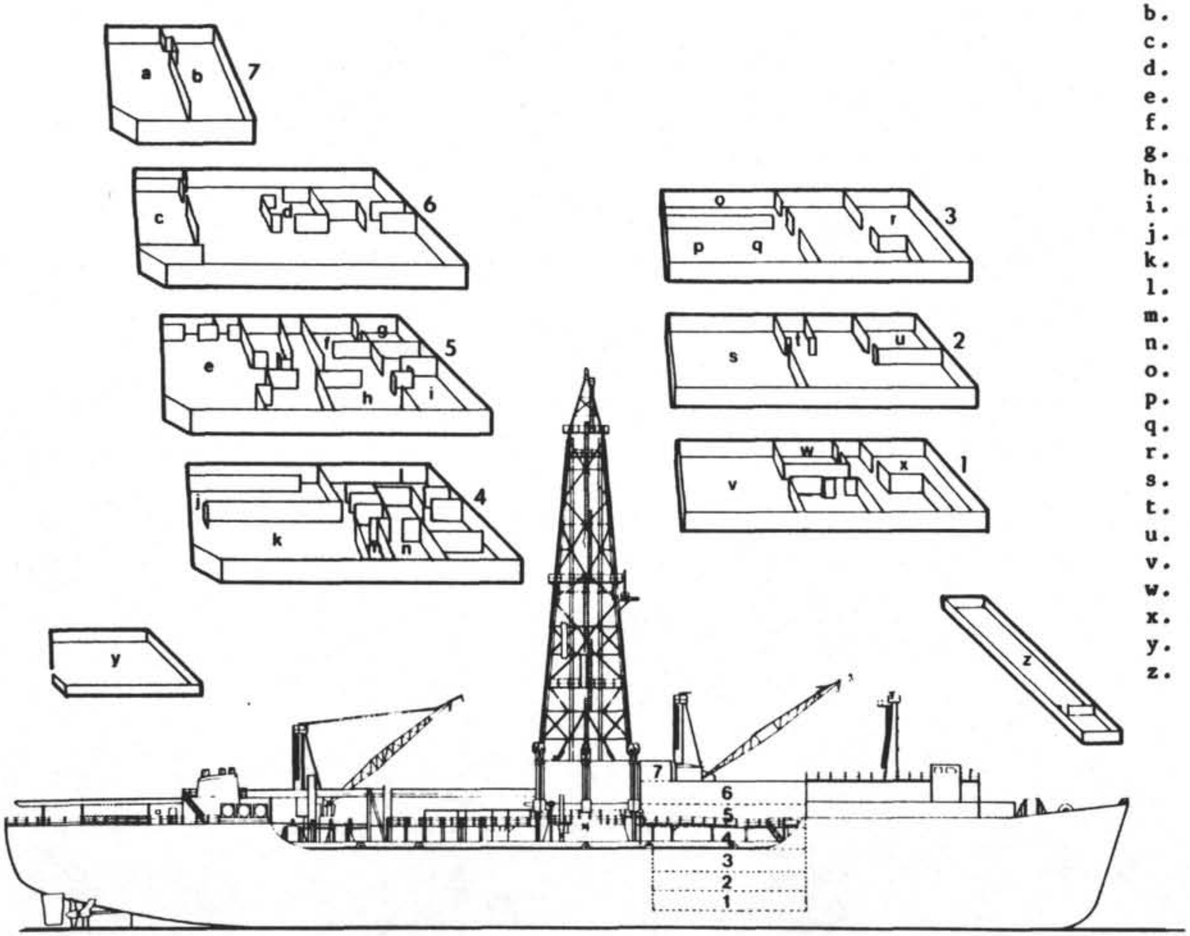


Figure 1. The drillship JOIDES RESOLUTION used in the Ocean Drilling Program.

ODP DRILLING VESSEL



a. Downhole Instruments, Logging
b. Downhole Instruments, Logging
c. Magnetics Lab
d. Core Splitting Lab
e. Chemistry Lab
f. Petrology Stations
g. Thin Section
h. Paleo Stations
i. Paleo Prep Lab
j. Computer
k. Science Lounge
l. Computer User
m. Study
n. Co-Chief's Office
o. Electronic Shop
p. Photo Darkroom
q. Photo Finish Room
r. Fan Room
s. Core Storage Reefer
t. Cold Storage
u. 2nd Look Lab
v. Core Storage Reefer
w. Freezer
x. Storage
y. U/W Geophysics
z. Library

Figure 2. Scientific work spaces are contained in a seven-story structure built on the rig's starboard side, between the rig floor and crew's quarters.

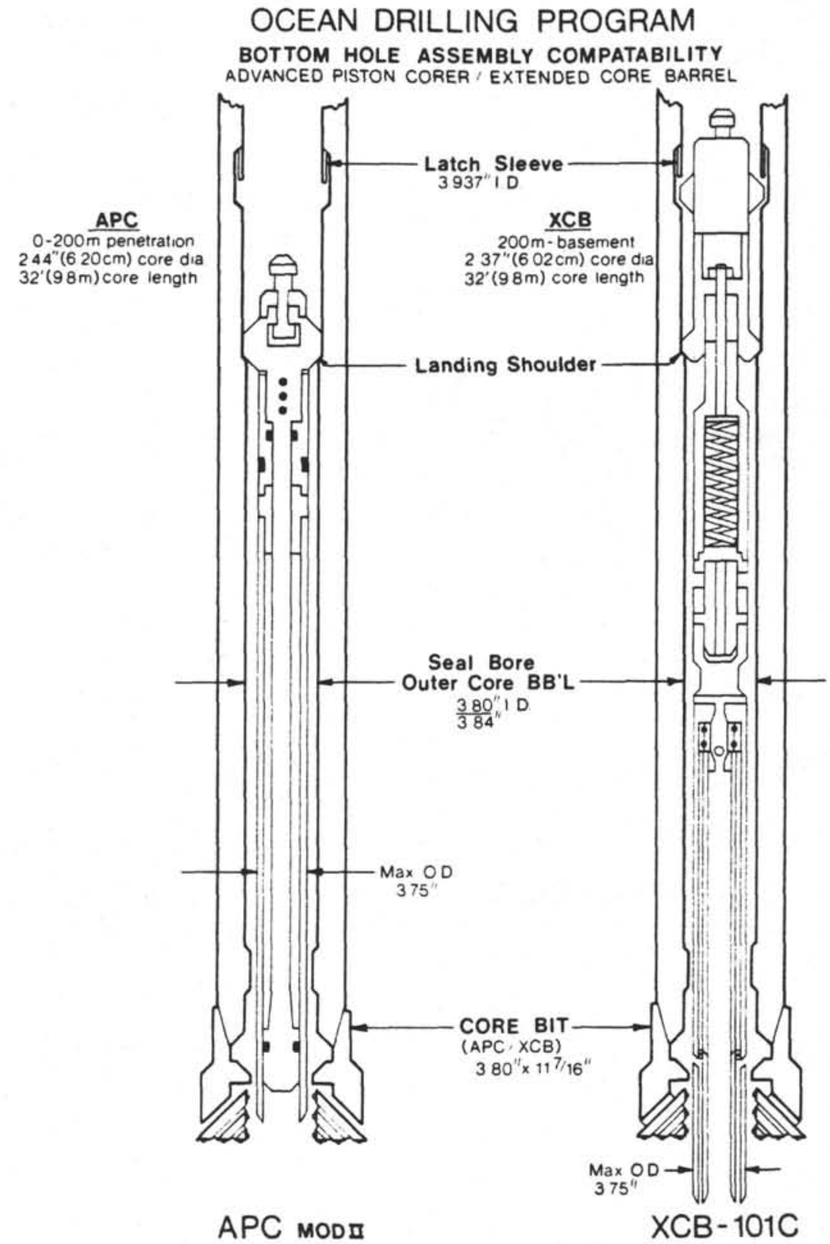


Figure 3. (Left) Advanced hydraulic piston corer (APC). Operational sequence is as follows: (1) Corer is seated and sea water is pumped down the drillpipe at 350 gpm to initiate action; (2) Locking pins shear at a maximum of 2,800 psi and the outer seal sub then drives the core barrel into the formation as fluid above the piston head is vented; (3) At the end of the stroke, dampening parts are uncovered, pressure fluid is vented to decelerate the core barrel; (4) At the surface, a drop in pump pressure indicates that the corer has fully extended; (5) Core barrel is retrieved, the bit is washed down to the next coring point, and the process repeated until the formation becomes too indurated.

(Right) Extended core barrel (XCB). In soft formations the core barrel employs a cutting shoe that extends 6-in. below the bit, which prevents sediments from being washed away by jet action from the drill bit. In harder formations, the cutting shoe retracts into the drill bit (against the pressure of an internal spring) allowing indurated sediments to be cut predominantly by the roller cones and jetting actions of the bit.

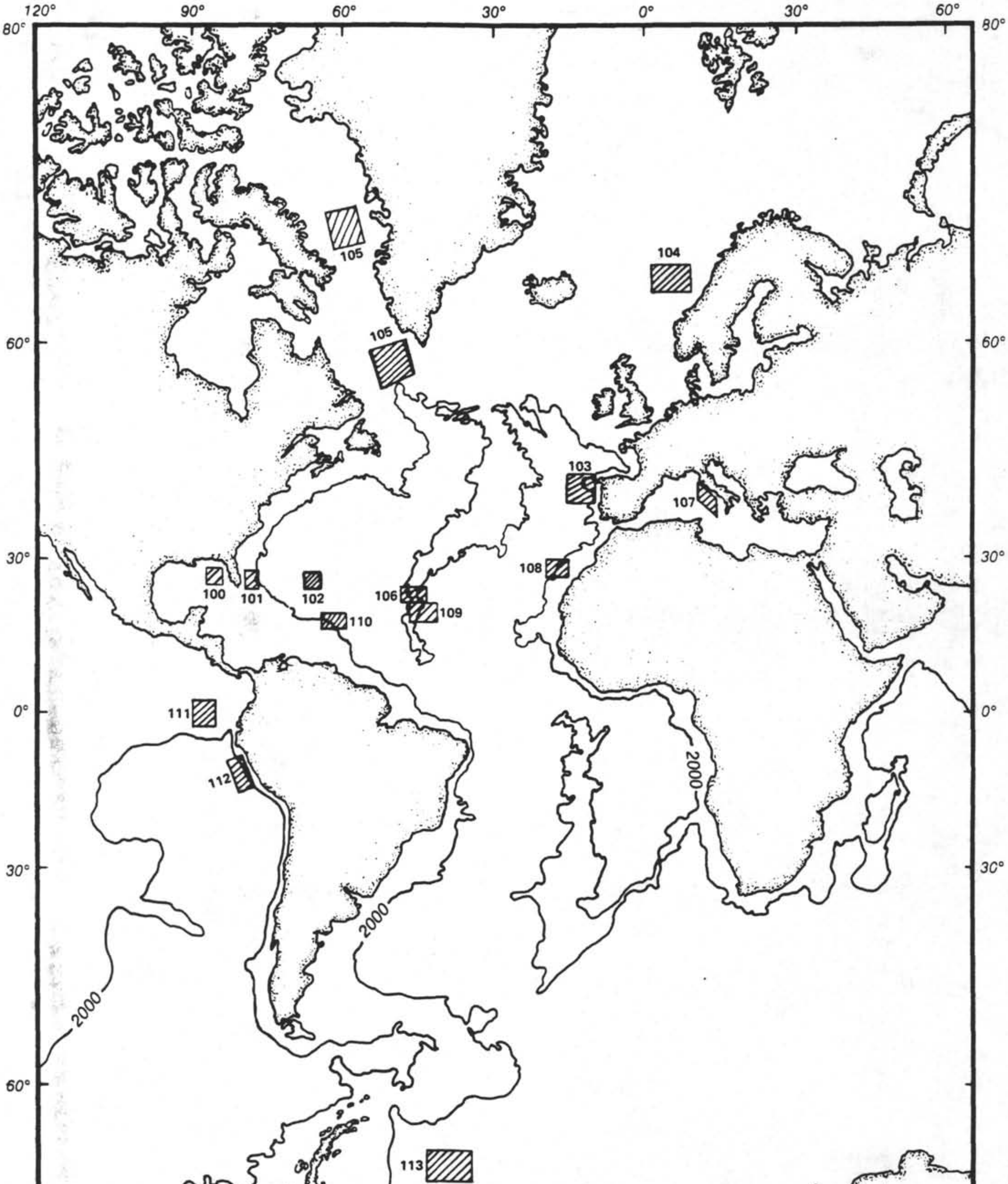


Figure 4. Drillsite areas for first two years of Ocean Drilling Program.

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THE OCEAN DRILLING PROGRAM II: JOIDES RESOLUTION SCIENTIFIC DRILLSHIP OF THE '80'S

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ABSTRACT

The Ocean Drilling Program, which began operations in January, 1985, required a drilling vessel with increased operational capabilities to achieve its ambitiously redefined objectives in sub-seafloor research. The vessel selected would be called upon to continue and exceed the remarkable accomplishments of Glomar Challanger and the Deep Sea Drilling Project.

During 1984, the Sedco/BP 471 drillship was selected for that mission and was converted to a scientific drilling/coring vessel. In addition to a more than two-fold increase in scientific laboratory and berthing accommodations in comparison to the Challanger, the following operational upgrades have been incorporated:

1. Increased drill string capability to 30,000 feet (9144 meters) by means of a tapered drill string with additional racking capacity.
2. Increased available power for dynamic positioning, pipehandling and increased transit speed.
3. Riser handling capability.
4. State-of-the-art drilling systems, including in-line heave compensator, electric top drive, "Iron Roughneck" and dual-drum coring winch.
5. New downhole systems, including high resolution sonar and television capabilities for reentry, and the use of downhole motors for coring and bare-rock spudding.

The Sedco vessel, unofficially re-christened "JOIDES Resolution", has now completed several months of ODP operations with only minimal "teething problems". In nearly all respects the desired capabilities have been achieved or exceeded. This paper describes the improvements and discusses planned additional upgrading of capabilities.

BACKGROUND AND INTRODUCTION

At the end of 1983, the world-renowned Deep Sea Drilling Project/International Phase of Ocean Drilling was demobilized. The technical accomplishments of DSDP/IPOD and the drillship Glomar Challenger were unprecedented and truly remarkable. The vessel pioneered in the fields of dynamically-positioned deep-water drilling, deepwater reentry operations and scientific wireline coring while carrying a self-contained geological laboratory and towing seismic profiling gear into all the oceans of the world.

The newly organized Ocean Drilling Program, also to be funded by the U. S. National Science Foundation and several international partners, sought to expand the scope and horizons of scientific drilling and coring in the oceans. One provision of the ODP effort was to be a longterm contractual obligation with increments of five years (an advantage never enjoyed by the DSDP). For the ambitious new program, the aging Challanger was considered to be deficient in laboratory and berthing space, available power for positioning, transit speed, modern automated drilling systems, storage capacity, and other areas. Her excellent material condition notwithstanding the ship's life expectancy did not match that of the program. In addition the extended goals of the new undertaking required a rig that was capable of, or readily convertible, to drilling with a marine riser.

Under the reorganization, Joint Oceanographic Institutions (JOI), Inc. was selected by NSF to manage the Ocean Drilling Program and the Texas A & M Research Foundation became the successor to Scripps Institution of Oceanography as science operator. JOI and TAMRF developed specifications for a replacement vessel and, through the competitive bidding process, the Sedco/BP 471 drillship was selected as the vehicle of the Ocean Drilling Program.

The ship's name reflects her ownership and class. She is owned 50% by British Petroleum Corporation and 50% by Sedco-Forex, an arm of Multinational Schlumberger Ltd. She is the first of a class of Sedco-designed drillships that are 470 feet (143.2 m) in length. (A sister ship, Sedco 472, is currently under contract to Exxon in the Gulf of Mexico.) The vessel is operated by Underseas Drilling, Inc., a subsidiary corporation of Sedco-Forex with offices in College Station, Texas.

The vessel was built by Hawker Industries in Halifax, Nova Scotia in 1978. She is classed by the American Bureau of Shipping and is registered under the Liberian flag. To illustrate further her international character, a breakdown of her two rotating crews by citizenship reveals that she is staffed by 65 Americans, 30 Portuguese, 16 Filipinos, 10 British, 8 Dutch, 4 Canadians, 2 Australians and 1 Spaniard.

Although the ship's official registered name remains Sedco/BP 471 she has been given the additional name of JOIDES Resolution to reflect her unique scientific mission under the guidance of the Joint Oceanographic Institutions for Deep Earth Sampling and to commemorate HMS Resolution, flagship of the explorer and adventurer Captain James Cook. She is shown in Figure 1, operating north of the arctic circle on ODP Leg 104.

THE VESSEL

Sedco/BP 471 has a history of successful deep-water operations in the oilfield, and at one time held the water depth record for offshore oil drilling. When the ODP contract was awarded, she was drilling for Getty Oil Company in the deep Mississippi Canyon area of the Gulf of Mexico. At that time, the ship was fully equipped for dynamically-positioned riser drilling in water depths of up to 6000 feet (1829 meters).

Conversion of the oil rig into a scientific research vessel began in Mobile, Alabama in August, 1984 and was completed in Pascagoula, Mississippi, in January 1985. General contractor for the conversion was M & M Division of Ham Industries of Pascagoula. The marine riser, most of the riser handling equipment and much of the drilling fluid recirculating and processing equipment were removed and put into storage. Because of the initial phase of the ODP was to be confined to riserless drilling and coring, the primary thrusts of the shipyard conversion project were the installation of scientific spaces and the upgrading of drilling and pipe handling equipment. Table 1 is a summary of the features and capabilities of the ship upon completion of the conversion phase.

Table 1
Dimensions-Capacities-Capabilities

Length	470 ft
Beam	70 ft
Draft (Summer Load Line)	24.5 ft
Displacement, maximum	18600 sh.tons
Maximum complement	122 persons
Cruising speed	12 knots
Shaft horsepower, cruising	9000
Thruster horsepower, (12 thrusters)	9000
Electrical generating capacity	13.5 MW
Water distilling capacity	650 bbl/day
Fuel storage	4000 sh.tons
Drill water storage	1500 sh.tons
Liquid mud storage	4100 bbl
Bulk mud/cement storage	13600 ft^3
Scientific deck space	14500 ft^2
Drawworks	2800 hp
Mud pumps (two pumps)	1700 hp each
Rig hoisting capacity	600 tons
Maximum water depth, drilling ops.	27000 ft
Maximum drill string length	30000 ft
Maximum logging/ reentry depth	20000 ft

Central to the operational capabilities of Resolution is the tremendous amount of available power and the flexibility to apply it where and when it is needed. Completely diesel-electric, the vessel uses a silicon control rectifier (SCR) system to produce DC power. Five EMD 16-645-E9 turbocharged engine- generators and two 16-645-E8 blown units (Figure 2) can generate up to 13.5 Megawatts--enough for a residential community of about 14,000 people. (Fuel consumption can be as much as 15,000 gal/day.) Computerized automatic stationkeeping (ASK) and power management (PMS) systems apportion, prioritize and distribute the electrical load for maximum efficiency and/or operational safety. Figure 3 shows the engine control console with the PMS computer in the background.

The SCR system permits feeding AC power into a common bus to supply individual SCR's which power DC traction motors on major equipment such as the thrusters, main shafts and drilling equipment.

The Honeywell ASK system features full redundancy and the capability of positioning in the short, intermediate and long baseline modes. The nature of current ODP operations dictates that intermediate baseline positioning (IBS) be used in nearly all cases. With IBS, a single acoustic beacon is deployed, by free drop or on a taut wire, and a fixed array of hydrophones on the vessel senses the incoming pulses. Computers process the minute differences in arrival time, compute the position error and issue commands to the thrusters and main shafts to maintain station. In this mode, stationing can be maintained within one percent of water depth or 50 feet (15.2m), whichever is ordered, in nearly any environmental conditions short of a major storm. The operating water depth range is from 500 to 27000 feet (152 to 8229m).

Varying degrees of automation may be selected with the PMS system. It is used primarily to monitor demand and supply at the various points of the ship's power grid and to provide usage and warning information. It is sophisticated enough, however, to anticipate an engine overload, start an additional unit, warm it up and bring it on line--all without a single human command. The PMS can likewise avoid a power failure in the case of overload or loss of a generator by automatically shedding lower priority loads and maintaining uninterrupted power to critical points such as thrusters, ASK system, drawworks, etc.

Scientific laboratory and storage spaces account for over 145,000 square feet (1347sq. meters). The majority of dedicated space is in the seven-level module that now occupies the starboard casing hold area from tank top to bridge roof level. A library module was installed forward of the deck house on the forecastle deck and existing space on the poop deck aft was converted for use as an underway Geophysics lab. The laboratory complex is certainly the most modern and complete geological laboratory afloat. The ODP has received several requests from researchers of institutions in scheduled ports of call who wish to use our laboratory facilities while the vessel is in port.

Additional upgrades to the existing vessel were the construction of a special work/storage area for coring and other downhole tools, installation of a specially designed drill pipe guide/support structure in the moonpool to provide a 350 foot (106.7m) radius of bending for the drill string, and fitting out the fantail area with winches, booms and other equipment for handling towed geophysical profiling gear. The former riser hold has been converted for storage of casing and drill pipe and the remaining half of the former casing hold is a storage and staging area for ODP shipments.

A large volume high pressure air system serves double duty by supplying the drill string heave compensator while the drillship is on site and the towed seismic airguns while it is underway. Two large aqua-chem distillation units keep pace with the daily consumption of about fifty tons of potable water for "hotel", laboratory, and rig use.

Bucyrus-Erie cranes (two 60T and one 30T) are used for loading and for over-the-side deployment of equipment and instruments.

Other features that enhance the vessel's range and environmental capabilities are winterization of work areas with a circulating hot water system, an American Bureau of Shipping (ABS) hull ice classification of 1B, a helideck and helicopter fuel storage tanks, and storage capacity for 26,200 barrels of marine gas-oil.

THE DRILLING RIG

The rig required some modification to bring it to a true 600 ton capacity for handling the 30,000 foot ODP drill string, but the major emphasis of the conversion was modernization to state-of-the-art drilling technology.

To accommodate continuous wireline coring operations, all traveling components are constructed with a minimum four inch (10.2cm) throughbore, and the six-sheave crown block has a unique configuration to complement the split Dreco traveling block. The traveling block-mounted Western Gear motion compensator, at 400 tons working load, is the largest drill string compensator in the world (Figure 4).

Minor structural bracing was added to the Dreco derrick to bring its dynamic load rating to 600 tons. The Oilwell E-3000 drawworks received a major overhaul during the shipyard conversion period and was fitted with a second Dretech electromagnetic brake. Hoisting capacity has increased by upgrading the SCR system and by installing larger EMD traction motors.

The drill string is rotated by a Varco electric top drive (Figure 5). The unit is powered by a DC traction motor and can develop as much as 41,000 ft-lb (5670kg-m) of torque. The rpm range is adjustable from 10 through 225. Top drive drilling offers many advantages over the traditional rotary table and kelly arrangement, including the ability to drill with longer sections of pipe, reduced connection time, greater flexibility in dealing with stuck pipe situations, etc.

