DEEP SEA DRILLING PROJECT
UNIVERSITY OF CALIFORNIA, SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY

Scientific Objectives and Highlights

The goal of the original 18-month Deep Sea Drilling Project was to gather scientific information which would aid in the determination of the age and processes of development of the ocean basins in the Atlantic and Pacific Oceans. The primary strategy to secure this information was to drill deep holes in the ocean floor, relying largely on technology already developed by the petroleum industry. Cores were collected and in-hole measurements of physical properties made.

Cores from the ocean floor provide reference sections for future studies in biostratigraphy, physical stratigraphy, and paleomangetism and afford new studies of the physical and chemical aspects of sediment provenance, transportation, deposition and diagenesis. In-hole measurements provide petrophysical data which permit inference of lithology over intervals where no cores were secured.

Scientific objectives for the three-year extension period were directed largely toward an understanding of the interaction of the continents and ocean basins and is being prosecuted mainly in outer fringes of the ocean areas, or in places that are intermediate between oceanic and continental. Extension period drilling and coring has been done in the Atlantic Ocean, Gulf of Mexico, Mediterranean Sea and Caribbean Sea. It is continuing in the Pacific Ocean and the Indian Ocean.

A preliminary description of core material is done initially by ship-board scientists during each of the 55-day cruises of the drilling research vessel, Glomar Challenger, and at several shore-base laboratories. Core samples and descriptions are then distributed for research purposes to qualified scientists through-out the world without regard to their affiliation. Cores taken are stored aboard the ship in portable refrigerated vans until they can be sent to repositories in the United States. Cores from the Atlantic are stored at Lamont-Doherty Geological Observatory of Columbia University. Pacific cores are stored at Scripps.

Scripps Institution of Oceanography of the University of California at San Diego is the managing institution for the Deep Sea Drilling Project. Actual drilling is being done by Global Marine Inc., of Los Angeles, under contract to Scripps.

Advice regarding scientific planning is being provided by panels whose members are broadly representative of the nations' scientific community, drawn from many Universities, Government agencies and industrial organizations.

Many individuals from the petroleum industry have also furnished technical advice and assistance to the Project.

Scripps holds a $68.3 million contract with the National Science Foundation for DSDP which is a part of the National Science Foundation's National Research Program of Ocean Sediment Coring.

The Joint Oceanographic Institutions Deep Earth Sampling(JOIDES), consisting of Lamont-Doherty Geological Observatory of Columbia University, Woods Hole Oceanographic Institution, the Institute of Marine Sciences of the University of Miami (Fla.), the Department of Oceanography of the University of Washington(Seattle), and Scripps assisted in the formulation of the plans for the Deep Sea Drilling Project.

Following are the scientific highlights of all completed 55-day legs of DSDP.

Leg 1 - Orange, Texas to New York, August 11 to September 23, 1968. Dr. Maurice Ewing, Director and Dr. J. Lamar Worzel, Associate Director of Lamont-Doherty Geological Observatory, Columbia University were Cruise Co-Chief Scientists.

DSDP got off to an auspicious start on August 19, when scientists aboard the Glomar Challenger recovered a core at the Sigsbee Knolls in the Gulf of Mexico which showed traces of oil and gas. Water depth was 11,753 feet and drill bit penetration into the floor of the Gulf was 480 feet.

Sailing into the Atlantic Ocean, Upper Jurassic sediment was recovered on the Bermuda Rise, east of San Salvador Island, in 18,523 feet of water after the drill bit has penetrated 923 feet below the bottom of the ocean.

At the conclusion of Leg 1, Dr. Ewing termed DSDP, "a new era in the science of geology".

"The science of geology up to now has been built mostly on observations that can be made on continents, but the Glomar Challenger makes it possible to drill in three miles of water and to recover core samples several thousand feet down," Dr. Ewing said at a press conference in New York City.

Leg II - New York to Dakar, September 30 to November 25, 1968, Dr. Melvin N. A. Peterson, Project Chief Scientist and Dr. Terry Edgar, Coordinating Staff Geologist for the Deep Sea Drilling Project - both from Scripps - were Cruise Co-Chief Scientists.

Drilling across the Mid-Atlantic Ridge, the expedition recovered cores of basement rock beneath nearly three miles of water, the first time such a feat had been accomplished.