Two Oilwell A1700PT triplex single acting 1700 HP slush pumps provide smooth and ample circulating power for coring operations. A dual Halliburton HT-400 pumping unit with a jet mixer is used for cementing casing and plugging core holes, as well as for high pressure/low volume hydrogeologic investigations. It has even been used for hydraulic piston coring applications.

Automated pipehandling systems feature a Varco dual elevator handling system and a Varco "Bigfoot" Iron Roughneck (Figure 6). This equipment not only protects the drill string from slip damage and improper torque on connections, but it makes the rig floor a safer working environment for the drilling crew. The Western Gear automated horizontal piperacker has been expanded to include a third bay to accommodate the full 30,000 foot tapered ODP drill string.

THE DRILL STRING

The special needs of scientific coring and downhole instrumentation in the deep oceans have dictated some unusual drill string design requirements. The dimensions of wireline deployed equipment necessitate maintaining a four inch (10.2cm) minimum inside diameter from the derrick to the outer core barrel. The demand for longer total drill strings and the dynamic stresses inherent in suspending a long unsupported string from a floating vessel had reached the tensile strength limitation of the DSDP five inch S-135 drill string because of the great weight involved. To maintain the inside diameter while increasing the tensile strength of the upper portion of the string, a "tapered" drill string design was developed by ODP. In addition, an even stronger steel with a minimum yield strength of 140,000 lb/sq.in. (96,500 N/sq.cm) was used. Final design criteria were developed by the TAMU-ODP development engineering group. Vallourec, the successful bidder on the pipe, and Hughes Tool contributed to tool joint and upset design.

The lower portion of the drill string, from the bottom hole assembly to a maximum length of 18000 feet (5486m) is comprised of five inch 19.5 pound tube to American Petroleum Institute (API) dimensional specifications, but with S-140 metallurgy. Tool joints are API 5-1/2 inch Full Hole slightly modified to provide a minimum 4-1/8 inch (10.5cm) I.D. The upper section of the string is made up of non-standard 5-1/2 inch pipe, also S-140, with 1/2 inch (1.3cm) wall thickness. Tool joints on the upper string are API 5-1/2 inch Internal Flush. The heavier pipe is used at all times when the suspended string exceeds 18,000 feet (5486cm) and generally from the beginning of drilling/coring operations in any ODP hole. The entire string of drill pipe is coated internally and externally with inorganic zinc to retard corrosion and to prevent contamination of cores with rust flakes.

The uppermost member of the drill string consists of one or more heavy walled drilling joints (HWDJ)[1]. The HWDJ are machined from drill collar stock to produce a tube of 5-1/2 inch O.D. by 4-1/8 inch I.D. with hubs 13 inches (33cm) long by 8 inches (20.3cm) in diameter each five feet. The hubs are designed to distribute bending stress as vessel motion brings the drill string into contact with the flaring guide horn. They are used only when relatively high stress cycles are generated by slow penetration and/or string weight.

The bottom hole assembly (BHA), which provides the drilling weight, is composed primarily of 8-1/4 inch (21cm) drill collars bored out to 4-1/8 inch (10.5cm). Connections are API 6-5/8 inch Full Hole modified to a seven inch (17.8cm) pin length. Outer core barrels are merely drill collars modified for their special purposes.

WIRELINE SYSTEMS

Wirelines and their systems are nearly as important to the scientific objectives of the ODP as are the drill string and drilling equipment. All coring with the various DSDP and ODP coring systems[2] is done by wireline retrieval techniques. An increased emphasis is being placed on downhole investigations using the electric (logging) wireline. Reentry and emergency pipe severing systems also depend on the electric wireline.

A custom-built National dual drum coring winch (Figure 7) is located on the roof of the drawworks house. Two working coring lines are installed at all times and the winch provides full redundancy with the exception of the DC traction motor (which can be exchanged in an emergency with any of several motors on board). The coring line is a 1/2 inch (1.3cm) 3 x 18 swage formed "pulling" line of double extra improved plow steel and has a breaking strength of 30,000 pounds (13,608 kg).

Located between the helideck and the piperacker (Figure 8) is the TAMU logging winch. The electric-hydraulic logging unit provides a 20,000 foot (6096m) capability for reentry, logging, explosive pipe severing and other electric wireline operations. The winch was built for the ODP by Stewart and Stevenson to TAMU specifications. Again a dual installation of critical components, such as pumps and motors, is featured. A spare drum of 15/32 inch (1.2cm) seven conductor logging cable is stored on a nearby platform, and the entire drum skid may be replaced at sea. The cable drums are of extra high strength and capacity and were original equipment on a logging winch built in 1965 for Project Mohole. That winch and its drums were in service for the duration of the Deep Sea Drilling Project. Depending upon the activity in progress, the logging cable conductors may be connected to the Schlumberger "Cyber Service Unit" logging van, the dynamic positioning control room (atop the bridge), the downhole measurements lab (atop the laboratory stack), or the underway geophysics lab on the poop deck. A "special operations" intercom telephone net connects those locations, plus the driller's console and the bridge.

A wireline motion compensator is installed adjacent to the logging winch. Designed and built by Schlumberger, the compensator is provided by the ODP Borehole Research Group. The active electric-hydraulic horizontal unit is unique in the industry in that it relies upon accelerometers as heave sensors. Such a system is required to decouple the vertical motion of the vessel from open-hole logging and seismic sondes, as there is no marine riser or other fixed link to the seafloor for reference.

A third major winch will give JOIDES Resolution an underwater television capability for reentry and other subsea work. The new winch is also electric-hydraulic and holds 20,000 feet (6096m) of coaxial cable. It will be located on the mezzanine deck below the rig floor and will be rigged for deployment of the cable either external or internal to the drill string. The first assignment of the coax system will be to aid in spudding and drilling the bare volcanic rocks of the Mid-Atlantic Ridge on ODP Leg 106, currently in progress.

SUMMARY

The international scientific community is better prepared in the mid 1980's than ever before to investigate the sediments and basement rocks of the vast areas of the deep ocean. The capabilities of drilling deeper holes in deeper water in more challenging environments are more than matched by increased laboratory space with more advanced scientific instrumentation, more sophisticated electric wireline measurements and techniques, and with the equipment to employ them.

The vehicle of this expanded scientific effort is a newer, larger, faster drillship staffed by professionals of the world's largest offshore drilling contractor. It is equipped with state-of-the-art machinery and electronics. The textbooks will continue to be rewritten and the world, as well as the scientific community, will become familiar with JOIDES Resolution, aka Sedco/BP 471.

ACKNOWLEDGEMENTS

The contributions of the shipboard staff and the management of Sedco/BP 471 to the preparation of this paper are greatly appreciated. The often behind-the-scenes efforts of engineering, design, logistics, and operations personnel of Sedco-Forex, Earl and Wright, TAMU-ODP and the various contractors have produced a complex machine that works. It is because of their efforts that seagoing personnel have an opportunity to produce results.

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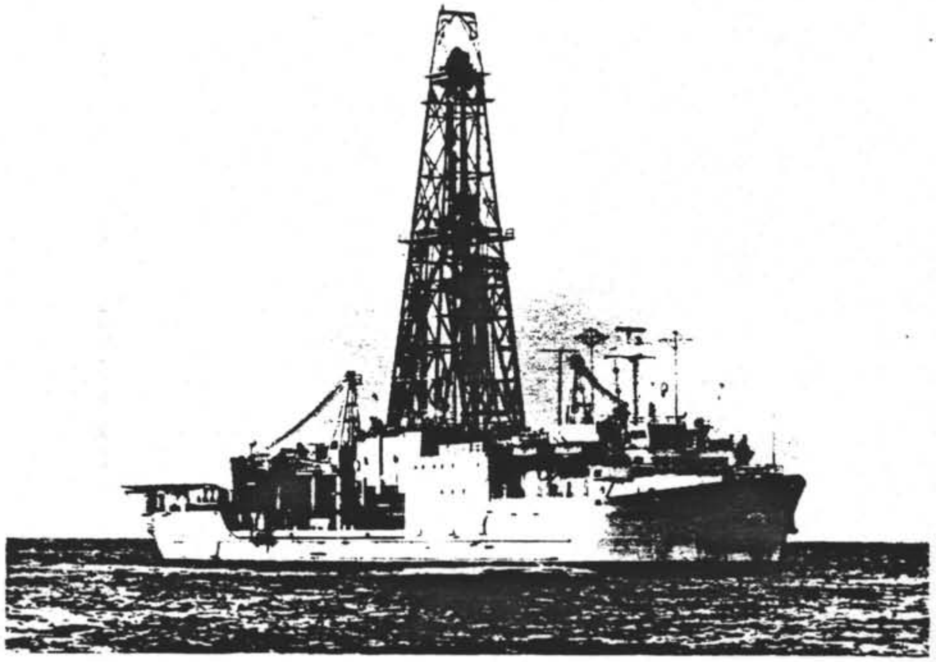


Figure 1: JOIDES Resolution on location in the Norwegian Sea on ODP Leg 104.

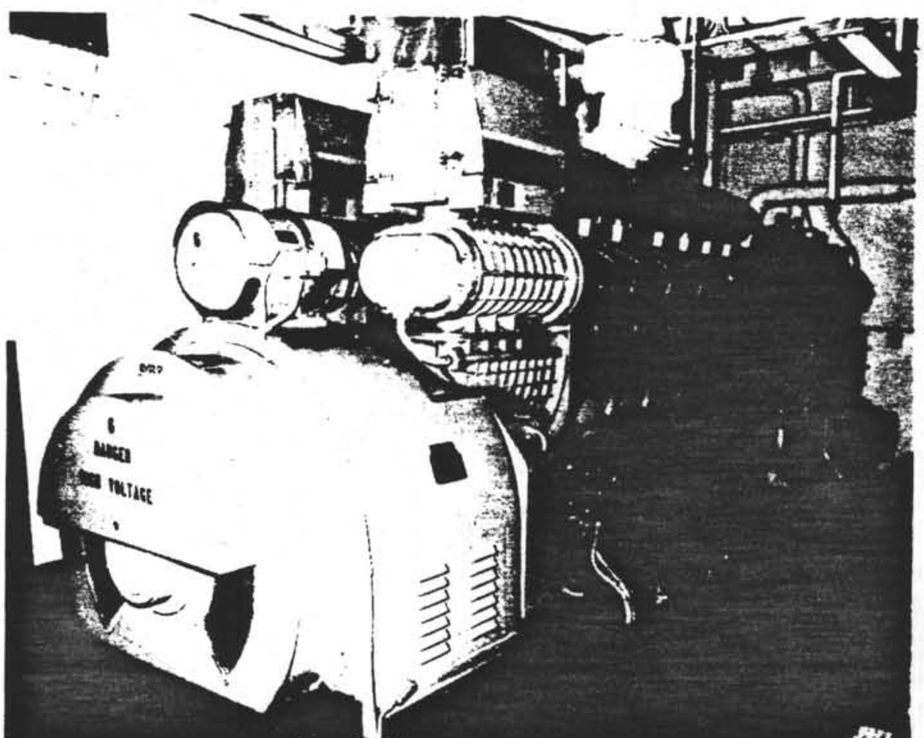
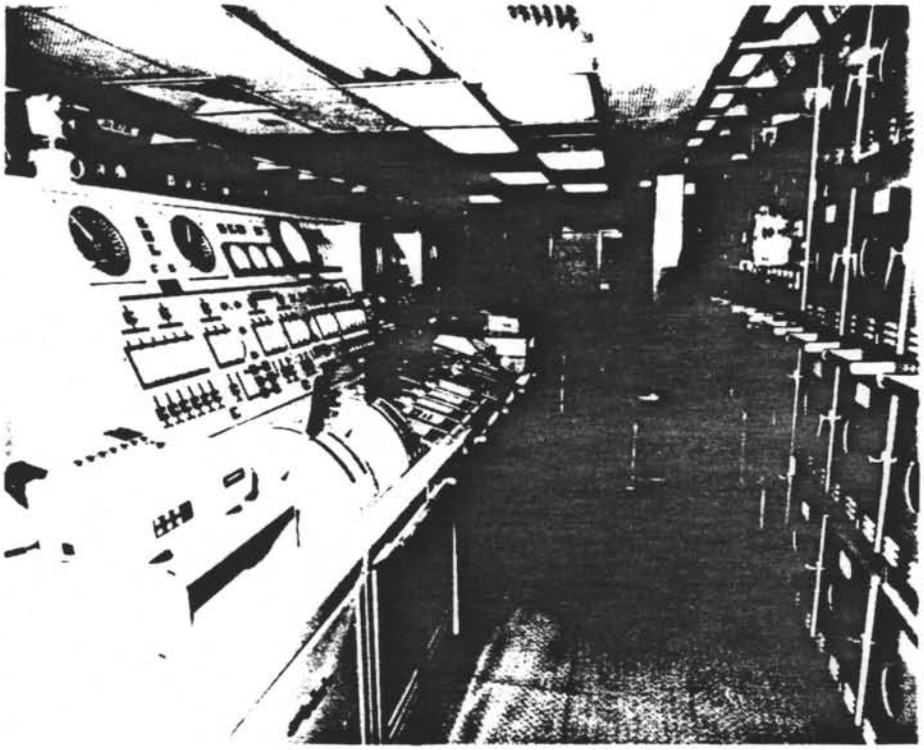


Figure 2: Ship's service engine/generator



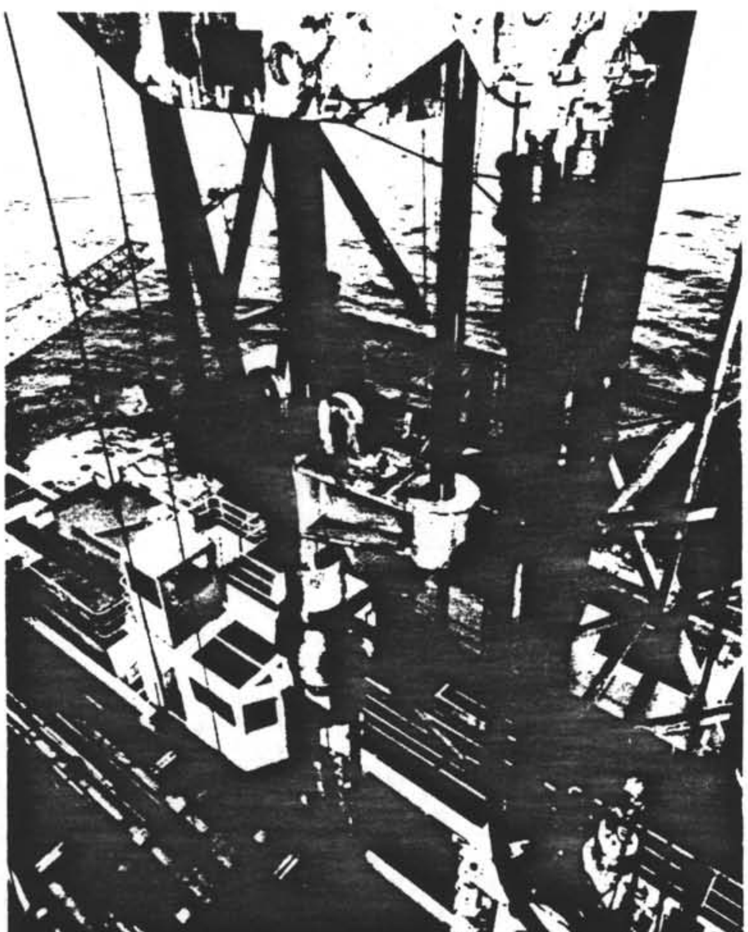


Figure 3: Engine control console, PMS computer in background

Figure 4: Drill String Heave Compensator

Figure 5: Electric top drive/swivel assembly

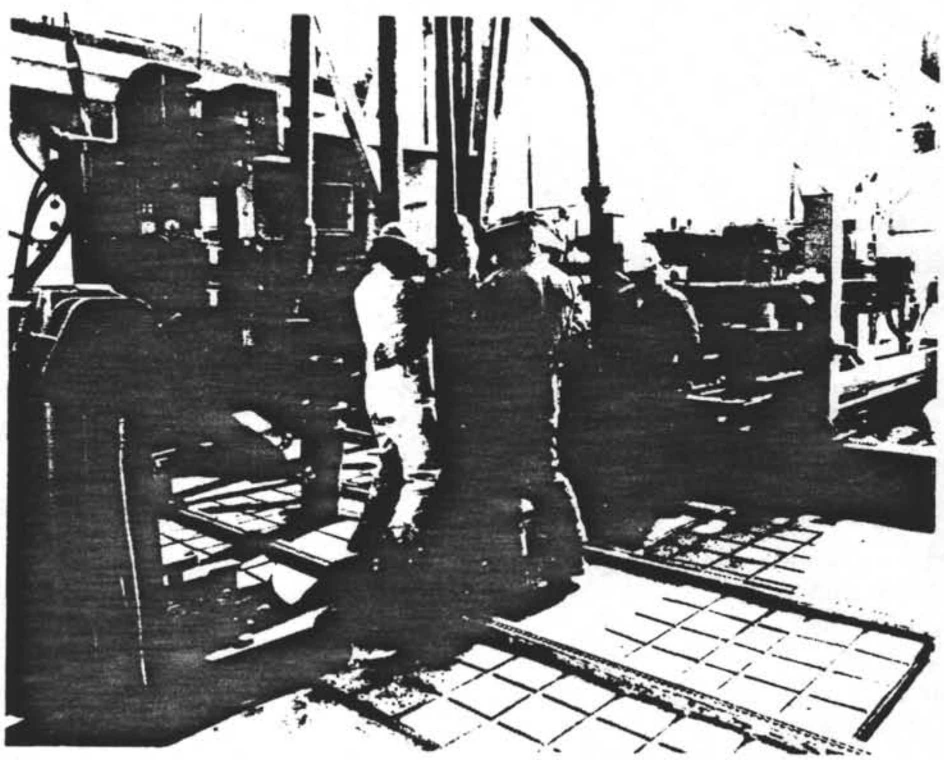


Figure 6: Rig floor during coring operations, showing dual elevator retractor, "iron roughneck" and pipe stabber

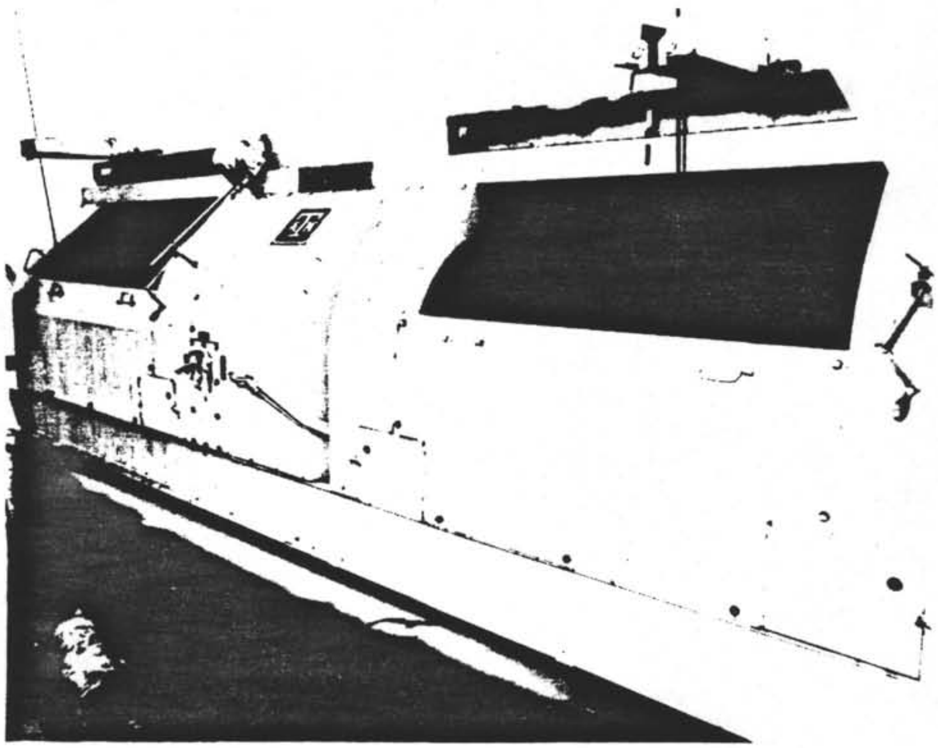


Figure 7: Dual-drum electric coring winch

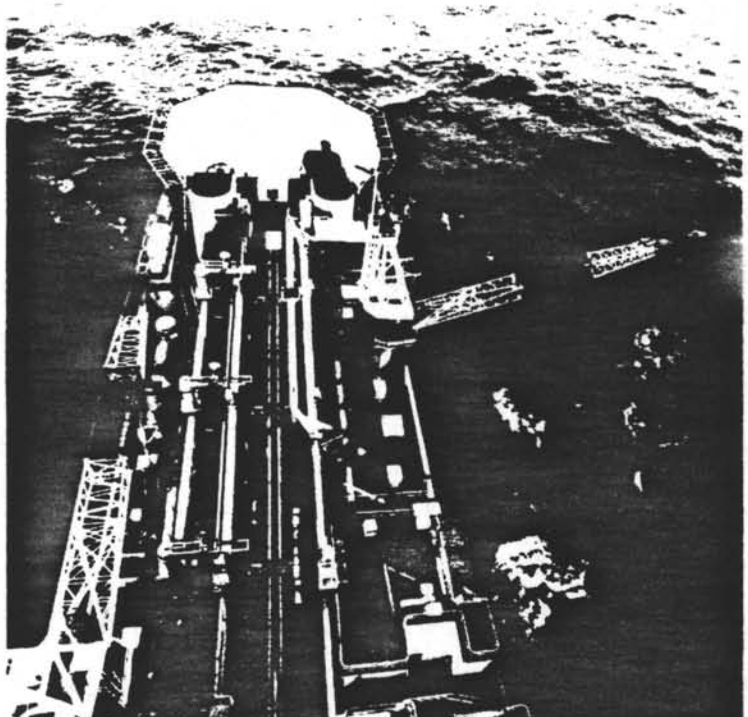


Figure 8: Downhole seismic experiment in progress; logging equipment, crane-deployed airgun and piperacker area shown

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The Ocean Drilling Program III: The Shipboard Laboratories on "JOIDES Resolution"

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ABSTRACT

JOIDES Resolution (a.k.a. SEDCO/BP 471), the scientific drillship of the National Science Foundation's Ocean Drilling Program, contains over 12,000 square feet of laboratory space. Years of experience gained in the previous JOIDES program of scientific ocean drilling (the Deep Sea Drilling Project) have provided many ideas for improving upon the capabilities of a scientific drillship. Each laboratory on JOIDES Resolution is designed to include state-of-the-art equipment and techniques.

A laboratory module seven stories high was added to the ship. This allows for ship investigations of sedimentology, physical properties, paleomagnetics, chemistry, petrography, and paleontology. In addition, thin section, X-ray diffraction/X-ray fluorescence, underway geophysics, logging and downhole measurement, computer, photographic, core storage, and library facilities are all available.

This paper emphasizes the new instrumentation that was acquired or developed for the laboratories. Some techniques and equipment are in use for the first time at sea. Our experiences with these through the program's early cruises are related. The program plans to continually update its shipboard laboratory capability.

INTRODUCTION

A principal feature of the 470-foot JOIDES Resolution, the drillship of the Ocean Drilling Program (ODP), is its seven story laboratory module. This was constructed on the starboard side of the vessel (Figure 1), a commercially-operated dynamically-positioned drillship with riser capability (a.k.a. SEDCO/BP 471) (1). The laboratory structure contains the world's largest and most varied array of research equipment in operation at sea.

Eight of the vessel's ten major analytical areas are arranged in two upper deck levels (Decks 5 & 6) of the laboratory module (Figure 2). These areas cover sedimentology, physical properties, paleomagnetics, paleontology, chemistry, and petrography, as well as dedicated laboratories for scanning electron microscope (S.E.M.) and X-ray diffraction/X-ray fluorescence equipment. A ninth analytical area, the borehole instrumentation laboratory, sits on top of the laboratory structure (Deck 7). The underway geophysics laboratory (Y) is a tenth major area for data collection and analysis. It is located at the stern of the vessel under the helicopter deck.

The lower levels of the laboratory module (Decks 1-4) are taken up with additional scientific work spaces that provide support for the analytical areas. These include computer, photographic, and electronics repair facilities, refrigerated core storage, offices, a "second look" lab, and the science lounge. At main deck level, forward of the vessel's accommodations areas, is the ship's science library (Z).

These facilities occupy more than 12,000 square feet of science work space on the drillship. JOIDES Resolution is unique in the variety and technological level of the equipment provided by these laboratories and in its extensive use of computers in data collection and analysis.

Every effort was made to include state-of-the-art instrumentation in the design of the laboratories. Selection of equipment was based upon advice from a JOIDES Advisory Group on Equipment and Laboratories (JAGEL). ODP also contracted with an architectural firm having experience in laboratory design to assist in the development of the laboratory layouts and furnishings. In addition, the ODP scientific and technical staff that gathered at Texas A&M University hailed from major oceanographic institutions all over the world. Many key personnel transferred from the Deep Sea Drilling Project, the program's predecessor at Scripps Institution of Oceanography. During the vigorous start-up phase of purchasing, testing, and development of new equipment, this pool of expertise ensured both a fresh approach to the problems of laboratory research at sea and continuity for data handling procedures that had been developed over the past 15 years of deep sea drilling.

Early in the planning it was decided to place in the new laboratories operationally sensitive high-technology equipment that had never before been used at sea. The decision was predicated upon the high degree of operational stability expected of the ship and various types of vibration insulation being designed into the laboratory module, its furnishings, and equipment mountings. To date this bold descision appears justified. Beginning with a shakedown cruise in January, 1985, ODP has now completed five operational legs, the last two in high latitudes. Each cruise sails with a technical support crew of up to 25 personnel, increasingly becoming better trained and more experienced. Below we describe each laboratory area in turn, emphasizing experience gained with the newer pieces of shipboard equipment. [More detail on the individual laboratories and their equipment may be found on ODP Technical Note No. 2, 1985 (2).]

The cores recovered at the drill floor are held in plastic liners about 9.5 meters long. These flexible liners are transferred to the catwalk at bridge deck level (Figure 3) where they are cut into 1.5-m long sections. From there they enter the first of the laboratory module's analytical areas.

1. SEDIMENTOLOGY LABORATORY

The sedimentology laboratory is divided into four areas: core entry, core splitting, core sampling, and core description (Figure 3). The 1.5-meter core sections are brought into the core entry area for labelling and entry of their details in the central computer's data base. After whole-round core measurements are made in the magnetics and physical properties laboratories, the sections are cut longitudinally in the core splitting room into "working" and "archive" halves. The core splitter is an improved version of that used on Glomar Challenger, but is isolated in a separate room in the interests of cleanliness and noise reduction for other parts of this laboratory level. Archive sections pass on to the core description area while working sections go on to the core sampling area: separate tables are available for each, as well as a variable-height photography table. Bench space around the core-description table contains microscope and slide preparation stations. Smear slides are prepared using hot plates stationed under benchtop fume absorbers, and Isotemp ovens. A variety of mounting media and stains is available.

The optical equipment located in the sedimentology lab is similar to that which is available in the paleontology and petrography laboratories. Equipment here includes two ZEISS microscopes on board. These microscopes and all others aboard the ship are mounted on vibration isolation units specially designed by ODP's senior technicians. The units have proven very successful, allowing routine use of high-power magnification with little or no vibration blurring.

Core sampling equipment available in the sampling lab includes FELKER radial arm saws, a drill press with diamond coring bits and a minicorer, heat guns, and heat sealers. Computer terminals are conveniently located for direct input of sampling data and for printing sample labels.

2. PHYSICAL PROPERTIES LABORATORY

The ODP has made a major commitment to geotechnical data collection with expanded shipboard capabilities for physical, thermal, mechanical, and acoustic measurements of sediments and rocks. JOIDES Resolution's physical properties laboratory is adjacent to the sedimentology areas (Figure 3). Samples pass through this area both before and after core splitting (Figure 4).

Core sections are routinely scanned in the whole-round by a G.R.A.P.E. device (Gamma Ray Attenuation Porosity Evaluator) as used on Glomar Challenger. This evaluator has been extensively reconfigured in order to scan cores vertically in JOIDES Resolution's laboratory. A mechanical stage transports the shielded, 10-millicurie ^{137}Ce source and its detector past vertical core sections at up to 30-50 cm/min. A second range of slower speeds (5-30 cm/min) is available for greater resolution. A DEC PRO 350 computer monitors sediment or rock density and automatically senses anomalous areas that warrant a second slower scan. Alternatively, scans can be run under manual speed control. Data are displayed and logged at a dedicated computer terminal. The G.R.A.P.E. device can also be used for two-minute counts on discrete samples.

Thermal conductivity equipment, designed at Woods Hole Oceanographic Institution, has five needle probes for simultaneous measurements on whole-round cores. Data are collected, reduced, and displayed on a dedicated PRO 350 computer. Thermal conductivity results used in conjunction with data from a downhole temperature measurement tool provide estimates of heat flow.

Shear strength measurements on split sediment core sections are obtained with a motorized vane equipped with torque transducer and rotational outputs. The output data are recorded on a HEWLETT PACKARD XY flatbed recorder.

A HEWLETT PACKARD Faxitron allow X-radiographs to be made of slab samples on board ship. An auto-exposure unit, entension collar, and plexiglass sample trays facilitate use of this equipment.

Bulk and dry density, porosity, and water content analyses are made on discrete samples taken from the split cores using a computerized balance on a specially gimballed table and a Quantachrome automated pycnometer. The pycnometer provides accurate volumetric measures on up to five samples at a time. Standard submerged weighing capabilities are also provided.

Two transducer configurations are available for shear and compressional wave velocity analyses. A blade-type transducer mount for use on soft sediment samples contains both a bender element for shear wave generation and a compressional element. Samples of rock and lithified sediment are tested using a frame-type transducer mount.

A GDS consolidation/triaxial testing system provides analyses of sediment stress history, strength, mechanical properties, and permeability. Data collection and reduction for this system are computerized through an HP-85B link to three digital pressure controllers. Permeabilities are obtained through indirect computation of consolidation results or directly from a low hydraulic gradient test using a syringe flow-pump system.

Other physical properties laboratory equipment includes hand-held trovanes, soil test penetrometers, and Atterberg limit devices.

3. PALEOMAGNETICS LABORATORY

The paleomagnetics laboratory occupies a separate area on the bridge deck level of the laboratory module (Figure 3). It features two magnetometers: a three-axis, pass-through 2G cryogenic (superconducting) magnetometer and a fluxgate spinner magnetometer. The cryogenic magnetometer generally scans whole-round core sections prior to splitting, but is also capable of discrete sample measurement. It is linked to a DEC PRO 350 microcomputer that controls pass-through movement and acquires magnetization intensity values from each of the three axes. Presently, only a few cryogenic magnetometers of this type are operational in shorebased laboratories. The ODP unit is now reaching its full potential after continuous use on three cruises. Preliminary indications are that although a sea-going unit is supremely attractive for its whole core scans and sensitivity, it is unlikely, becasue of vessel motion, ever to reach the resolution reported for similar shore-based equipment.

A BARTINGTON susceptibility meter, equipped with a whole-core scanning loop sensor, operates in-line with the cryogenic magnetometer's pass-through system to give a continuous record of down-core susceptibility. A separate single-sample sensor is used to measure discrete sample susceptibilities. A low-field, three-axis, alternating field demagnetizer (up to 10 mT), operates in line with the cryogenic magnetometer and is also linked to the PRO 350. The magnetization remaining after partial demagnetization is measured by the cryogenic magnetometer on a second pass-through.

A MOLSPIN spinner magnetometer, interfaced to an EPSON HX-20 microcomputer, measures very strongly magnetized samples and serves as a backup for the cryogenic magnetometer. General paleomagnetic lab support equipment includes a SCHONSTED fluxgate probe magnetometer for monitoring ambient magnetic fields within the magnetic shields and around the lab area, and a SCHONSTED single-axis alternating-field demagnetizer capable of demagnetizing discrete samples up to 1000 Oe.

After photography of the split archive core sections in the sedimentology laboratory and completion of sampling for both shipboard and shore-based analyses, all core sections are prepared for refrigerated storage on the upper and lower 'tween deck levels (Figure 2, Decks 1 & 2). Samples for shipboard analyses pass one deck down to the laboratories on the foc'sle deck (Figure 2, Deck 5).

4. PALEONTOLOGY LABORATORY

The paleontology laboratory aboard <u>JOIDES Resolution</u> is divided into adjacent preparation and microscope study laboratories (Figure 5). The paleo-prep lab is set up for processing micro-paleontological samples and making slides. It contains standard equipment such as sieves, hot plates, infra-red lamps, ovens, and chemicals, as well as a LABCONCO steam laboratory glassware washer and benchtop slide warmers with fume adsorbers. Optical equipment and a library of reference materials required for micropaleontological research are located in the microscope study lab. The optical equipment includes two ZEISS WL microscopes with a full range of objectives, including those required for Nomarski and phase contrast microscopy, and four ZEISS SR stereomicroscope (type III POL) that can be used by paleontologists is located in the petrography laboratory. Polaroid and 35mm camera backs and a SONY TV video system are available for adaptation to any microscope. Other optical equipment includes drawing tubes to aid in making sketches of microscopic images, and stage and eyepiece micrometers.

5. PETROGRAPHY AND THIN SECTION LABORATORY

The petrography and thin-section laboratory (Figure 5) has equipment to make thin sections either by traditional methods or in large quantities, and optical equipment for detailed shipboard analysis. When only one or two thin sections are required they are made "by hand" using a BUEHLER Petro-Thin thin-sectioning system and thin-section grinder. When large batches of thin sections are required, as during an ocean crust drilling leg, the LOGITECH LP-30 lapping machine can produce approximately 200 high-quality thin sections in one week. The sections are polished on a LOGITECH WG-2 polishing system. Special support equipment in the thin-section lab includes a LOGITECH CS-10 thin section cut-off saw and IU-20 vacuum impregnation unit used to impregnate porous or friable specimens with synthetic resins. Delicate or critical samples are cut on a LECO VC-50 Vari-speed diamond saw.

A range of microscopes is available for thin-section and rock-sample study: four ZEISS standard WL polarizing petrographic microscopes with reflecting light, photographic, and video capabilities; two ZEISS photomicroscopes (type III POL) that can accept both 35mm and Polaroid camera attachments; and two standard ZEISS SR stereoscopes. All of the microscopes have interchangeable accessories. Petrographic descriptions of thin sections are recorded in the ODP database through computer terminals located adjacent to the microscope stations.

6. CHEMISTRY LABORATORY

Facilities for shipboard chemical analyses are greatly expanded on <u>JOIDES Resolution</u> over those in use during the Deep Sea Drilling Project (Figure 5). In addition to routine shipboard analysis of sediment, rock, and pore water samples, the chemistry laboratory plays a major role in the safety of the vessel. Samples of sediment or entrained gases and other hydrocarbons are taken upon initial core recovery and are rigorously monitored. Results are relayed directly to the ODP Operations Superintendent in order to maintain safety in drilling operations.

Gas monitoring equipment in the chemistry laboratory (Figure 6) includes two HEWLETT PACKARD 5890 Gas Chromatographs (GC's), one dedicated to hydrocarbon monitoring for natural gas analysis and the other with a capillary column. The gas chromatograph configured for natural gas analysis has one 10- and two 6-port switching valves allowing very precise separation of hydrocarbons on a run-time of about 20 minutes. A thermal conductivity detector (TCD) and flame ionization detector (FID) are hooked up in series to the unit. The GC is connected to a Lab Automation System (LAS) that converts and integrates data output, generating a customized report for each run. The LAS also runs the capillary column gas chromatograph. Because the column is quartz, there is improved separation between peaks of similar compounds. Alternatively, this GC can be run with a single Poropak column for separation of light hydrocarbons, an option which allows very quick analysis of hydrocarbon shows that may directly affect drilling operations.

A DELSI NERMAG Rock-Eval II Plus TOC is used for whole-rock pyrolsis. It can rapidly evaluate type and maturity of organic carbon, calculate petroleum potential, and detect oil shows. It has a printing recorder and an automatic sampler that holds 48 samples.

A PERKIN-ELMER CHNS Elemental Analyzer is also available for measuring amounts of organic carbon in sediment samples, as well as hydrogen, nitrogen, and sulfur. Analyses typically take 12 minutes per sample, but only after extensive sample preparation time.

A TURNER Fluorometer in the chemistry lab and a HALLIBURTON ultraviolet ray box in the core lab produce qualitative analyses of hydrocarbon shows.

The carbonate bomb, with a precision of ±5% and a 5-minute run time, serves as the principal measuring device for large numbers of carbonate samples. The bomb is a simple hand-held unit with a pressure gauge on top, indentical to those used previously on Glomar Challenger. A COULOMETRICS analyzer, that makes accurate photometric measurements of carbonate constituents in sediments, may also be run. It has a possible precision of ±1%. Both devices use concentrated hydrochloric acid to dissolve all carbonate compounds in a small dried and ground sediment sample.

The shipboard DIONEX Ion Chromatograph (IC) has three columns: one for anions, a second for monovalent cations, and a third for divalent cations. The chemists measure amounts of lithium, sulfate, calcium, magnesium, sodium, and potassium in interstitial water squeezed from the whole round core samples. The IC is microprocessor-controlled, with data passed to the LAS, and includes an autosampler that can hold 56 samples.

The laboratory's automated BRINKMAN titration system measures the pH, alkalinity, and chlorinity of interstitial water and can also be used for calcium and magnesium measurements. Salinity or total dissolved solids for interstitial water are measured with a temperature-compensated refractometer.

Colorimetric measurements of ionic concentrations in pore water samples are conducted on a BAUSCH & LOMB Model 1001 Spectrophotometer. With a wavelength range from 190 to 950 nm, ionic concentrations of nitrate, silica, ammonia, bromide, and other common pore-water constituents can be measured. The spectrophotometer accommodates a variety of cell types and sizes, facilitating the precise analysis of small (microliter) sample volumes.

The chemistry laboratory contains a number of other instruments necessary for shipboard geochemical analyses. These include four Carver hydraulic presses, with one hydraulic pump for every two presses. Each press is capable of 25 tons constant pressure. Two gimballed tables support balance systems: the first table has twin CAHN 29 balances for small samples (up to 1250 mg), and the second table has twin SCIENTECH balances for larger samples (1 mg to 50 g). A LABCONCO 39-port freeze drier is available for removing water from sediment samples, and can hold 39 individual samples of up to 15 cc each. The ship's portable water is run through a BARNSTEAD water purifier to produce both lab and reagent (18-ohm) grade waters by osmotic pressure. There are hardended steel ball SPEX mill grinders and electronic agate mortar/grinders for homogenizing dried sediment samples, and a shatterbox for pulverizing basalt or hard-rock samples. One fume hood in the chemistry lab is for solvents, and two others are for chemical reactions. An ashing furnace is located in the adjacent X-ray lab.

7. XRF/XRD LABORATORY

JOIDES Resolution's X-ray fluorescence/diffraction laboratory (Figure 5) is the most advanced of its kind on any ocean research vessel. An APPLIED RESEARCH LAB 8400 Hybrid Spectrometer is used for X-ray fluorescence analysis. This instrument is fully microprocessor-controlled with automatic sample loading. It has an end-window Rhodium X-ray tube, 60 kV generator, and two independent goniometers with scintillation, flow proportional (P-10), and sealed Kr detectors. Supporting the 8400 is a DEC Micro-11 computer with 28-megabyte Winchester disk drive. The unit is presently set up to analyze for ten major and nine trace elements. The system can be upgraded in the future with either a third goniometer, several single-channel monochromators, or a Si/Li detector for energy dispersive analysis.

A PHILIPS ADP 3520 is used for X-ray diffraction analyses (Figure 7). The ADP 3520 is also fully microprocessor-controlled with automatic sample loading, and is configured with a Cu X-ray tube and monochromator. A second DEC Micro-11 computer with a 28-megabyte Winchester disk drive supports this system. Software support includes quantitative, search-and-match of the JCPDS and user data bases, line profile analysis, and statistical analysis programs.

8. S.E.M. LABORATORY

The shipboard ISI SX-25 Scanning Electron Microscope is located next to the petrography laboratory. It has a continuous magnification range from 15x to 100,00x and working distances from 8 mm to 38 mm, giving a capability for both high resolution and large depth of field. The S.E.M. operates with an accelerating voltage of 25 kV and uses Polaroid Type 52 (positive) and Type 55 (positive and negative) films. It is capable of backscatter electron imaging as well as secondary electron imaging. Experience to date suggests that this has been a successful shipboard deployment of an operationally sensitive piece of equipment. The specially designed vibration isolation mountings used aboard ship for this and other major pieces of laboratory equipment have worked well in all cases. The quality of S.E.M. images at higher magnifications deteriorates with vessel motion and with some drilling operations. However, 1500x magnifications are possible in all but storm conditions and considerably higher magnifications are possible in calmer seas.

The two remaining analytical laboratories are not involved in handling core samples, but are designed for the acquisition of geophysical data.

9. DOWNHOLE INSTRUMENTATION LABORATORY

The downhole instrumentation laboratory, located on top of the laboratory structure (Figure

2), houses equipment and work space for logging tasks. Lab space is divided into two sections: (1) a "wet" lab for storage, cleaning, and major repair of tools, and storage for ancillary equipment; and (2) a "dry" lab for computer and electronic equipment and repair facilities. A MASSCOMP computer data acquisition system in the dry lab is linked through a closed circuit to the main logging winch. Surface panels for different logging tools are also linked with data acquisition; graphics are provided by a VERSATEC plotter.

A comprehensive range of logging tools are available as part of the standard wireline logging package offered by Lamont-Doherty Geological Observatory (L-DGO) through a sub-contract to SCHLUMBERGER. The reader is referred to a companion paper for this session (3) that describes further this laboratory and its logging tools. ODP also makes available to shipboard investigators its own suite of downhole tools, including a core orientation multi-shot compass/camera, a pressure core barrel, an in situ pore water sampler, and a downhole temperature measurement tool.

10. UNDERWAY GEOPHYSICS LABORATORY

The underway laboratory, where single-channel seismic reflection, magnetometer, and echo sounder profiling data are collected, is located below and forward of the ship's helicopter deck (Figure 2). JOIDES Resolution does not, at present, routinely collect underway geophysics data on all transits between drill sites or between ports and drilling areas, as did Glomar Challenger for DSDP. Despite our up-to-date seismic profiling system, we are as yet unable to collect good quality seismic data at the full cruising speed of the vessel (around 15 knots). At speeds of up to 10 knots reasonable records are possible, but valuable operational drilling time is lost if we do not transit at full cruising speed. For this reason ODP only routinely collects underway data at slower speeds (approximately 8 knots) during approaches to and departures from drill sites and excellent quality records are usually obtained at these times. These records allow location of the optimum drill site and determine its relationship to the regional geology by comparison with previously-run site survey records. Our development plans are to improve towing configurations to allow operation of the equipment at full cruising speed. In the meantime, data collection during transit depends upon a perceived scientific need for data over key or under-explored areas of the ocean. All data collected are eventually deposited with, and become freely available from, the National Geophysical Data Center (NGDC) in Colorado.

The standard seismic sources aboard JOIDES Resolution are two 80-cubic-inch and one 400-cubic-inch SEISMIC SYSTEMS INC. waterguns. Two types of airguns are also available, each with variable chamber sizes: one BOLT 1500-C airgun with 120- or 300-cubic-inch chambers and three BOLT 1600-A guns with chambers from 5 to 80 cubic inches. Mounted on winches on the fantail are two 100-meter-long TELEDYNE streamers, each containing 60 hydrophones.

Data recording for the seismic system is independent of the main VAX shipboard computer. A super-micro MASSCOMP-561 computer is the central unit used for seismic recording, processing, and display. As well as real-time recording of unprocessed analog data on EDO 55 recorders, digitized data are processed and displayed, almost in real time, using either a PRINTRONIX graphic printer or a VERSATEC plotter where a wider record with higher resolution is required. The software and interfaces for the various components of the ODP seismic system were developed at the University of Texas at Austin. Software packages that allow various filtering, move-out, auto-correlation, deconvolution, and depth conversion are presently available. Other programs are under development.

Two GEOMETRICS 801 proton precession magnetometers are towed from winches on the fantail. They are linked to a recording system which displays real-time traces on a strip chart but data are also recorded in the header of the tapes that record for the seismic system.

Echo sounding is by hull-mounted 3.5-kHz and 12-kHz transducers. The sounder data are displayed, after amplifying and filtering, on EDO-WESTERN recorders. Both frequencies may be passed through a RAYTHEON CESP-III Correlator to improve the signal-to-noise ratio. A towed transducer fish configuration is presently under consideration, which would allow high-resolution 3.5-kHz records to be collected at the vessel's full cruising speed.

Navigational data aboard ship are now primarily dependent upon a MAGNAVOX Combination Transit and Global Positioning System (GPS), after an initial period of cruises in which the ship's original satellite navigation system was used. Data from the Magnavox unit are recorded on the headers of the seismic tapes and sent to the VAX computer where navigation plots are generated. Satellite coverage for GPS is steadily being increased. In regions that are presently covered, the system allows the ship a remarkable positional accuracy to within 10 meters.

11. COMPUTER FACILITIES

JOIDES Resolution is unique as a research vessel in its integrated use of computing equipment for data collection and analysis and for word-processing in the production of shipboard reports. The central computer system performs a wide range of laboratory-oriented functions, including core-log entry, core sampling, data analysis, presentation graphics, monitoring for microscopy and chemistry, and manuscript preparation. These tasks are accomplished through conveniently located micro-computer workstations placed all over the ship. A central theme in the design of the shipboard system was the offloading of common tasks onto the workstations to allow more efficient use of the central system.

The shipboard system is based on the VAX 11/750 super-mini computer, using up to fifty DEC PRO 350 microcomputers as intelligent workstations. The central system and its associated components are housed in the computer complex on the main deck (4) of the laboratory structure (Figure 2). This climate-controlled facility contains a user room with several workstations and system peripherals that include a laser printer, two high-speed printer/plotters, a 36" drum plotter, a bar code terminal, and two daisy-wheel letter quality printers.