First direct measurements of the speed of sound in the deep ocean sediment layers, a development which will greatly increase the value of a massive volume of records made by ocean sounding over the years.

Discovery of a flint deposit which suggest that the sinking of the Panama Isthmus once altered Atlantic Ocean chemistry by allowing an influx of Pacific water.

Leg III - Dakar to Rio de Janeiro, December 1, 1968, to January 24, 1969. Dr. Arthur E. Maxwell, Associate Director, and Dr. Richard P. Von Herzen, of Woods Hole Oceanographic Institution, were Cruise Co-Chief Scientists.

Two primary objectivers were engaged and met during Leg III: Investigate the tectonic development of the Mid-Atlantic Ridge (structure and movement of the crust) and examine the history of sedimentation in the South Atlantic. Efficiency also was high on this leg as 92% core recovery was achieved - 2,536 ft. in all-and drilling at each site was deep enough to penetrate the sedimentary column and reach the basaltic basement.

1. Almost unassailable evidence confirms seafloor spreading. The magnetic anomaly pattern is relatively uniform across the South Atlantic, which indicates a steady spreading of the seafloor over the past 150 millions years. This is, South American and Africa — probably a single geographic unit at one time — are drifting apart at the rate of 2 inches per year.

2. Sediment depths are uniform but age distributions vary widely. The constancy of sediment thickness formerly was regarded as "proof" against the seafloor spreading hypothesis. However, cores taken from points across the ridge showed that age distribution — from Recent to Upper Cretaceous — varied widely. Sedimentation rates are high near the ridge and become markedly lower as one moves away from the axis. Sediment age versus distance plottings correlate closely with the magnetic anomaly findings and also indicate a spreading rate of about 2 inches per year.

3. Cores reveal a wide variety of sediment types. Most consisted of fossilized skeletons of marine organisms — primarily nannoplankton chalk oozes and some foraminiferal ooze sediments. Sequences were similar in many of the holes, indicating wide variety of climatic conditions or oceanic circulation.

Leg IV - Rio de Janeiro to Panama, January 27 to March 24, 1969. Dr. Richard Bader, Associate Director of the Institute for Marine Sciences, University of Miami (Fla.), and Mr. Robert D. Gerard, of Lamont-Doherty Geological Observatory, were Cruise Co-Chief Scientists.

Among the collective objectives for Leg IV were those to examine further the seafloor spreading hypothesis in peripheral regions as well as in the Caribbean. Some of the discoveries were:

1. Widespread chert blanket ties Caribbean and North Atlantic to the Pacific. Cores extracted from the central Caribbean revealed a thick, hard layer of chert similar to ones found in the North Atlantic basin, near Bermuda, and off West Africa. These 60 to 100 million-year-old sediments suggest that the Caribbean and North Atlantic were open to the Pacific at one time — meaning that Central America must have been submerged. Chert is absent in the South Atlantic, however, suggesting that that area is a different geologic province.

2. Vema Fracture Zone cored (site 26). A surprising find in this feature, which is a steep-walled valley cutting across the Mid-Atlantic Ridge, was that sediments are filling it at a rapid rate — 1 ft. every 250 years. In addition, scientists postulate that all the sedimentation comes from the Amazon and that all of it has deposited since the Pleistocene age.

3. Barbados Island began as a block of ocean floor from three miles down. Drilling at site 27 some 200 miles north of Barbados, reached bentonitic clay at 1,557 ft. below the ocean floor. This clay is quite similar to hard beds found near the base of the oceanic foundation on Mount Hillaby and exactly like layers found beneath the coral reef veneer.

Leg V - San Diego to Honolulu, April 12 to June 5, 1969, was the first leg to explore the Pacific Ocean. Drs. Dean A. McManus and Robert E. Burns, both of the University of Washington (Seattle), were Cruise Co-Chief Scientists on this leg, which explored the history of sedimentation in the northeast Pacific Ocean.

A group of six sites offshore between San Francisco and Cape Mendocino was drilled, followed by a further series of five sites from north to south down longitude 140° West from the latitude of Cape Mendocino to south of Hawaii. The offshore sites are situated some two to three hundred miles from the coast of California and drilling here revealed that they have been receiving sediment from the mainland since at least late Miocene time (say 18 million years) which is rather longer than has previously been thought.