Each major system component has a redundant twin providing a backup in the event of irreparable component failure at sea.

The DEC PRO 350 P/OS operating system is exceptionally easy for a first-time user to learn and provides an integrated software environment from which to run various specialty software. Tutorials and classroom instruction for shipboard scientists and technicians are conducted routinely by the shipboard System Manager at the start of each cruise. For many participants the familiarity gained with microcomputer data handling and word processing aboard JOIDES Resolution represents a major turnaround in their approach to science.

SUMMARY

JOIDES Resolution is unique for the variety and up-to-date nature of the equipment housed in its shipboard laboratories. Many pieces of equipment were either specially designed for the vessel or were deployed in a shipboard setting for the first time. After five operational cruises, nearly every major piece of equipment is operating smoothly, and has added considerably to the immediate results of the drilling. The laboratory complex stands alone in integrated data collection and analysis through extensive use of computing facilities. Plans are to continually upgrade the laboratory capabilities as the Ocean Drilling Program develops. JOIDES Resolution is truly a state-of-the-art research facility for the earth sciences.

ACKNOWLEDGMENT

The laboratories of JOIDES Resolution are a tribute to the expertise, dedication, and enthusiasm of the senior ODP technical and computing personnel. This team scoured the world's commercial and scientific community in the search for the most up-to-date and effective equipment for the ship. They designed and fitted the equipment into the laboratories, and even took courses to learn how to use the newest pieces. They passed on their own considerable experience to ODP's new breed of marine technicians and have clearly infected them with their own professionalism and pursuit of excellence. Shipboard scientists will benefit hugely from their efforts in the years to come.

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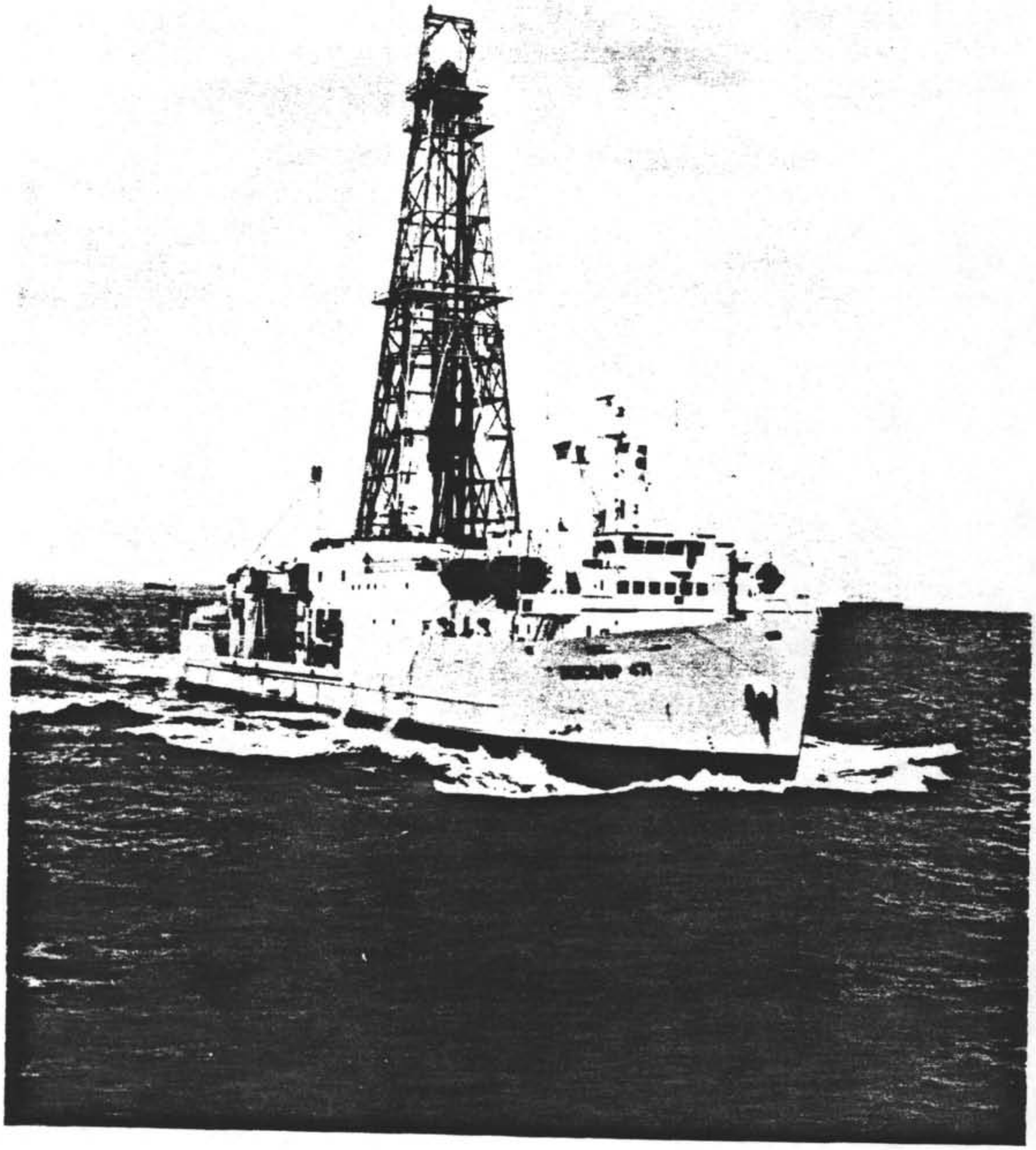
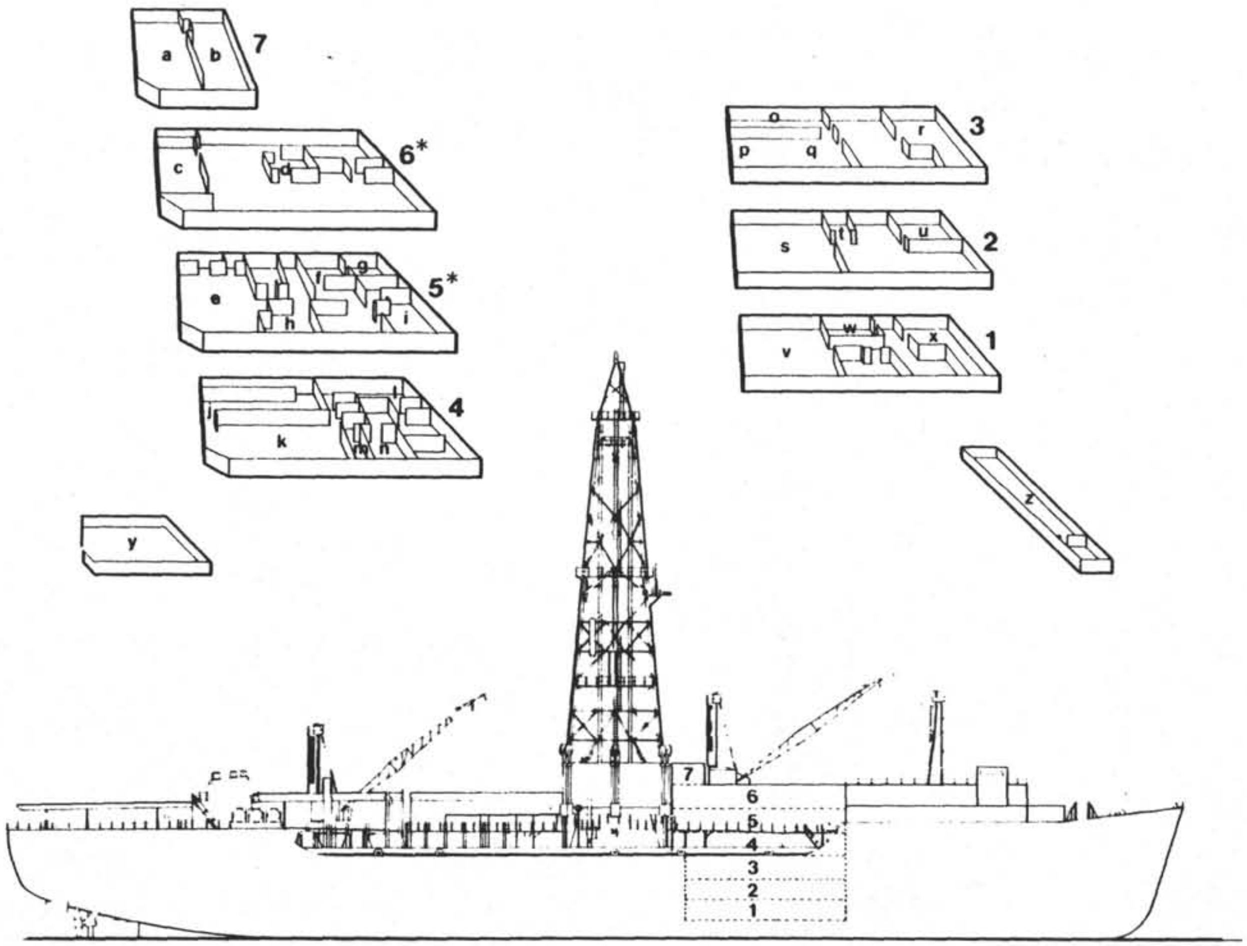


FIGURE 1: JOIDES Resolution (SEDCO/BP 471) underway from Miami at the start of the Ocean Drilling Program. Note the laboratory module on the starboard side forward of the derrick.

ODP DRILLING VESSEL



- a. Downhole Instruments, Logging
- b. Downhole Instruments, Logging
- c. Magnetics Lab
- d. Core Splitting Lab
- e. Chemistry Lab
- f. Petrology Stations
- g. Thin Section
- h. Paleo Stations
- i. Paleo Prep Lab
- j. Computer
- k. Science Lounge
- l. Computer User
- m. Yeoperson's Office
- n. Co-Chief's Office
- o. Electronic Shop
- p. Photo Darkroom
- q. Photo Finish Room
- r. Fan Room
- s. Core Storage Reefer
- t. Cold Storage
- u. 2nd Look Lab
- v. Core Storage Reefer
- w. Freezer
- x. Storage
- y. U/W Geophysics
- z. Library

FIGURE 2: ODP drilling vessel: exploded view of the laboratories in the module added during the conversion of JOIDES Resolution.

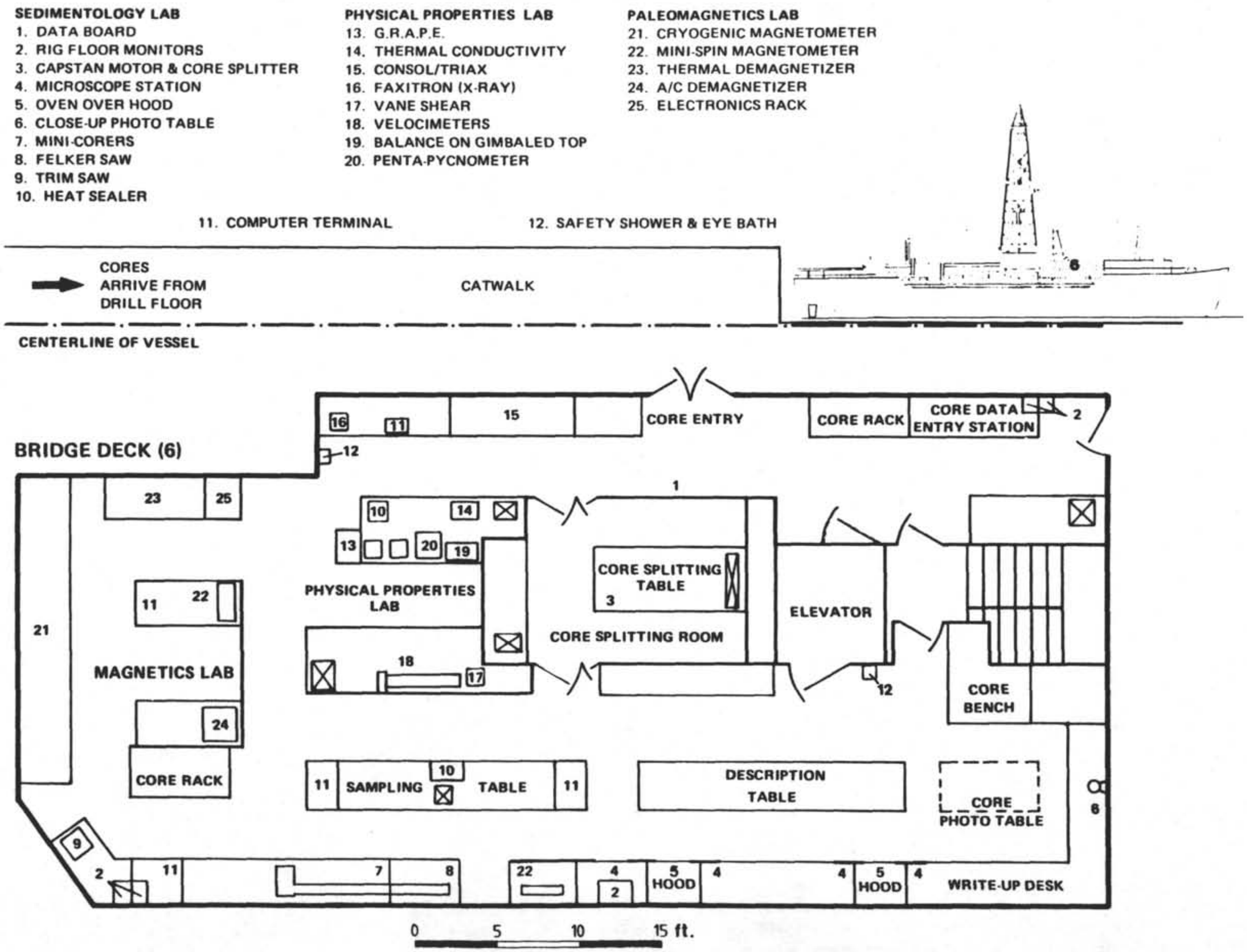


FIGURE 3: Plan of the bridge deck level (6) in the laboratory module with equipment locations.

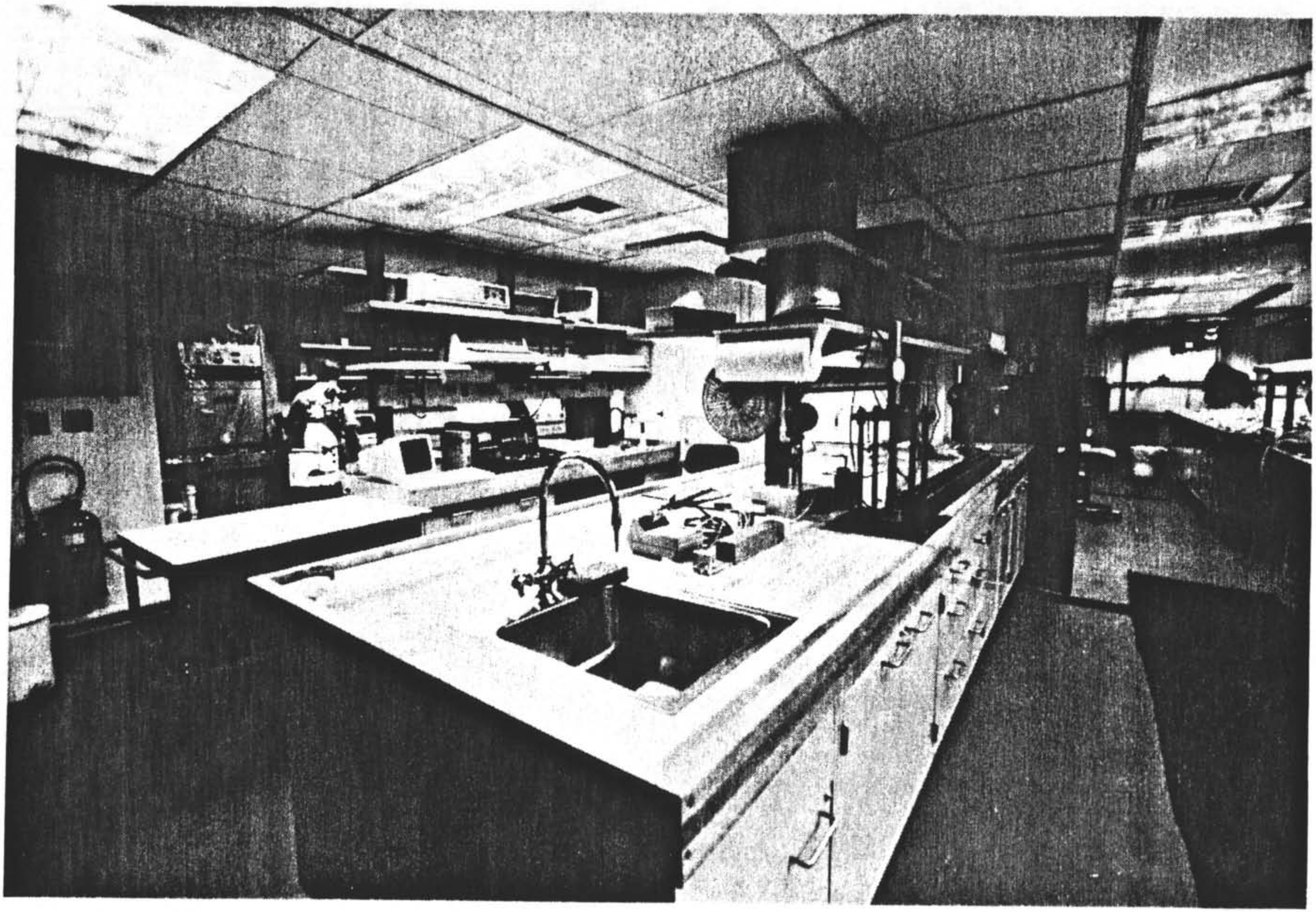


FIGURE 4: View of the physical properties laboratory area (for equipment locations see Figure 3). Bench in foreground contains velocimeters and vane shear equipment. Bench far right is core description area. (Note: In this photo, vertical G.R.A.P.E. device not yet installed.)

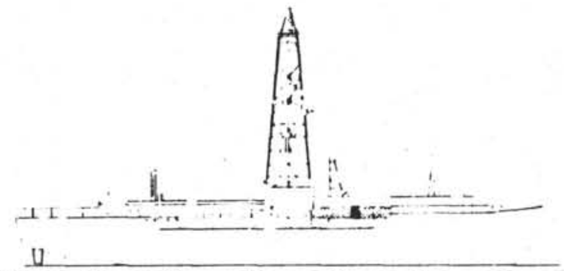
CHEMISTRY LAB
1. BALANCE TABLE GIMBALED
2. AUTOMATED C-H-N-S ANALYSER
3. ROCK EVALUATION SYSTEM
4. CANOPY HOOD
5. FUME HOOD
6. PRESSES
7. ION CHROMATOGRAPH
8. AUTOMATIC TITRATION
9. FREEZE DRYER
10. FREEZER BELOW
11. WATER PURIFICATION SYSTEM
12. GRINDERS
13. CHEMICAL HOOD
14. HYDROFLUORIC ACID HOOD
15. GAS STORAGE & CENTRAL REGULATOR
16. SAFETY SHOWER & EYE BATH
17. HP 1000 COMPUTER FOR CHEMISTRY LAB
18. GAS CHROMATOGRAPH
19. CARBONATE ANALYZER

XRD/XRF LAB
20. ELECTRONICS/COMPUTER CABINET
21. XRF MONITOR
22. PW/1730 X-RAY GENERATOR
23. GAS BOTTLE STORAGE
24. DEC. MINICOMPUTER AND XRD CONTROLLER
25. HEAT EXCHANGER
26. X-RAY SPECTROMETER
27. XRD PW 1720 GENERATOR
28. COLOR PLOTTER
29. COLOR TERMINAL

PETROGRAPHY & THIN SECTION LAB
30. MICROSCOPES
31. COMPUTER TERMINAL
32. SAW GS-10
33. PETRO-THIN GRINDER
34. LOGITECH LP - 30 GRINDER POLISHER
35. BUEHLER LAP WHEEL
36. W-20 VAC IMPREGNATOR
37. FINE POLISHER
38. SLIDE PREP
39. MICROSCOPE

PALEONTOLOGY LAB
40. CHEMICAL HOOD
41. STEAM WASHER BELOW
42. CANOPY HOOD
43. PALEONTOLOGY REFERENCES
44. MICROSCOPE/TERMINAL

S.E.M. LAB
45. SCANNING ELECTRON MICROSCOPE
46. MICRO FILM/MICORFICHE READER



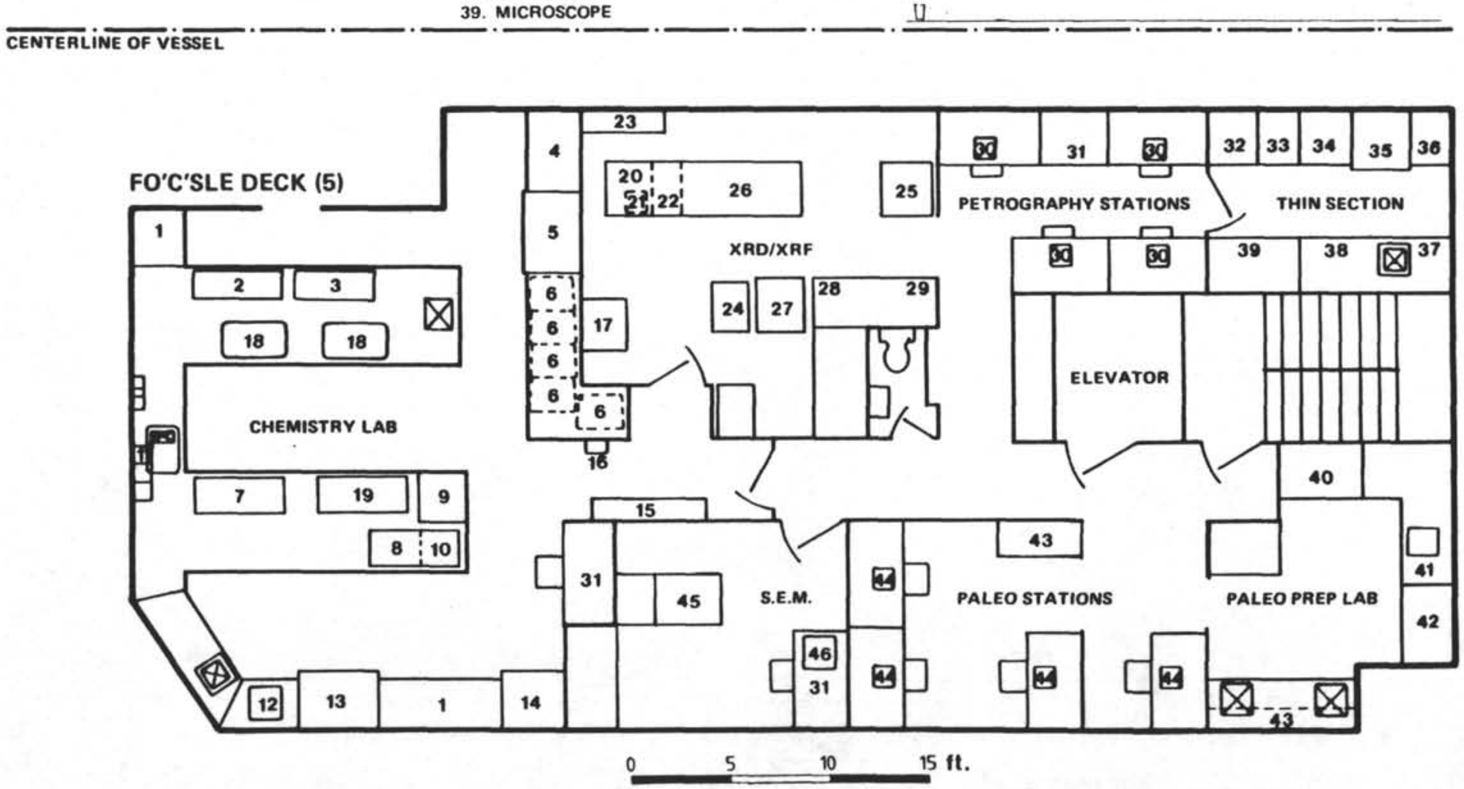


FIGURE 5: Plan of the foc'sle deck level in the laboratory module with equipment locations.

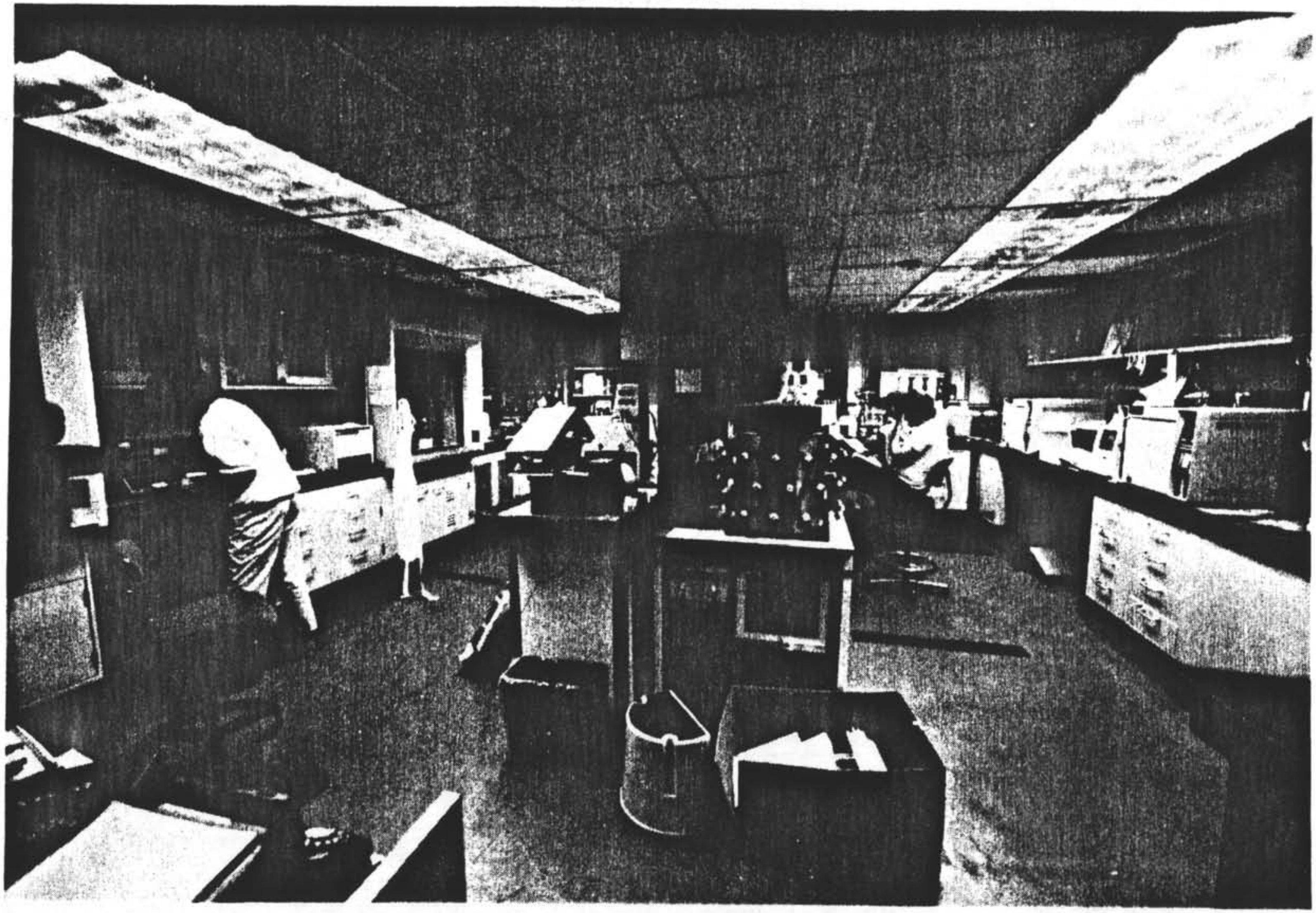


FIGURE 6: View of the chemistry laboratory (for equipment locations see Figure 5). Freeze drier is in the center foreground and gas chromatographs for hydrocarbon monitoring are on the right-hand bench.

FIGURE 7: View of the XRD/XRF laboratory (for equipment locations see Figure 5). X-ray diffraction equipment in foreground with automatic sample loader and terminal on bench. Note the vibration isolation spring mountings at floor level.

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THE OCEAN DRILLING PROGRAM IV:

DEEP WATER CORING TECHNOLOGY PAST, PRESENT AND FUTURE

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ABSTRACT

Using the technology developed during 15 years of the highly successful Deep Sea Drilling Project (DSDP), the Ocean Drilling Program (ODP) is continuing to pursue both the scientific objectives of recovering core samples from beneath the world's oceans and the technical objectives of advancing the state-of-the-art of deep water coring. The wide variety of wireline coring tools developed during DSDP (1968-1983) which are still in use include a standard Rotary Core Barrel (RCB), a through-the-bit Extended Core Barrel (XCB) and a Pressure Core Barrel (PCB) for recovering cores at in situ pressures up to 5000 psi. All of these are variations of rotary coring done in conjunction with TCI roller cone core bits.

Non-rotary coring tools and downhole instruments have included three generations of hydraulic piston corers for use in recovering undisturbed cores in unconsolidated sediments. The most recent version, the Advanced Piston Corer (APC), is about half as mechanically complex as its predecessors, yet delivers 76% greater coring thrust. Magnetic azimuth orientation for each piston core is available utilizing an Eastman multishot tool. A miniaturized electronic temperature measuring instrument can be used with the APC or a combined Heat Flow/Pore Water Sampler tool can be deployed in soft formations.

Current ODP tool developments include a wireline retrievable hard rock coring tool, driven by a 3-3/4 inch diameter mudmotor. A sea floor structure to stabilize a hollow rotor 9-1/2 inch PDM mudmotor is being developed to start holes on hard rock with little or no sediment cover.

Possibilities for future tool developments include: hydraulic sidewall samplers for hard rock or soft formations; in situ gas sampling in soft sediments; wireline retrievable downhole geotechnical instruments; a vibracorer to recover loose sands; and "smart" core barrels with the ability to interpret and adjust for changes in coring parameters.

INTRODUCTION

The coring technology in use today for deepwater core sampling for marine geology research has many historical roots, not the least of which are conventional oil-field technology and Project Mohole. When the Mohole effort was abandoned in 1966, it left behind an extensive body of engineering development which had demonstrated the feasibility of coring the deep ocean basins of the world from a dynamically positioned drillship. This technological legacy passed to the Deep Sea Drilling Project which began coring operations in August 1968.

At the outset of DSDP it was recognized that new technology would be required for the shipboard dynamic positioning problem as well as the shipboard drilling apparatus. Accordingly, the Glomar Challenger (Figure 1) was outfitted with then state of the art computerized dynamic positioning equipment, an innovative top drive for use in lieu of the conventional hex kelly/rotary table, a dual elevator system, advanced piperacker, high speed coring winch, a guidehorn structure in the moonpool to control the bending radius of the drillpipe, and, later, a first-of-its-kind heave compensator. The drillstring was the S-135, 5 inch drillpipe engineered during Project Mohole. All elements of the drillstring, including drill collars and bumper subs, were designed with a minimum 4-1/8 inch bore to facilitate wireline coring.

The policy toward coring tool development was, however, not geared toward innovations. In view of the mounting costs which had proved fatal to Mohole, DSDP began with the hope of using existing oilpatch coring technology rather than undertaking expensive development of new tools and techniques specifically for scientific coring. In the years that followed, this philosophy slowly gave way to a pro-development policy the goal became one of providing whatever tools were needed, by way of new development if necessary. The oil industry did not have technology adapted for the unique scientific objectives and did not provide the responsiveness and continuity necessary for effective and timely pursuit of expanding goals as DSDP progressed far beyond its initial, modest 18-month contract.

With the transfer of the JOIDES scientific program from DSDP to the Ocean Drilling Program the policy of technical and engineering development to meet scientific needs became a commitment. A new drillship, the JOIDES Resolution (Sedco/BP 471, Figure 2) was converted from a conventional offshore oil exploration vessel to a floating laboratory and drilling platform for scientific exploration of the deep ocean. All of the best concepts evolved over the 15 years of the Challenger's career were incorporated in the new ship.

The derrick and rig floor equipment were revamped with systems selected to optimize high speed wireline coring using a drillstring up to 30,000 feet long. A new heave compensator was designed and produced specifically for the Program and incorporated as a part of the traveling block. Both of these components, plus the swivel and power sub, were provided with a 4-1/8 inch axial bore for maximum flexibility in handling wireline coring equipment, logging tools, sinker bar assemblies, and downhole instruments.

A new emphasis was also placed on preparation of the coring tools for ODP deployment. The best of the DSDP equipment was adapted, and where necessary, modifications were made to increase intercompatibility between different types of coring tools to achieve the greatest downhole sampling flexibility while minimizing the necessity of tripping the pipe for changes in coring or sampling techniques. New development projects were initiated to meet specific downstream scientific objectives. A special emphasis is being placed on incorporating core sampling technology from the mining industry. Adaptation of the older DSDP techniques, use of current state-of-art technology from the oilfield, offshore and mining industries, and development of all new tools will continue in the ODP development plans for the foreseeable future.

HISTORY - DEEP SEA DRILLING PROJECT

Rotary Core Barrel (RCB)

The policy of using only existing technology for coring tools prevailed under the DSDP program for about five years. During that time all cores were taken with a simple rotary core barrel which was a slightly modified version of a commercially available oilfield tool from Hycalog. The RCB (Figure 3), which remained in service during all of DSDP, is essentially a passive core receptacle which latches into place behind a core bit and captures the incoming core, nominally 2.44 inches diameter by 30 feet long. A drill collar acts as the outer core barrel. A variety of different types of core catchers can be installed at the bottom of the inner barrel to retain the core within a clear butyrate liner. A check ball is provided to allow the trapped fluid above the incoming core to be vented without allowing backflow which would wash out the core. The entire barrel below the latch assembly is suspended on bearings so that it can "float" and be free from rotation relative to the incoming core. The RCB can be pumped to the bit at approximately 700 ft/min and retrieved at 500 ft/min by a sandline and sinker bar with an overshot to engage a fishing neck on the tool.

Results with the RCB have depended mainly on the type of formation encountered. Hard or well compacted sediments can be cored consistently at better than 50% recovery rate with minimal disturbance. Softer sediments, oozes or hard/soft interbeds are often badly disturbed or washed away. The RCB remains the only reliable coring tool for deep basement penetration, being the simplest and ruggedest of the coring tools.

Pressure Core Barrel (PCB)

The first significant departure from the existing-technology-only policy during DSDP was the development of a wireline retrievable pressure core barrel. Scientific interest in the nature and existence of gas hydrates in marine sediments, plus a desire by geochemists to obtain pressurized samples of pore fluids and gases, resulted in a mandate to provide a coring tool capable of retrieving deep ocean cores at in situ or near in situ pressures. DSDP conducted an industry survey in 1972-73 and found that the only reliable pressure core barrel which was commercially available at that time was not wireline retrievable and could not be adapted to the Challenger drillstring. The manufacturer of that tool, plus ten other oilfield related companies, eventually declined to participate in a program to develop a tool designed expressly for DSDP needs.

Thus, DSDP embarked on an engineering development effort, initially relying heavily on private consultants from industry, but eventually turning in-house for design engineering. The PCB went through three generations of testing, re-design and field tests. The latest version, shown in Figure 4, is a companion to the RCB, except that the core diameter must be reduced to 2.25 inches by use of a core bit with a smaller throat. The PCB and RCB can be used interchangeably if the smaller core is acceptable for RCB operations.

The pressure barrel features a mechanically actuated ball valve which closes as the tool is retrieved by the sandline. One meter of non-pressurized core is recovered below the ball valve, while up to 5.5 meters of core is captured in the pressure chamber above the valve on each run. For safety reasons, pressures in excess of 5000 psi are automatically vented off as the tool is recovered, thus maintaining a 4:1 safety factor in the pressure case. On deck, a sampling manifold allows investigators to take gas samples and monitor overpressure. Pressure must be relieved completely before the core material can be removed from the barrel.

The PCB performed successfully at several sites, recovering cores at pressures up to 4700 psi, but was used sparingly during DSDP. It is best suited for coring in formations that are moderately compacted. Oozes and soft sediments tend to be badly disturbed by the rotary drilling process while indurated sediment or basement rock inhibit full closure of the ball valve during retrieval.

<u>Pore Water/Heat Flow Sampler (PWS)</u>

The need to sample pore water fluids and record in situ temperatures in relatively undisturbed sediments resulted in development of an instrumented barrel which could be deployed in place of the standard rotary core barrel. The Pore Water Sampler (Figure 5) is landed in the outer barrel and latched in exactly as the RCB. A probe extends up to one meter beyond the bit face and contains a thermistor and pore water intake filter. The bit is then lowered to bottom and the weight of the drill collars pushes the probe into undisturbed sediment. An electronic timer then starts a sampling sequence. A valve opens to allow a pore fluid sample to enter the sample coil displacing distilled water into an overflow chamber through check valves. At the end of a preset time interval all valves are closed. During this process temperatures detected by the thermistor are stored into electronic memory. While the PWS is being recovered, a regulator vents off unsafe, excessive pressures from the overflow chamber. On deck, the sample coil can be removed and stored for analysis of the pore fluid aboard ship or ashore. The temperature measurements are dumped from the memory and permanently recorded before the batteries are removed.

<u>Hydraulic Piston Corer (HPC)</u>

The success of the engineering effort to produce the Pressure Core Barrel and the desire by sedimentologists, paleontologists and others to obtain undisturbed cores of soft sediments paved the way for the development of the Hydraulic Piston Corer. The HPC development marked a significant milestone in the official attitude of DSDP toward new technology as a means of responding to scientific needs. The spectacular technical success and scientific impact of the three generations of hydraulic piston corers demonstrated that developing new tools and techniques unknown to the oil industry or elsewhere had both economic and technologic merit. The policy had become: do whatever type of engineering was necessary to achieve the scientific objectives rather than accept the artificial limitations imposed by off-the-shelf technology.

The concept of the HPC was derived from various types of "conventional" piston corers used for years on oceanographic vessels. These tools relied, in general, on gravity as a driving force and lacked the ability to penetrate even soft sediments more than a few tens of meters. They did, however, demonstrate that the severe disturbance of unlithified sediments caused by rotary drilling could be virtually eliminated by non-rotary, direct insertion of a core barrel.

The initial version of the piston corer as adapted to the Challenger's drilling system was first field tested in 1978. It was designed to take a 14.4 feet long, 2-1/2 inch diameter core recovered in the same butyrate liner used in the RCB and PCB. Early results were extraordinary; sediment layers which had been homogenized when coring was attempted previously with rotary coring techniques were retrieved at 90+% recovery rates with practically zero disturbance. Figure 6 shows sections of cores taken at the same depth in adjacent holes by each coring system which demonstrates the value of piston coring for high resolution studies.

The original HPC-15 was soon replaced by the VLHPC (Variable Length Hydraulic Piston Corer) which could be assembled in several different configurations to take cores up to 30 feet long. The VLHPC was mechanically complex and difficult to handle on deck, however, and was replaced in 1983 by the latest version of the hydraulic piston corer dubbed the APC (Advanced Piston Corer) to differentiate it from its predecessors (Figure 7). The APC functioned equally as well as the VLHPC, while offering the advantages of 76% greater coring thrust and about half the cost and mechanical complexity of the VLHPC. On deck handling was facilitated by the fact that the tool was 30 feet shorter than the VLHPC in the extended condition.

All of the piston corers operate according to the same principles. The core barrel is locked together with shear pins and lowered to the bit where it lands and seals off the drillpipe. Hydraulic pressure is then applied to the entire drillstring by the ship's mudpumps until the load on the shear pins causes them to fail. The energy which has been stored (as compressed water) then drives the telescoping portion of the corer into the sediment beyond the core bit at velocities up to 26 ft/sec. The entire 30 foot stroke is generally completed in less than two seconds so that the corer is effectively decoupled from the heave induced vertical motion of the drillstring. The core barrel is then retrieved by the sandline, the bit is "washed" down to the next coring point and the process is repeated.

Piston coring can commonly continue to sub-bottom depths of about 200 meters. At that point refusal is defined as either excessive resistance to penetration by increasingly stiffer sediments or by overpulls in excess of 80,000-100,000 lbs. required to extract the extended barrel from sticky sediments.

Magnetic Core Orientation

The non-rotary nature of hydraulic piston coring and high resolution studies made possible by the lack of disturbance of the cores opened the way for paleomagnetic analyses of piston cores. To accomplish this, an in situ magnetic azimuth reference was required for each piston core. Technology required to accomplish this had been developed by the oil industry for directional drilling and well surveys, thus an adaptation of existing survey tools was possible. Battery powered, self-contained camera/compass tools were available from a number of oilfield vendors in singleshot and multishot versions. Each "shot" was a flash photo of a compass card with a reference "lubber" line superimposed. During DSDP a Kuster singleshot tool was deployed with the VLHPC or APC when magnetic orientation was desired for a given core. The singleshot unit was housed in a special pressure case which was an integral part of the sinker bar assembly on top of the core barrel spaced out so that the compass was centered in a special, non-magnetic drill collar. The lubber line was mechanically aligned with reference lines marked on the butyrate core liner which stayed with the core throughout analysis, handling and storage.

The Kuster singleshot was adequate in principle, but suffered in practice, and failed to provide bonafide orientation data all too often. Its primary shortcoming was the timing required to flash its one photo at the proper moment of the piston coring operation. Both mechanical and non-magnetic-sensor trigger/timer mechanisms were used without consistent success. At the start of ODP the Kuster singleshot was replaced by an Eastman-Whipstock multishot tool to improve the quality of orientation data. The multishot takes photos of its compass at set intervals (e.g. 30, 60, 120 seconds) from the time it is installed in its pressure case until it is returned on deck. A stop watch is used to determine at what time the significant orientation photo is exposed so that it can be located on the developed film strip.

Von Herzen Heat Flow Tool

The fact that the piston corers extended 30 feet beyond the bit, and more importantly, 30 feet beyond the disturbance of the borehole, presented another possibility for advantageous instrumentation. A miniaturized electronic temperature recording device was developed in 1982 in a cooperative effort between the DSDP engineering staff and a group at Woods Hole under the direction of Dr. R. Von Herzen. The electronic package, battery pack and thermistor probe were designed specifically to fit into tiny pressure-tight cavities in the wall of a special cutting shoe assembly for the VLHPC and APC (Figure 8). The electronic circuits were capable of monitoring and recording temperatures for several hours on one set of batteries; long enough to deploy and retrieve the piston corer with the special "heat flow shoe" at its leading edge. Once on deck the electronic memory could be interrogated with a desk top computer and the temperature data for the entire deployment cycle could be recorded. A temperature spike corresponding to frictional heating as the piston corer penetrated the sediments would identify the data of interest. The in situ temperature of relatively undisturbed sediments 30 feet below the drilled portion of the borehole could be derived from the temperature data immediately following the friction spike.

Extended Core Barrel (XCB)

The history of extended core barrels for use in deep water wireline coring dates back to 1971 and 1973 when a slightly modified oilfield version of the tool was acquired by DSDP from Christensen Diamond Products and deployed with moderate success. The XCB as known today did not get the impetus for full development until the hydraulic piston corers made their impact on DSDP coring operations.

The original concept of the extended core barrel was to improve upon quantity and quality of core recovery in certain types of formations using a wireline retrievable, rotary core barrel, but with a few significant improvements. The XCB would land and latch at the bottomhole assembly as the RCB, but the lower end of the tool would extend ahead of the bit 4 to 8 inches. The barrel would be driven with the drillstring by rotary torque transmitted at the latch. A spring was included to allow the cutting shoe to retract up into the roller cone bit when firm layers were encountered. To accomplish all of this a modified core bit was required with a 3-5/8 inch throat to pass the 3-1/2 inch diameter cutting shoe. The advantages were many: the cutting shoe being extended beyond the bit protected the incoming core from the aggressive hydraulic action required at the face of the roller cone bit, the drag bit trimming action of the cutting shoe resulted in a less disturbed core, the spring loading allowed the core barrel to stay "nosed into the formation" and automatically adjusted to enhance recovery of difficult-to-core hard/soft interbeds.

The early models of the XCB met with some problems typical of prototype tools and the XCB concept was shelved until 1979 when new interest was generated as a by-product of the success of the HPC. When piston coring operations were terminated in a given hole due to induration of the sediments, a time-consuming pipe round trip was required to change the core bit and bottomhole assembly for the RCB. This was necessary because the core bit used for piston coring had a throat opened up to allow the 3-1/2 inch diameter HPC barrel to extend beyond the bit. A tool was required which, 1) would be compatible with the HPC bottomhole assembly, 2) would enable coring to continue in the same hole using rotary coring techniques, and 3) could trim the core from approximately 3-3/4 inches to 2-1/2 inches in diameter. The XCB had finally acquired its mandate.

The current version of the XCB (Figure 10) provides all of the conceptual advantages of the original tool. It mates with the APC in a common bottomhole assembly so that high quality cores can be taken continuously from mudline to basement without a drillpipe round trip. The inner core liner is mounted on low friction bearings so that it can "float" rather than rotate relative to the core. A portion of the fluid pumped continuously to the jets in the core bit is diverted by a choke and directed to ports at the cutting structure of the cutting shoes. A variety of cutting shoes can be used, depending on formation type. A DSDP designed sawtooth shoe for soft formations is augmented by off-the-shelf diamond cutting shoes from the mining industry. A heavy duty, positive drive latch has been developed for the XCB to withstand the relatively high torsional and shock loads encountered.

The XCB can be used to advantage when coring in formations ranging from soft chalk or clay to fully indurated materials. It has recovered fully lithified volcanogenic rocks without missing the soft pelagic materials above and below. It is not adequate for more than nominal penetration (a few meters) into basement rocks.

ODP - RECENT AND CURRENT DEVELOPMENTS

The hiatus from drilling operations between the final cruise of the Challenger and the shakedown cruise of the JOIDES Resolution provided an ideal opportunity to tie up many loose ends in the engineering technology of deep water scientific coring. The 14-month period was used to make long overdue revisions to the design of the three front line coring tools: the RCB, APC and XCB. Each was modified for ease of on deck handling and space out adjustment in relation to their particular bottomhole assemblies. The APC and XCB were made fully compatible in the same optimized bottomhole assembly for the first time. The Eastman multishot was selected to replace the Kuster singleshot for HPC magnetic orientation and the necessary auxiliary sinker bar equipment was designed.

Also during the operations hiatus the groundwork was laid for new engineering developments to satisfy scientific needs.

Hard Rock Spud System

Re-entry cones placed on the sea floor to enable sonar re-entry for multiple bit runs in the same hole had been a proven technique in the DSDP arsenal since 1970. Deep penetrations into oceanic basement beyond the reach of a single bit required this capability. One major coring objective which proved elusive was young basalts along the ridge crests of active spreading centers where little or no sediment cover had accumulated. Without the minimum of 50-100 meters of soft sediment required to stabilize the bottom of the drillstring, the hole simply could not be started (spudded).

ODP is currently working on a hard rock spud system which will be deployed for the first time in November 1985. The system combines a unique sea floor structure, PDM mudmotors to drive the bit without drillstring rotation and a deep water TV system.

The sea floor structure (Figure 9) is comprised of two major elements. A guide base will be deployed first and allowed to land at any angle up to 18 degrees. The base will then be filled with cement and has rubber bags which also fill with cement to provide added mass and a 4-6 foot pilot hole leading to the basalt after the cement is drilled out. A hole 18-1/2 inches in diameter will then be drilled for a modified re-entry cone and 16 inch casing using a slightly modified Christensen PDM mudmotor. The casing will follow the hole, hopefully vertical, and the cone will be gimballed to settle in a vertical position.

After the 16 inch casing is cemented in place, coring in the basalt will begin using a special Christensen mudmotor with a hollow rotor to allow wireline coring. Slim (3 inch diameter) mining-type core barrels will be used in the early stages of development of the hard rock spud system. Redesign to allow use of the larger standard ODP rotary coring tools may be done in the future.

"Navidrill" Slimline Mudmotor Core Barrel (NCB)

A new coring tool intended to extend the range of XCB-type coring into hard rock is currently under development in a cooperative effort between Norton Christensen and ODP. The tool integrates a 3-3/4 inch diameter MACH I "Navidrill" PDM mudmotor with an XCB-type core barrel (Figure 11). At the beginning Christensen HWD4 mining core barrels with diamond impregnated core heads will be used. The overall NCB tool is designed to be wireline retrievable and compatible with the APC/XCB bottom hole assembly.

The NCB, scheduled for preliminary sea trials in August 1985, can conceptually be deployed in any of three modes. One option is to simulate the action of the XCB with the NCB cutter head extending ahead of the core bit only 6-12 inches. The mudmotor would then drive the core barrel and core head at 100-250 rpm faster than the drill string to optimize cutting efficiency of the diamond coring structure. A second option would allow the NCB to simulate the action of the APC by extending ahead of the core bit a full 30 feet. The high rpm core barrel would cut the core in mining-fashion. The core barrel would then be retrieved and the drill string would be drilled down to the next coring point. A third more unlikely, though attractive, option would be to allow the NCB to core ahead of the bit to a theoretically unlimited depth. After each 30 foot core the depth limit of the core barrel would be increased 30 feet by adding, drill rod to the core barrel assembly before returning it to the bit. This would allow a last chance to obtain cores from deeper in the formation if the core bit had worn out prior to reaching the scientific objective in single bit holes.

Venturi Vent Sub

A nagging problem encountered in the design and operation of all core barrels which do not have pistons (e.g. HPC) is venting the fluid out of the liner as the core enters. In most cases a simple check ball and vent orifice at the top of the core barrel is used to allow vented fluid to escape while preventing back flow into the liner. The vented fluid enters the annulus between the inner and outer core barrels and mixes with the fluid pumped to the bit jets. The flow restrictions at the bit jets and in the tight annulus result in back pressures at the liner vent ports as great as 200-300 psi. The check ball will not lift and allow the vented fluid to escape until the pressure in the core liner exceeds the annulus back pressure. This means that pressure on the top of the incoming core can present a force of up to 1400-1500 lbs. which resists entry of the core into the liner and inhibits full recovery.

If the back pressure sensed by the check ball could be eliminated or reduced, the force restraining the core as it enters the liner would also be reduced. One way to achieve this is currently under development. A venturi vent sub has been designed and will be tested on a simulated XCB system in August 1985. The sub directs the flow of the annulus fluid through a venturi orifice. The low pressure zone in the proximity of the Venturi stream is used to reduce the pressure above the check ball in the vent. It is theoretically possible to reverse the pressure regime around the check ball to maintain a constant flow out of the liner past the ball, even if no core is entering. Successful application of the venturi vent sub to any rotary type coring tool could greatly enhance recovery in hard-to-core materials such as loose sands, sticky clays and hard/soft interbeds.

FUTURE DEVELOPMENT POSSIBILITIES

Some of the concepts listed below represent definite plans to be pursued in the near future; other are visionary blackboard ideas at best. Although all are technically feasible some will prove to be impractical and die on the vine; others will bear fruit and play their role in helping to advance the deep ocean sciences.

Heave Compensated Hydraulic Piston Coring

All rotary coring techinques can now be done while using the drill string heave compensator. During hydraulic piston coring operations, however, the heave compensator cannot be used for a number of reasons. Several design adaptations to the APC, the sandline winches, or both, are feasible which could make these systems compatible. Heave compensation would do much to reduce disturbance of piston cores taken during heavy weather and aid in positive depth definition.

Sidewall Sampler

The oil industry uses electric and explosive sidewall samplers for obtaining small cores from the sides of boreholes. ODP does not currently have this capability although the ability to obtain samples from zones of zero recovery would be very desirable. Although the industry does not offer a sidewall sampling tool exactly suited to the ODP drill string, adaptations of existing designs may be possible. Other concepts worth considering include a hydraulic sidewall sampler for soft formations based on APC technology, or a hydraulically driven downhole motor with a right angle drive to operate a small diamond core head in hard formations.

Gas Samplers/Pressure Core Barrels

The current version of the Pressure Core Barrel is limited to recovering cores at in situ pressures no higher than 5000 psi in unindurated formations suited to conventional rotary coring. Other tools expressly designed for in situ pressure sampling may expand this technology. An adaptation to the APC for in situ sampling of gases in soft sediments is possible. Core barrels capable of handling pressures higher than 5000 psi or able to core and capture hard rock in a pressure chamber have been considered. Techniques and equipment to remove and sample solid core material on deck under in situ pressure have already been devloped in the oceanographic community and could be adapted.

Wireline Retrievable Geotechnical Tools

Geotechnical investigators have already developed in situ vane shear testers, cone penetrometers and packer-type, inflatable formation testers for use at the seafloor and in shallow subsea boreholes. Adaptation of these tools for wireline operations aboard the Resolution would open a new avenue of deepwater borehole research.

Loose Sand Recovery Tools

A consistently difficult coring problem occurs in regions where loose sands are encountered. Any free flowing material made up of hard particles resists piston corer penetration due to incompressiblity. Rotary coring or XCB coring commonly alluviates light particles and washes them away before they can be captured in the core barrel. Core catchers often fail to retain portions of the material which are fortuitously coaxed into the core barrel.

Some investigators have successfully used vibracorers for taking samples in such formations. They are capable of significant penetration in materials which frustrate high thrust piston coring techniques and do far less disturbance to the cored material than rotary techniques. A vibracorer suitable for ODP deepwater applications has been envisioned using hydraulic power to provide vibratory impacts to an APC-type core barrel.

A full closure, universal core catcher is on the drawing boards which could provide the ultimate retention capability for a vibracorer when sampling loose sand. The universal core catcher is planned to accommodate any type of core material by using an elastic sleeve which could close off the bottom of the core barrel completely with compliant cores materials or close down tightly around hard rocks and prevent them from slipping away.

Acoustically Coupled Heat Flow Shoe

The current Von Herzen Heat Flow Shoes for use with the APC must be opened after each core run to attach a connector to the electronic memory and read out the temperature data. This process is time consuming at best and risks loss of data through accidental distubance of wiring, damage to pressure seals or moisture contamination of the circuitry. A logical next step is to provide acoustic coupling through the metal wall of the cutting shoe to interrogate and clear the memory, check battery life and set up the system for the next run, all without opening the pressure cavities until new batteries are required.

Kevlar Sandline for Wireline Coring

The state-of-the-art of Kevlar rope technology has advanced to the point that only cost now prohibits its use in place of conventional wire rope for retrieving deepwater core barrels. Kevlar's natural advantages over steel make it ideal in many ways for this application. Its extremely high strength-to-weight ratio, especially in water, would allow for significant increases in coring tool payloads at similar depths plus higher overpulls to free stuck barrels. It is corrosion resistant and exhibits much higher fatigue and snarling resistance than steel wire. It is also inherently safer than wire rope since it can be cut with handtools rather than a torch and does not produce sharp, broken wire barbs.

"Smart" Core Barrels

Experience with numerous types of core barrels in a variety of subsea formations has taught many lessons about how to optimize core recovery. It is not always possible to apply optimum techniques, however, since the personnel operating the equipment have very little, if any, real time information concerning vital coring parameters. Is the core jammed in the bit throat? Is the core barrel full? Is the core being washed away? Is core bit rpm too high or too low? Is core recovery rate matching bit penetration rate?

Such questions must constantly be asked during the coring operation but the answers often are not found until the core barrel is back on deck.

Application of the simplest principles of cybernetics to downhole tools could produce "smart" core barrels able to adjust automatically to adverse changes in coring conditions. Anti-jam devices, full barrel signalers and flow rate adjusters would be likely first steps in this development.

CONCLUSIONS

Within a program which is both scientifically and economically viable such as ODP, the future may see technological breakthroughs in deepwater coring tools and borehole research not yet imagined. The possiblities discussed in the preceeding paragraphs are only those which can be identified today; tomorrow the list will be expanded. The number of possible new tools and instruments is exceeded only by the number of scientific questions remaining to be answered.

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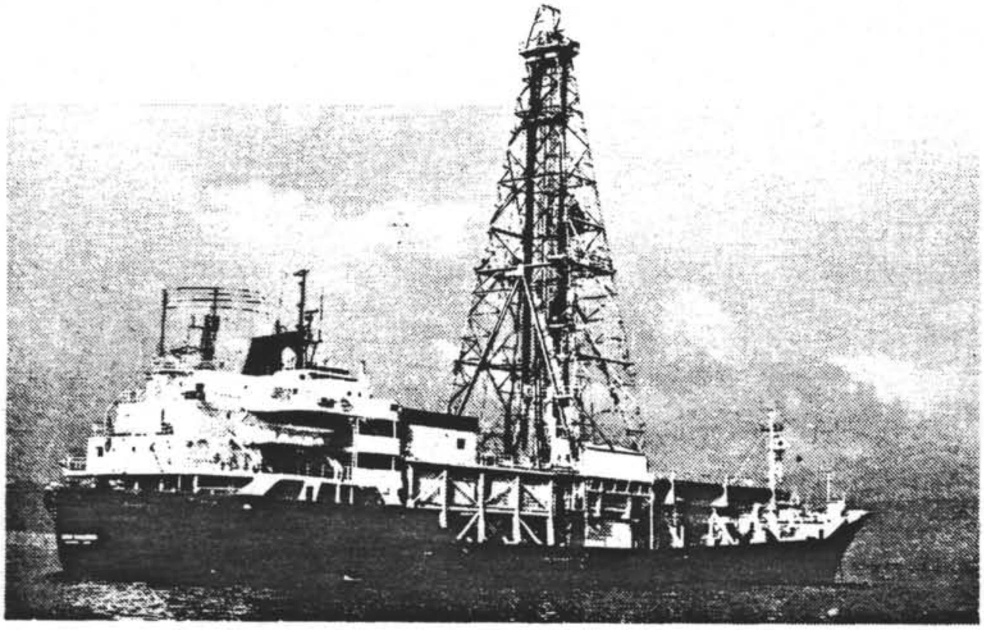


Fig. 1 GLOMAR CHALLENGER, drillship of the Deep Sea Drilling Project 1968-1983.

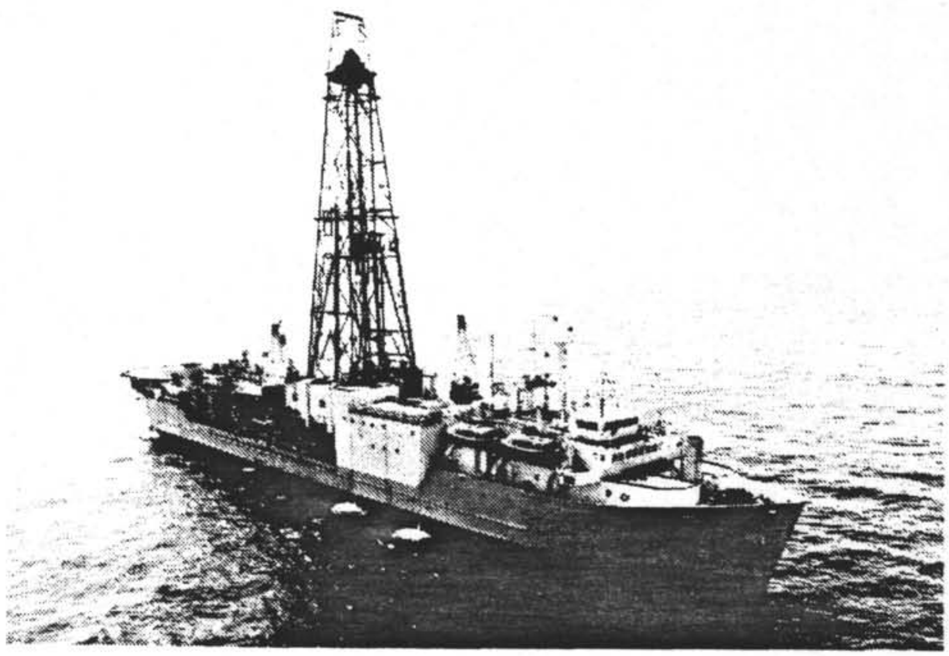
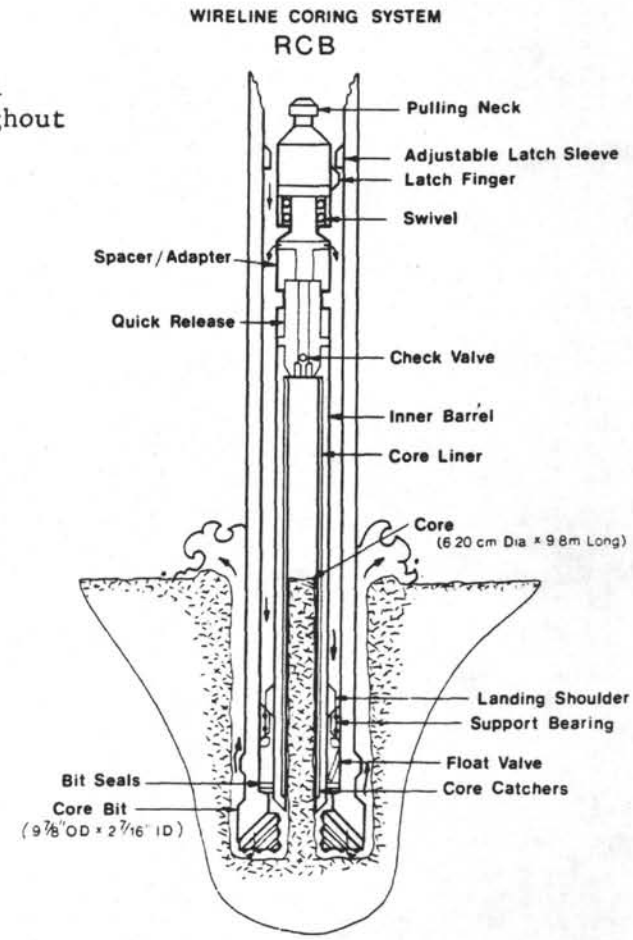


Fig. 2 JOIDES Resolution (Sedco/BP 471) drillship of the Ocean Drilling Program 1984 -

Fig. 3 Rotary Core Barrel. Conventional wireline core barrel used throughout DSDP and ODP coring operations.



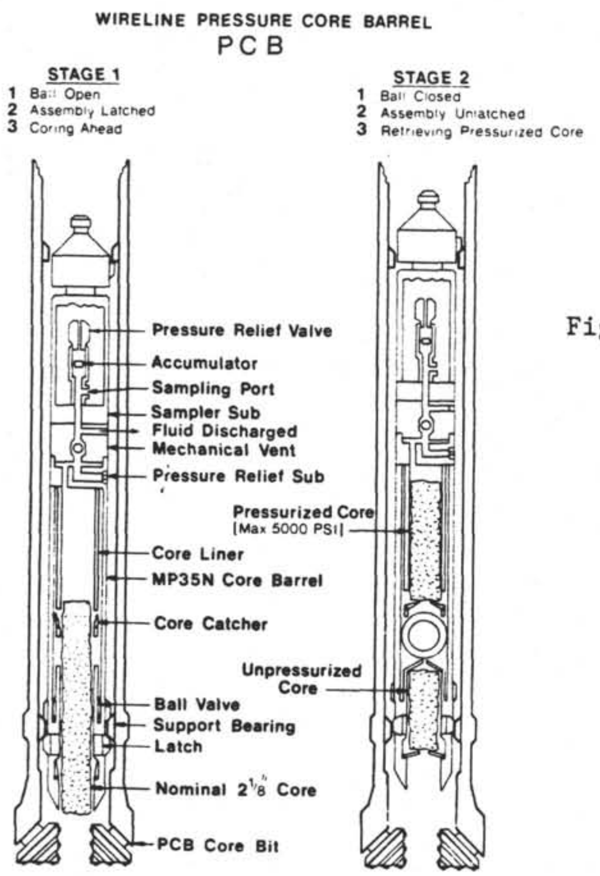
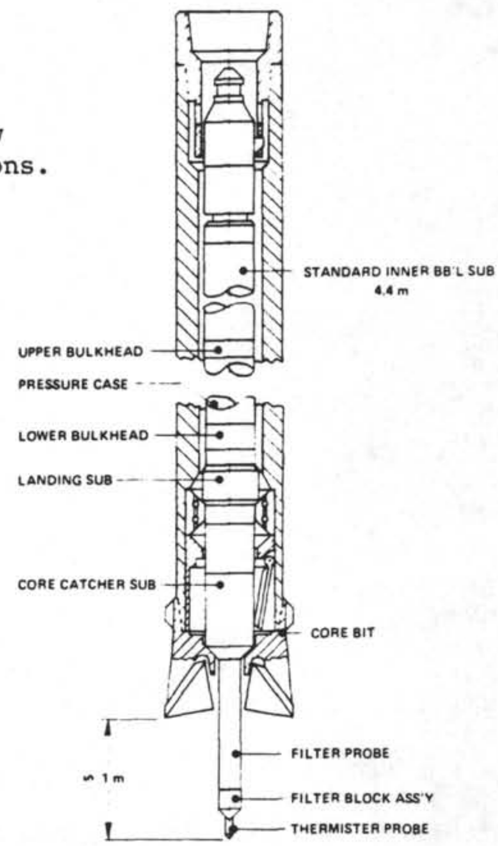


Fig. 4 Schematic of the latest version of the Pressure Core Barrel (PCB-III) used during DSDP.

Fig. 5 Schematic of the Pore Water/Heat Flow Sampler used in DSDP and ODP operations. Later versions included pore fluid pressure measuring capability.

PORE WATER/HEAT FLOW SAMPLER
PWS



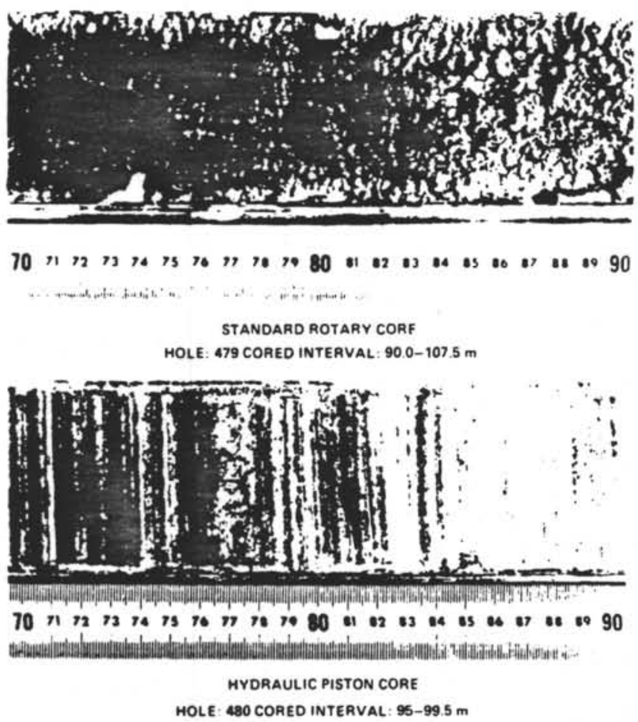


Fig. 6 Comparision of diatomaceous ooze cores recovered in adjacent holes using RCB and HPC.

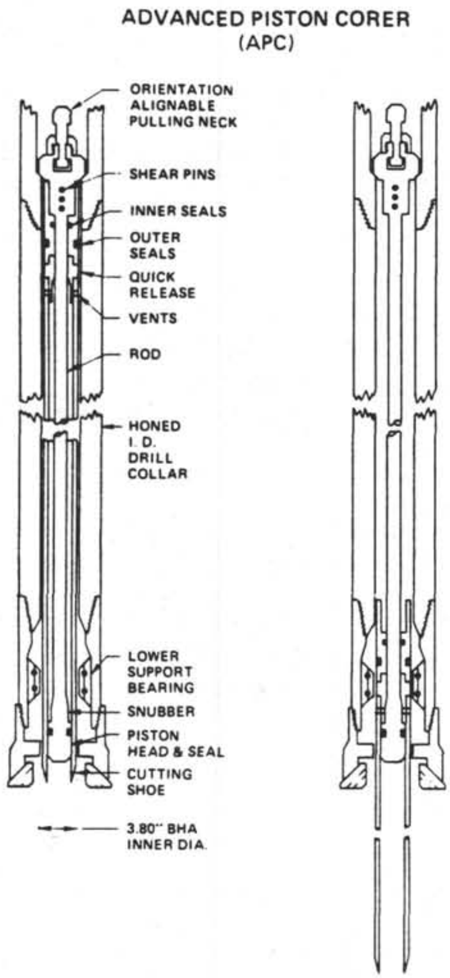


Fig. 7 Schematic of the Advanced Piston Corer as used in DSDP and ODP coring operations in soft sediment.

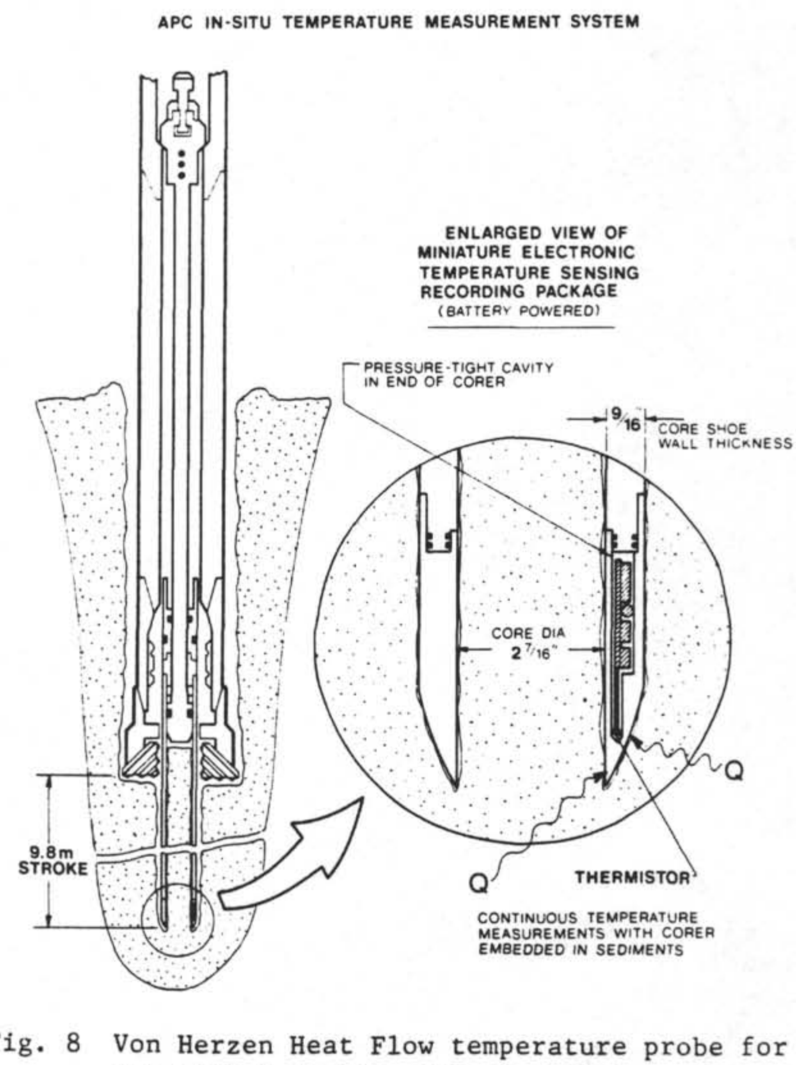
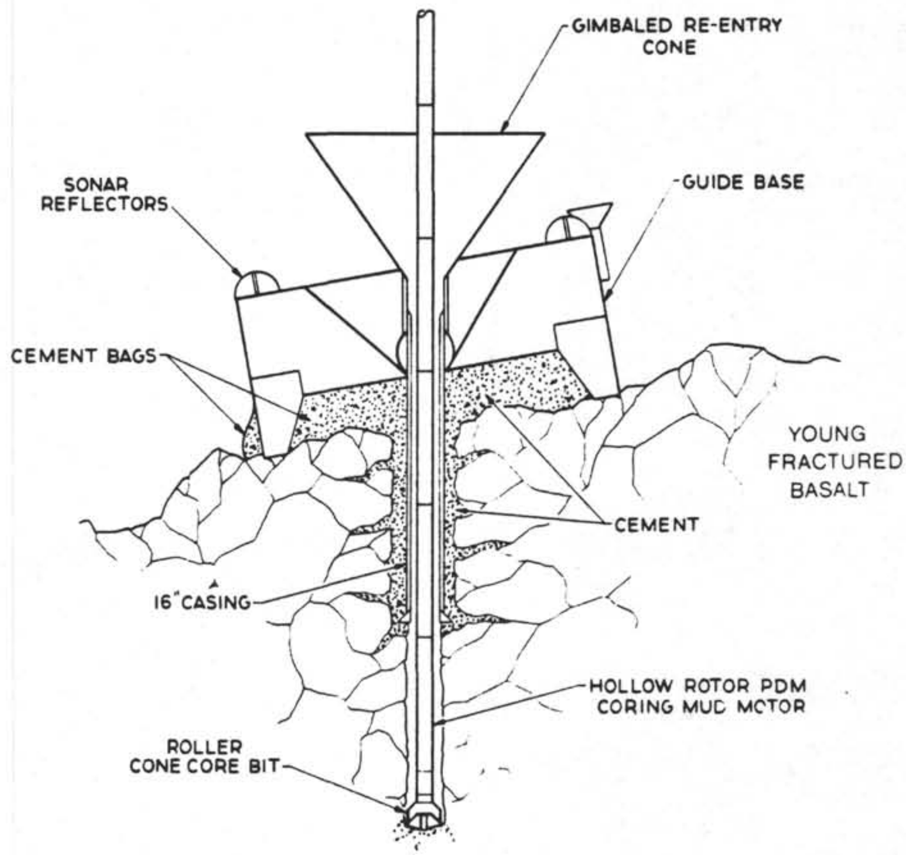


Fig. 8 Von Herzen Heat Flow temperature probe for use with hydraulic piston coring.



HARD ROCK SPUD SYSTEM

Fig. 9 Major elements of Hard Rock Spud System for use at sites with little or no sediment cover. First deployed at Mid-Atlantic Ridge, ODP Leg 106, November 1985.

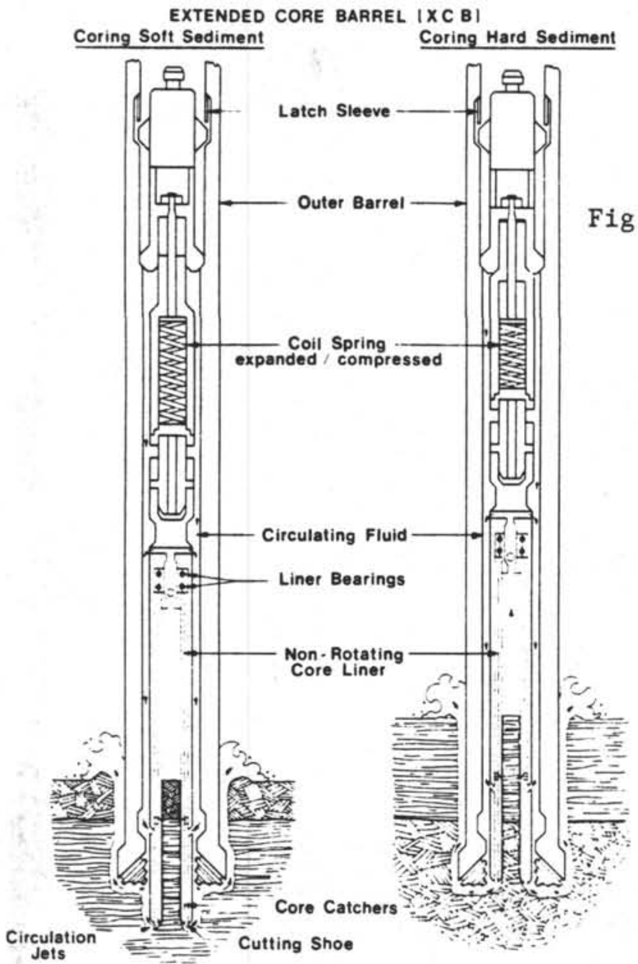


Fig. 10 Schematic of the Extended Core Barrel as used in the early operations of ODP.

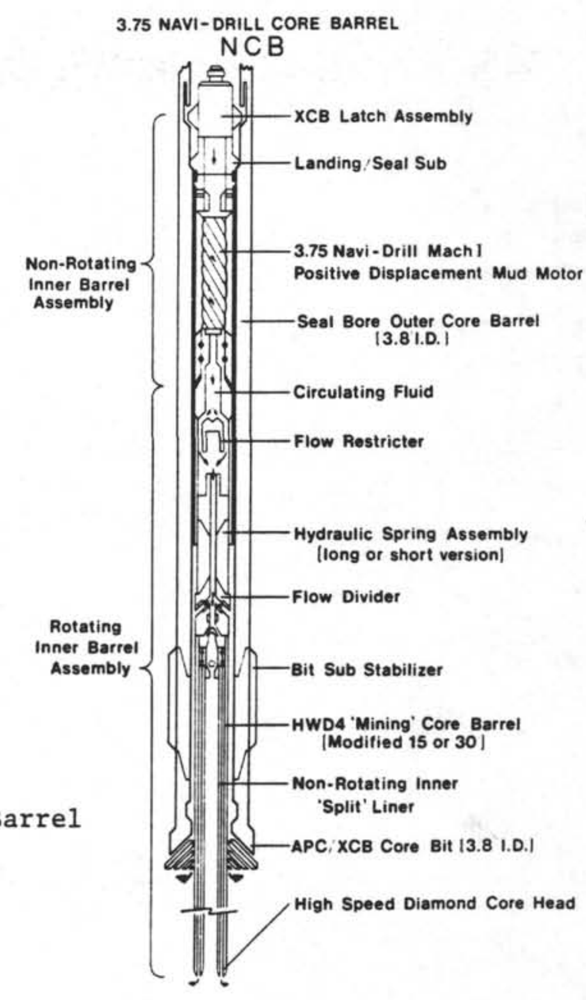


Fig. 11 Schematic of the "Navi-Drill" Core Barrel concept first tested on ODP Leg 104, July - August 1985.

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THE OCEAN DRILLING PROGRAM V:
LOGGING FOR THE OCEAN DRILLING PROGRAM - RESULTS FROM THE FIRST TWO LEGS

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ABSTRACT

All wells drilled by the Ocean Drilling Program which penetrate more than 400 meters of sediment, and any wells with significant basement penetration, are now logged as part of routine operations on the JOIDES Resolution. Standard logs include resistivity, sonic velocity, neutron porosity, density, and both natural and induced gamma-ray spectrometry. Specialty logs include an acoustic borehole televiewer and a 12-channel full waveform sonic tool. During the first two ODP legs, logs were obtained in shallow water carbonates and evaporites of the southern Blake Plateau, and in 110-Ma basalts of Oceanic Layer 2 in the western Atlantic. The results demonstrate the importance of high quality physical properties measurements recorded in situ to augment information obtained from the recovered core.

INTRODUCTION

Due to the prohibitive expense of continuous coring in large-diameter boreholes, wells drilled by the oil industry are seldom cored. Properties of interest to the petroleum geologist (such as composition, porosity, clay content, and pore fluid constituents) must therefore be determined indirectly from well log measurements made in situ. Assuming that the relationship between the physical properties and the measured quantities is known, petroleum geologists can determine almost all of the important characteristics of a potential reservoir rock from geophysical well logs.

The Ocean Drilling Program differs from commercial drilling operations in that all ODP boreholes are continuously cored. This enables the correlation of in situ measurements to rock properties of the recovered core. If core recovery were perfect and surface measurements could duplicate in situ conditions, there would be very little need for well logs. However, it is well known that core recovery generates changes in the recovered rock properties (1,2). Furthermore, recovery in both sedimentary and basement rocks has been quite variable. Low recovery precludes an accurate reconstruction of the lithologies encountered by the well-bore. Also, the measurement of physical properties from the recovered core allows only the determination of matrix properties; the additional influence of fractures and alteration zones, which cannot be adequately sampled, can only be determined by in situ measurements.

The response of geophysical well logs to changes in the characteristics of sedimentary materials is fairly well known. Empirical knowledge of this relationship has been gained largely by observations in areas where both core and logs have been obtained in lithologies of interest to the petroleum geologist. However, it is becoming increasingly clear that this empirical knowledge must be supplemented by a better understanding of the physics behind the well log response, particularly for scientific well logging in igneous and metamorphic environments. As traditional log analysis relies heavily on the empirical correlations developed in sediments, accurate analyses of geophysical logs in hard rocks require careful, new correlations before the response of the logs can be related to in situ properties. This theoretical foundation is critical to the success of the scientific logging program on the JOIDES Resolution.

The new Ocean Drilling Program has generated considerable interest in portions of the well logging community, partly due to logging results achieved during the later phases of the Deep Sea Drilling Project, and partly due to the unique lithologies penetrated by the ODP drill-bit. As a result of this interest, we have been able to obtain state-of-the-art technology for use on the drill-ship. We have also gained access to log calibration test pits in order to determine the responses of the new logging tools to hard rock environments. The promising results from the first two ODP legs emphasize the importance of well logging to the goals of the Ocean Drilling Program. Significant future contributions will result from the continued committment on the part of the ODP to the routine collection of log data.

TOOL DESCRIPTIONS

The logging suite for the Ocean Drilling Program currently consists of the following devices, selected with the unique aspects of the program in mind: natural gamma-ray spectrometry (NGT), thermal-epithermal neutron porosity (CNT-G), compensated gamma-gamma density (LDT), dual induction (DIL), sonic velocity (LSS), and induced gamma-ray spectrometry (GST). Also included is a three-arm caliper for the determination of hole size, and natural gamma for depth correlations between logging runs. These devices are run under a sub-contract by Schlumberger Offshore Services. An acoustic borehole televiewer (BHTV) and a 12-channel full waveform sonic tool (MCS) are also available, and are owned and operated by Lamont-Doherty Geological Observatory as part of the standard logging service. Facilities are also available to record measurements from additional devices run by shipboard scientists, as was done on Leg 102 to measure magnetic susceptibility and vector magnetic field.

The NGT, CNT-G, and LDT are recorded together in one logging run. A single logging run is also made to record LSS, DIL and caliper. The GST, BHTV, and MCS each require a separate logging run. Logging time curves which take into account trip time in the drill-pipe for each of these lowerings are shown in Figure 1. From the figure it can be seen that an upper limit of about 35 hours is required to obtain a complete set of logs in a 500-m borehole, regardless of the water depth.

The Natural Gamma-ray Spectrometry Tool (NGT)

By measuring natural gamma-ray emission in five different energy windows, the NGT can determine the amounts of the three major sources of natural radiation (K, Th, and U) in the rock surrounding the well-bore. The relative proportions of these elements is controlled by mineralogy, clay content and alteration history (3). Thorium and potassium are the primary radioactive elements present in clay, where their relative abundance allows the

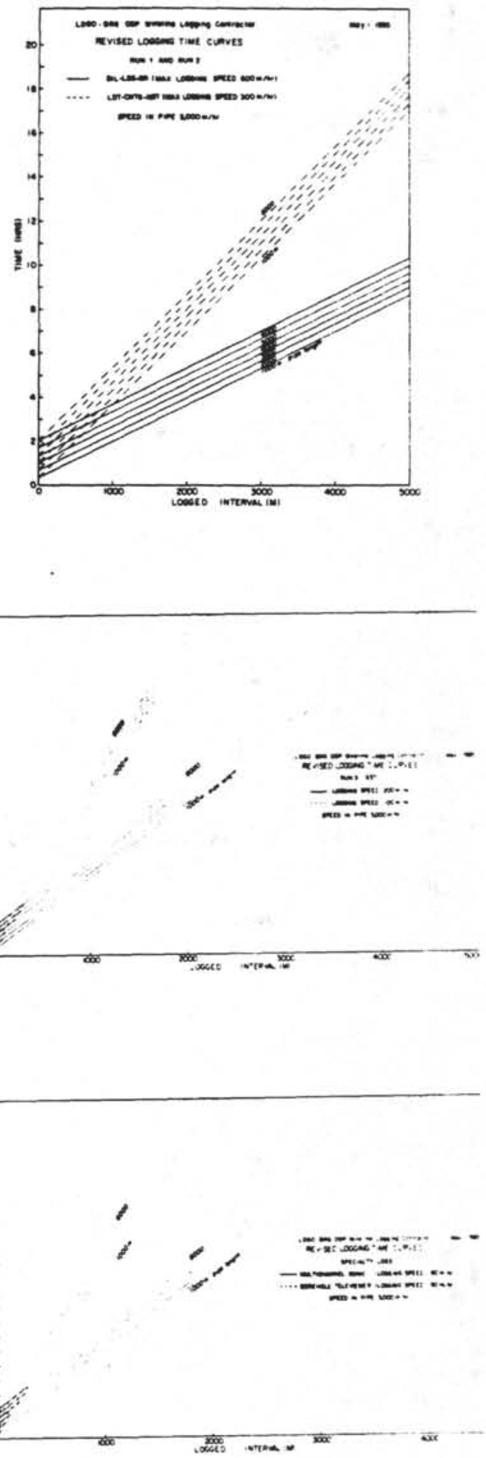

Figure 1: Curves showing the amount of time required for each logging run. The curves are based on a rate in the pipe of 3000 m/hr. Logging rates in the formation are 600 m/hr for DIL-LSS-GR, 300 m/hr for LDT-CNTG-NGT, and 100 or 200 m/hr for GST, depending on the required statistical precision. The BHTV is run at 90 m/hr, and the MCS is run at 180 m/hr.

determination of clay type. Uranium is often associated with organic matter in carbonates. In igneous rocks the relative proportions of the three elements is indicative of rock type; an increase in potassium in particular is evident where fractures and voids within the oceanic basalts have been filled with alteration minerals (4).

The Lithodensity Tool (LDT)

A radioactive source is mounted on a pad applied to the borehole wall by an eccentering arm and emits gamma rays into the formation. The gamma rays interact with electrons in the formation by Compton scattering, losing energy until they are absorbed through the photoelectric effect. The number of scattered gamma rays reaching two detectors at different distances from the source depends on the electron density of the formation, which in turn is related to the densities of the solid and fluid phases and to the porosity (5). Formation density can be determined by comparing counts at the near and far detectors. By measuring the number of low energy gamma rays arriving at the far detector, the LDT can also determine the photoelectric cross-section of the formation, which is determined largely by mean atomic number. In simple lithologies the photoelectric cross-section is all that is required to determine the composition of the rock.

The Compensated Neutron Tool (CNT-G)

Two pairs of detectors are used in the CNT-G to measure the number of epithermal (intermediate energy) and thermal (low energy) neutrons which are transmitted through the formation from a high energy neutron source mounted on the tool. Data from both sets of detectors can be processed to obtain a measure of formation porosity (6,7). Thermal neutrons are affected by bound hydrogen in clays, whereas epithermal neutrons are not. Thus the difference between thermal and epithermal neutron porosity is partially dependent on clay content. As the presence of chlorine and other neutron absorbers will strongly affect the thermal porosity measurement, the epithermal measurement is critical in ODP wells, where the chlorinity of the borehole fluid (seawater) is high.

The Long-Spaced Sonic Tool (LSS)

The LSS is a dual receiver dual source sonic tool which can provide a real-time measure of formation compressional velocity and a set of full waveforms from each source-receiver pair. If a refracted shear arrival is present, its velocity can be computed from the full waveforms, and the frequency content and energy of both compressional and shear arrivals can also be determined. Variations in energy and frequency content are indicative of changes in fracture density, porosity, and in the material filling the pores (8). In some cases compressional-wave attenuation can also be computed from the full waveforms (9).

The Dual Induction Log (DIL)

The DIL measures spontaneous potential (SP) and three different resistivity values (ILD - deep induction; ILM medium induction; SFLU - shallow spherically-focussed log). Currents are induced in the formation by magnetic fields generated by coils on the logging tool. The magnitude of the induced current depends on formation conductivity. Therefore, ILD and ILM are most accurate in formations with low resistivities. The SFLU is a true resistivity device, and is the preferred measurement when formation resistivity exceeds a few hundred ohm-m. Formation resistivity can be related empirically to inverse porosity through Archie's Law. However, this relationship is invalid in the presence of clays. Similarly, empirical relationships have been found that relate permeability to porosity, but they are also highly dependent on pore geometry and rock chemistry.

The Gamma-ray Spectrometry Tool (GST)

The GST is a relatively new device containing a neutron accelerator which generates pulses of 14 MeV neutrons. The neutrons lose energy through scattering interactions with the atoms within the rock surrounding the borehole. When they reach thermal energy levels they are "captured" by elemental nuclei and gamma rays of capture are emitted. As each element has a unique emitted spectrum, analysis of the combined spectrum recorded downhole provides an estimate of the elemental composition of the formation (10). In ODP wells the GST is run in a "capture-tau" mode, which allows the calculation of the elemental proportions of six elements: Ca, Cl, Si, Fe, H, and S. The measurement accuracy is largely determined by statistics; the slower the logging speed the more accurate the results. A major advantage of the GST is that it can be run inside the logging pipe, and thus can be used in wells which otherwise could not be logged due to well-bore instability.

GST results can be used to determine the relative proportions of a variety of different minerals through linear inversion, if the relative proportions of each element in each mineral are known. Less accurate analyses of lithology can be determined from various elemental ratios (11,12). The relative amounts of silicon and calcium can be related simplistically to the relative proportions of quartz and calcite; the relative proportion of hydrogen is an indication of porosity, and the chlorine/hydrogen ratio yields an estimate of the salinity of the borehole and formation fluids. Iron concentration provides an estimate of "shaliness", whereas the presence of sulphur can be related to the occurrence of anhydrite and/or gypsum. However, the linear inversion can yield very precise measurements of the various lithologic components, if the secondary characteristics of the mineral assemblages are taken into account.

The Acoustic Borehole Televiewer (BHTV)

The borehole televiewer is an acoustic device which scans the wall of a borehole, producing an image of the reflectivity of the rock walls. A high-frequency (1.3 MHz or 400 KHz) transducer is mounted on a shaft rotating 3 times per second and transmits an acoustic pulse every 540 microseconds which is reflected from the borehole wall. The amplitude of the received signal is related to the reflectivity and surface roughness of the well bore. The signal is displayed on a 3-axis oscilloscope by modulating the intensity of the oscilloscope beam, and is oriented with respect to magnetic North. The televiewer data can also be processed to display the travel-time of the reflected pulse to study the shape of the borehole. The televiewer allows the location and orientation of fractures (13), the strike and dip of bedding (14), and the delineation of structural variations in pillow basalts (15). The orientation of far-field stresses can also be determined from BHTV-derived measurements of borehole shape (16,17).

Multi-Channel Sonic Tool (MCS)

The multi-channel sonic tool is a 12-receiver single-source acoustic logging device. The receivers are spaced 15 cm apart in a 1.65-m array. The emitted source energy travels as a compressional pulse in the borehole fluid, is refracted at the borehole wall, and is refracted back into the borehole fluid and recorded at the receivers, to produce what is effectively a 12-fold common source borehole refraction experiment. As the maximum source-receiver offset is much greater than the offset of the LSS, the MCS is less affected by invasion or drilling-induced well-bore damage. Furthermore, the greater number of receivers aids in the determination of rock properties, and the much shorter receiver spacing helps in the delineation of fractures and thin beds and in the correlation between the received waveforms (18).

WELL LOG CALIBRATION

The ODP Schlumberger LDT, CNT-G and NGT were run in the USGS test pits at the Denver Federal Center, in order in determine the log responses to igneous and metamorphic rocks (19). The calibration facility consists of three pits, about 10 feet in diameter and 25 feet deep. A different type of rock is used for calibration in each test pit: a fine-grained granite (Sierra White), a coarse-grained granite (Rockville) and a medium-grained metamorphosed granodiorite (Cold Spring Green). A series of saw-cuts was made in each block to simulate in situ fractures.

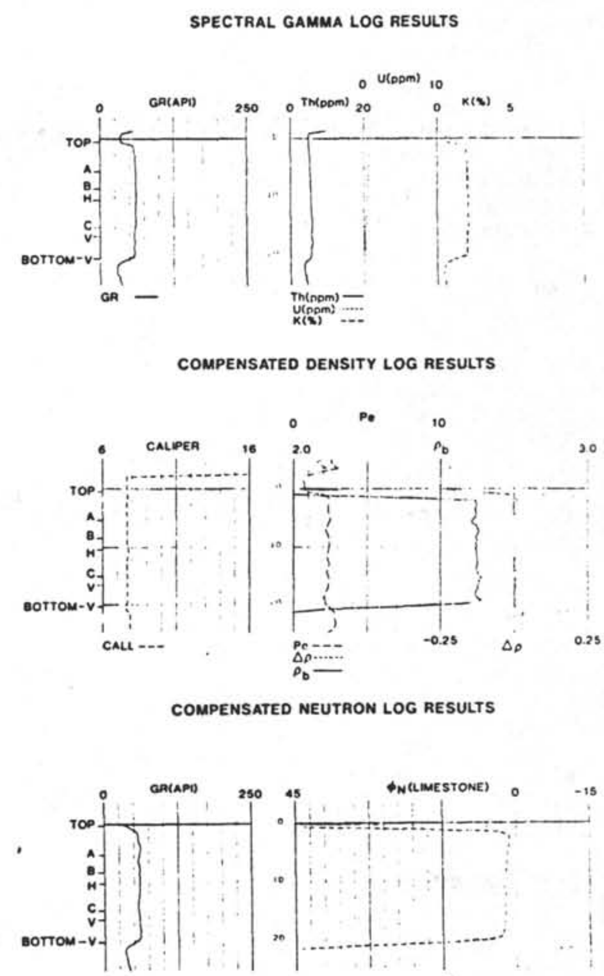

Figure 2: Results of the calibration runs in the Sierra White test pit at the Denver Federal Center (after 19). The positions of sawcuts which simulate natural fractures are shown (H=horizontal; A,B=inclined; V-V=vertical; C=inclined non-intersecting).

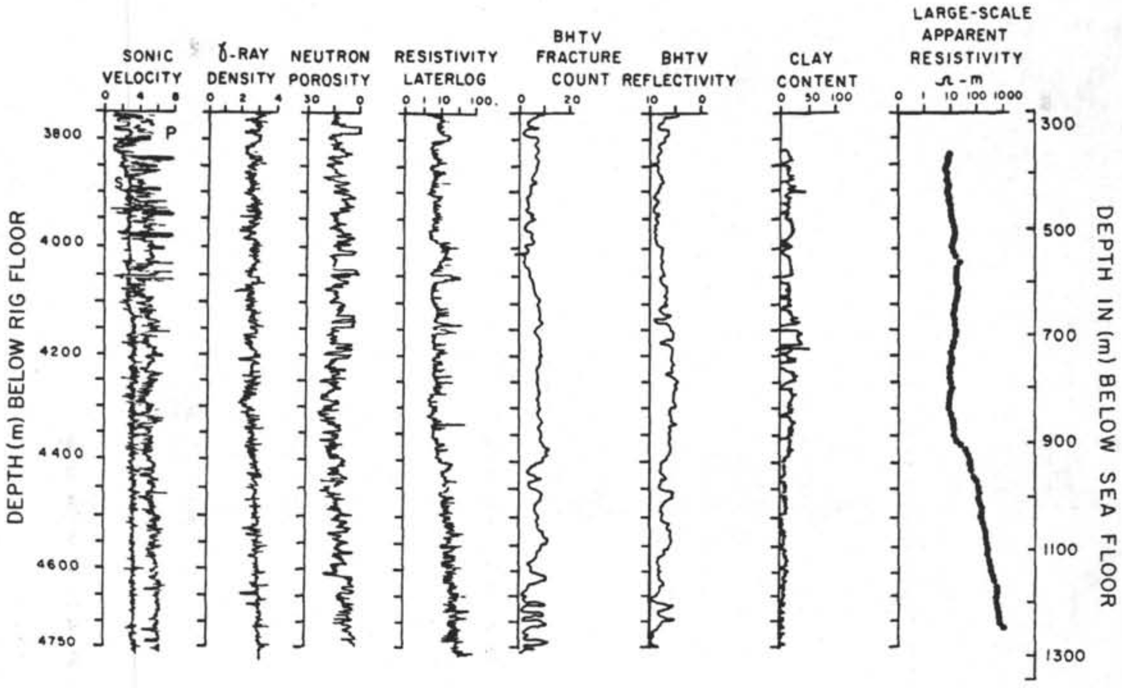

Figure 3: Logging results from Leg 83 in DSDP Hole 504B (after 20). Compressional and shear sonic velocities were measured during the logging run. Also shown are gamma-gamma density, neutron porosity, and resistivity logs. Fracture count and reflectivity were determined from borehole televiewer images. Large-scale resistivity was measured over several tens of meters, for comparison to the resistivity log. Clay content was calculated on the drill-ship, and is the standard (MSI) log.

A complete suite of logs, including Schlumberger, Dresser Atlas and USGS devices, was run in the test pits. An example of the results of the Schlumberger calibrations made in the Sierra White using the ODP tools is shown in Figure 2 (19). Also shown are the locations of vertical (V-V), horizontal (H) and inclined intersecting (A,B) and non-intersecting (C) saw-cuts. The results are in quite good agreement with core measurements of density (2.65 g/cc) and potassium, uranium and thorium (1.71%, 1.18 ppm, and 3.76 ppm) but the logged porosity is low. The effect of the fractures on the log response is quite subtle.

CASE STUDIES

Results from DSDP Hole 504B

Hole 504B was drilled and logged on a succession of DSDP Legs to a sub-bottom depth of over 1350 m (more than 1070 m into Oceanic Layer 2). The well is sited in 5.9 Ma crust near the East Pacific Rise, and has served as a "type section" of young oceanic crust (20).

Figure 3 shows the principle logging results. Although the exact boundaries are subject to interpretation, the presence of Oceanic Layers 2A, 2B, and 2C can easily be determined from the

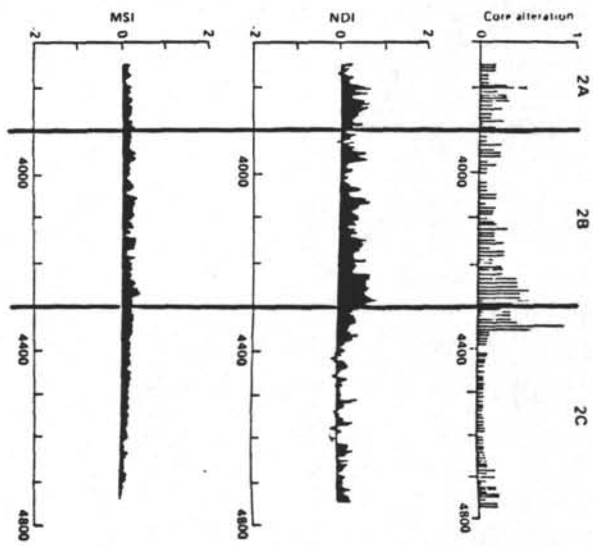

Figure 4: Comparison between the standard Minimum Shale Index (MSI) from Schlumberger CYBERLOOK and NDI, the hydroxyl mineral content computed by the differencing scheme discussed in (21). Also shown is alteration determined from the recovered cores.

log curves. An example of a unique application of these measurements is the calculation of the clay content log shown in Figure 4 (21). A standard clay indicator is shown on the left, and a new method for determining the degree of alteration is shown in the center.

Analysis of the cores (shown on the right) indicated the presence of a mineralized stockwork at 4200-4300 m, and a sharp decrease in alteration below the stockwork in Layer 2C. The new method clearly delineates these variations, whereas the standard technique is ineffective.

DSDP Hole 418A -- results from Leg 102

During Leg 51 DSDP Hole 418A was drilled to a sub-bottom depth of 868 m in 110 Ma oceanic crust in the western Atlantic. The well penetrated over 500 m of basaltic basement. During the same leg a suite of poor-quality logs was obtained

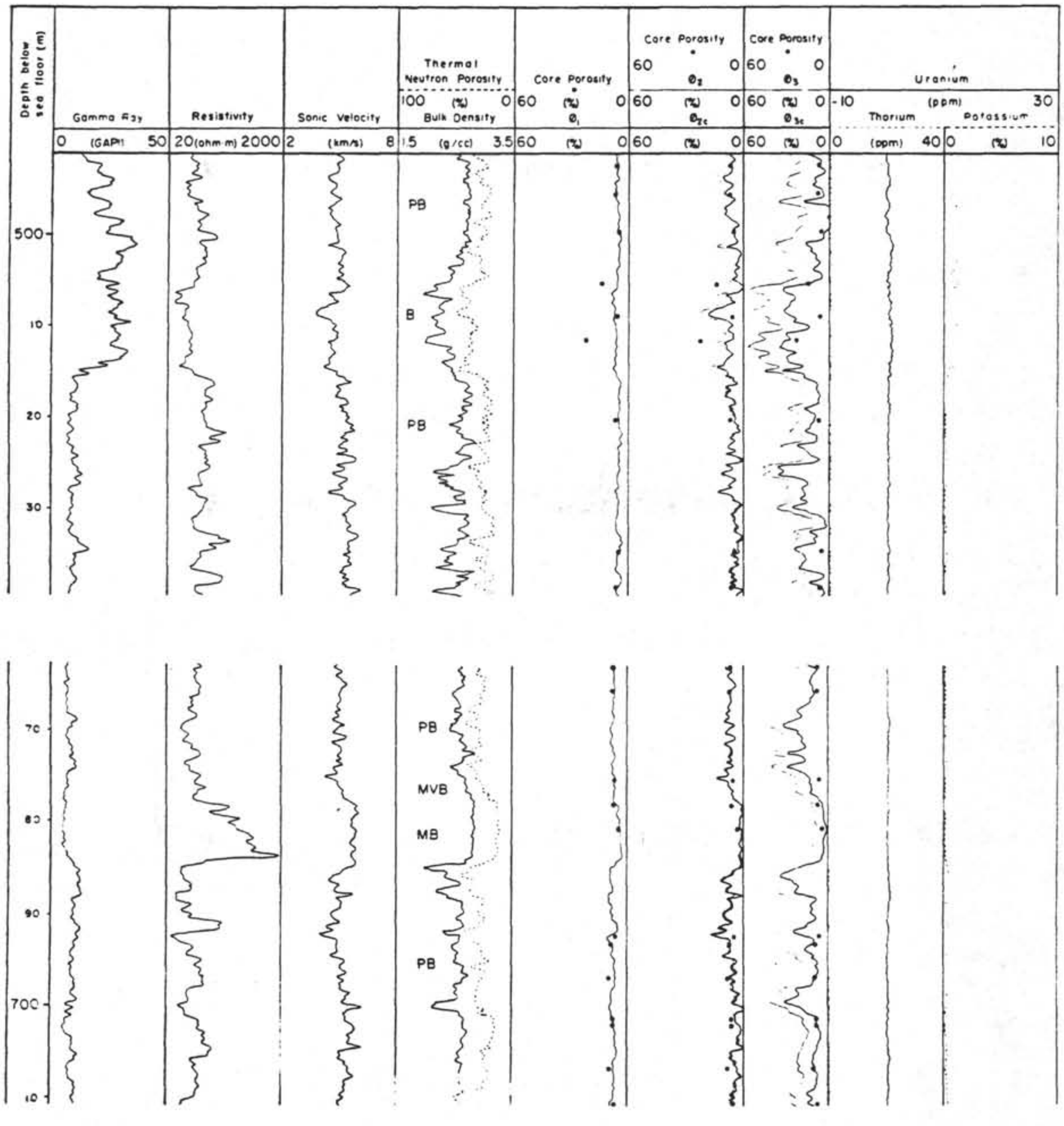

Figure 5: Sample data set from ODP Leg 102 in two different sections of DSDP Hole 418A. These sections of the well include pillow basalts (PB), breccias (B), massive vesicular basalts (MVB), and massive basalts (MB). Natural gamma, resistivity (SFL), sonic velocity (LSS), thermal neutron porosity (CNT-G), and bulk density (LDT) logs are shown on the left. Porosity computed from the resistivity log (phi1), sonic log (phi2), and epithermal neutron log (phi3) are compared to core measurements both before and after correction for hole conditions, lithology, and clay content. Note that the corrected values are lower and more closely match the laboratory data. The NGT results are shown on the far right. The uppermost pillow interval is characterized by high potassium yield, which increases the natural gamma. The results indicate the presence of vein-filling minerals in this interval.

in a companion hole (417D). Hole 418A was re-entered during Leg 102 (4). A complete set of logs, including standard Schlumberger logs (electrical, nuclear, and radioactive) and two specialty logs (BHTV and MCS), was obtained in the basement section. Two other logs (magnetic susceptibility and vector magnetic field) were also run by shipboard scientists. The log responses in sample sections of the well are shown in Figure 5. Pillow basalts can be identified by the fine-scale variability of density, porosity, resistivity and velocity, whereas massive basalts show fairly constant values, confirming the massiveness of the rock and the lack of altered zones. The presence of alteration materials in the uppermost section, and the abrupt transition at 516 m, is detected by variations in the measured gamma ray and potassium content. The difference between the raw data and the core measurements is quite pronounced in this well. Part of this discrepency is due to the inherent sampling bias. However, the true responses of the density and neutron logs are masked by the rock matrix itself or by the presence of clay. The log data can be corrected using the results of the test pit calibrations and laboratory physical properties measurements. After this correction the laboratory and log results are in much better agreement.

DSDP Site 612 -- results from DSDP Leg 95

A sample data set from DSDP Leg 95 illustrates some of the features of logging results in the Cenozoic sediments of the Baltimore Canyon Trough (22). Figure 6 shows sonic velocity and density logs and the shipboard core measurements, which, in general, were markedly lower than the log values. This discrepency has been explained by expansion and disturbance of the laboratory samples due to removal from in situ conditions (2). The accuracy of the in situ density and sonic velocity measurements was confirmed by generating a synthetic vertical seismic profile, which matched seismic reflection profiles recorded by the USGS.

ODP Holes 626D, 627B, and 634A -- results from ODP Leg 101

During ODP Leg 101, a series of shallow wells were drilled into carbonates of the southern Blake Plateau (23). Logging was attempted in three of these wells. In hole 626D a neutron porosity log was run through the drill pipe, yielding detailed information on the location of well-lithified grainstones separating unlithified sediments that have been winnowed by the Gulf Stream. The stratigraphic section

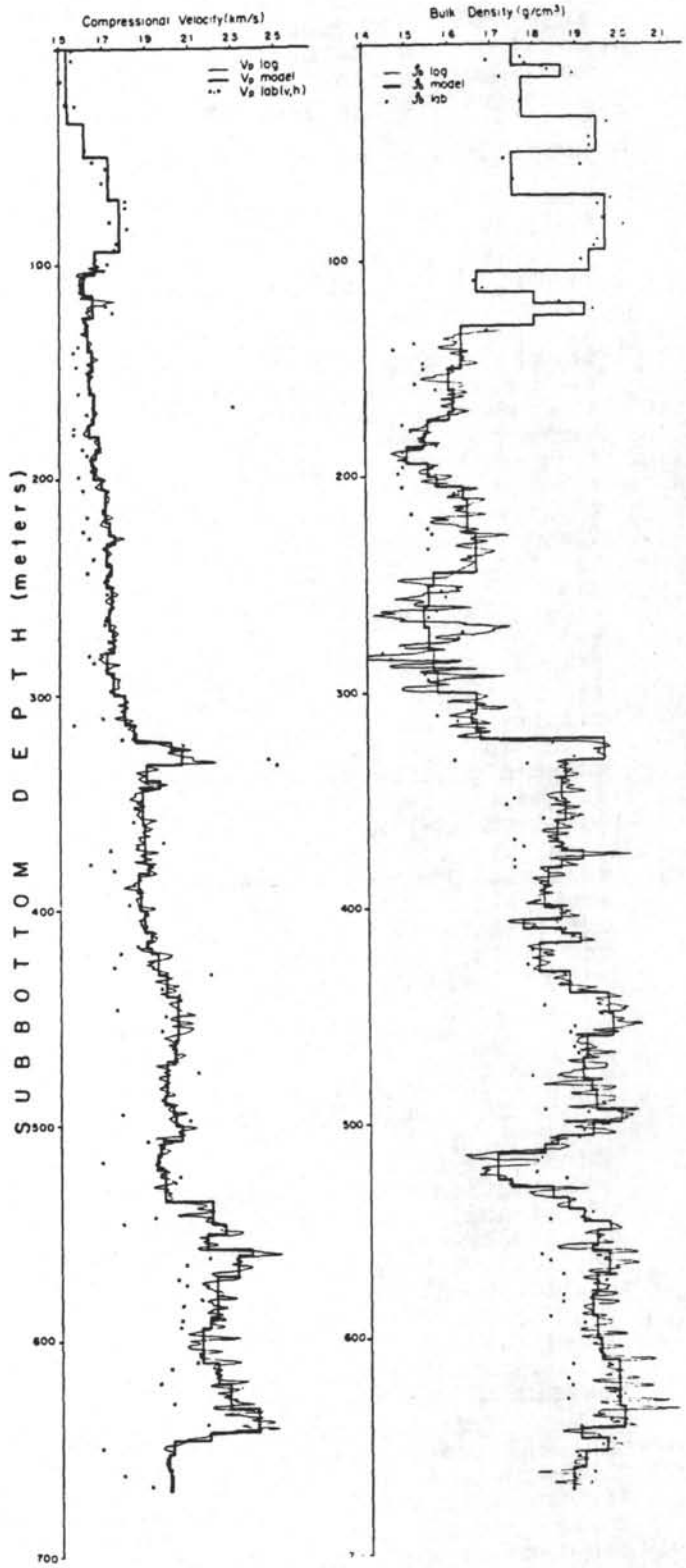

Figure 6: Logging results from DSDP Leg 95 at Site 612 (after 22), showing compressional velocity and bulk density logs and the layered model used to compute the VSP synthetic. The crosses indicate the results of shipboard laboratory measurements. The lower velocities and densities measured in the laboratory are caused by sample unloading.

in Hole 627B was logged with the NGT/CNT-G/GST combination, but after logging the bottom 70 meters the hole collapsed, ending the logging run. The most valuable logging run of Leg 101 was the first application of the GST to scientific research in Hole 634A.

Figure 7 shows the interpreted results of the GST log. This log was recorded through the drill pipe, and proved essential for lithology determination (core recovery was less than 5%). All of the curves shown in this figure were derived from measurements made by the GST, except for the neutron porosity curve shown for comparison to the GST-derived porosity. Core data suggested that the lithology in this interval was predominantly calcareous chalk and grainstone with varying amounts of interbedded chert. The lithologic information obtained by the GST enabled the complete stratigraphic`section to be determined, as shown in the right-hand track. By utilizing the elemental yields computed from the GST log, estimates of bulk density and seismic velocity were obtained, and a synthetic vertical seismic profile was computed. The depths of major impedence contrasts visible in multi-channel seismic site surveys could then be identified. Ironically, this analysis procedure reverses the usual application of logs, where chemical composition is inferred from measurements of bulk properties such as seismic velocity and density.

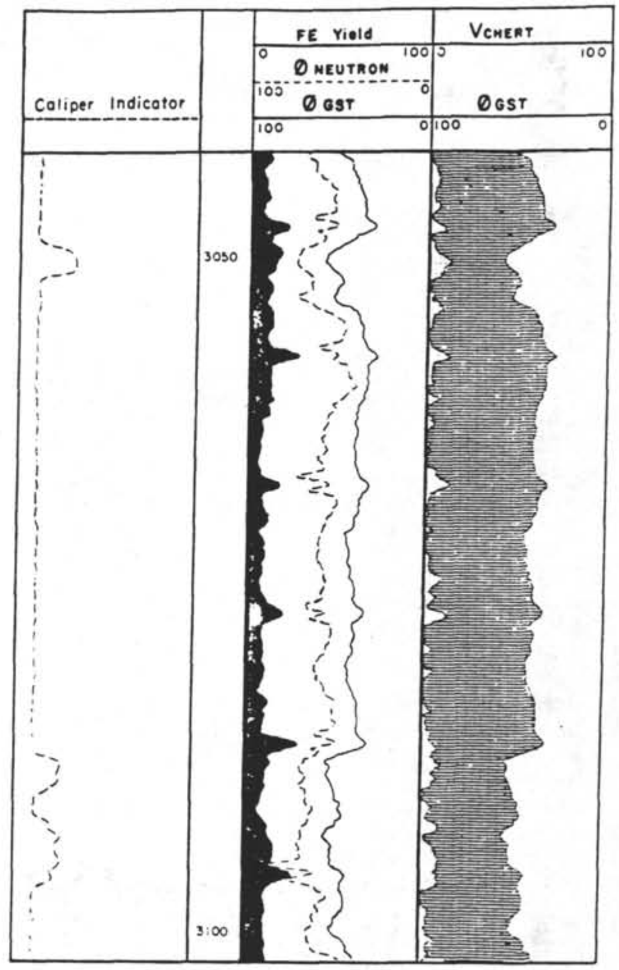

Figure 7: Section of GST lithology log from ODP Hole 634A, showing a caliper indicator and computed iron yield, neutron (CNL) porosity, GST porosity, and quantities of chert and calcite. The caliper indicator is computed from the neutron capture cross section curve. The high iron yield is a reflection of the presence of the drill pipe. Peaks in the yield indicate the locations of pipe collars.

FUTURE IMPROVEMENTS

The logging operations on board the JOIDES Resolution are being continually updated as new technology becomes available. A mechanical heave compensation system designed to eliminate the effects of the ship's motion has been developed and will be installed prior to Leg 105. The relative motion of the ship is detected by an accelerometer. The displacement (determined by double integration of the accelerometer output) is compensated for by changes in the position of a sheave mounted at the end of an hydraulic cyllinder. By changing the position of the sheave, the length of the wireline is adjusted to compensate for the ship's motion. The system can fully compensate for +/- 15 foot displacements at periods from 1 to 100 seconds. Another addition prior to Leg 105 will be a shipboard scientific log analysis package. The analysis capabilities will include most of the applicable oilfield analysis routines, plus a statistical package for factor analysis. The factor analysis routine is a powerful tool in the development of workable models for log response in the lithologies encountered during drilling in the oceanic crust. The package will be installed on the shipboard logging computer, which enables the immediate analysis and interpretation of the acquired data on each leg before the ship returns to port.

New devices are being developed for addition to the standard shipboard logging package. For instance, a wireline packer system, which measures in situ pore pressure and permeability, is currently under development. The packer will also be able to sample uncontaminated formation fluids, which is a difficult and time-consuming procedure using the currently available technology.

CONCLUSIONS

The logging devices currently

available to the Ocean Drilling Program represent a state-of-the-art system designed with the goals of the Program in mind. Logging results from the first two ODP legs have been remarkably successful, demonstrating the importance of in situ measurements in both sedimentary and basaltic sequences. New improvements of the shipboard logging system include the addition of a heave compensator to eliminate the effects of ship motion, the expansion of shipboard log analysis capabilities, and the development of a new wireline packer system. These improvements will enhance the benefits of the shipboard logging program to the scientific community, and ensure that significant future contributions will result from the continued committment on the part of the ODP to the routine collection of log data.

ACKNOWLEDGEMENTS

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