Drilling along the north - south line showed a thin layer of sediments overlying a rough basement topography. The sediment consists of a layer of red clay underlain by richly fossiliferous material. In the north, this material is dominently calcareous, but further south the abundance of siliceous Radiolaria increases.

In Site 38 and 39 a very complete record of Radiolaria for the time span between late Oligocene and early Eocene times (say 30-50 million years) in tropical regions was recovered.

Leg VI - Honolulu to Guam, June 12 to August 5, 1969. Dr. Alfred G. Fisher, of Princeton University, and Dr. Bruce C. Heezen, of Columbia University, were Cruise Co-Chief Scientists.

On this leg, 34 holes were drilled at 17 sites in five contrasting areas of the Pacific: (1) Pacific basin floor, (2) Shatsky Rise, (3) Horizon Ridge, (4) Caroline Ridge, (5) Philippine Sea.

In the Pacific Basin floor a pelagic sequence of Tertiary brown clays rest on carbonate oozes, with chert and lithified ash, of Cretaceous age. This layered sequence comprises the acoustostratigraphic opaque zone of reflection seismology. Tertiary chert bearing carbonate oozes were encountered on Horizon Ridge.

On Shatsky Rise, Neogene carbonate oozes lie unconformably on similar sediments of Eocene and Upper Cretaceous age; Lower Cretaceous and Jurassic carbonates here have abundant chert. The Jurassic (Thithonian?) sediments are the oldest so far recovered from the Pacific, and indicate that a significant expanse of deep sea floor existed in the West Pacific before the close of the Jurassic.

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On the Caroline Ridge, Pleistocene to Oligocene carbonate ooze and volcanic ash lie on a very smooth "basement" of olivine dolerite. In the Philippine Sea, Oligocene brown clay, thick volcanic ash, and red metamorphosed limestone rest on an irregular "basement" of olivine basalt. The presence of igneous rocks immediately below Oligocene sediments in both the Philippine Sea and Caroline Ridge areas suggest an extensive re-organization of the crust in these areas in Paleogene time.

Leg VII - Guam to Honolulu, August 8 to October 3, 1969. Dr. Edward L. Winterer and Mr. William R. Riedel, both of Scripps Institution of Oceanography, were Cruise Co-Chief Scientists.

During Leg VII, a total of seven sites was drilled in four different geologic provinces: one site in the Marianas Basin, directly east of the Marianas Trench; a trio of sites along the line close to the equator within the salient of the Pacific between the Marianas and Melanesia, commonly known as the Caroline-Ontang region; two sites within the Central Basin between the Gilbert and Line Islands; and a site on the Hawaiian arch north of the island of Oahu.

Site 65 was drilled in a water depth of 20,112 feet, a new record for this type of drilling. Drilling in the Marianas Basin reached into late Cretaceous biogenous sediments without any calcareous fossils, similar to the sediments accumulating in the region today. Since, in general, calcareous fossils are only absent from sediments deposited in very deep water, this discovery raises serious doubts concerning the existence of a postulated Darwin Rise in the Region during late Cretaceous time.

The Caroline-Ontong region was shown to be an ideal area for continuous coring to recover sediments of middle and late Tertiary age. It appears that sedimentation there has been continuous since that time with the sedimentation rate close to 25 meters per million years for the past thirty million years, a rate rather higher than that generally accepted. Some excellent stratigraphic sections were recovered.

Drilling in the Central Basin raised further questions about the existence of the Darwin Rise, since here basaltic basement was reached beneath Upper Cretaceous pelagic clays and Tertiary radiolarian oozes and cherts. No biogenous calcareous pelagic sediments were discovered, suggesting that this region, like the Marianas Basin, also has remained deeper than the compensation depth for calcium carbonate for at least the past 80 million years.

Leg VII established the following records:

1. Longest drill string ever suspended from a ship or floating rig-20,792 feet.
2. Deepest water ever worked for DSDP-type of drilling 20,112 feet.
3. Deepest penetration of the ocean bottom - 3,231 feet.

Leg VIII - Honolulu to Tahiti, October 8 to December 2, 1969. Dr. Joshua I. Tracey, Jr., of the U.S. Department of the Interior Geological Survey and Dr. George H. Sutton, of the Hawaii Institute of Geophysics, University of Hawaii, Cruise Co-Chief Scientists.

A total of eight sites was drilled on this cruise across the equatorial Pacific. Six of these sites span an equatorial section of the Pacific Ocean floor near the 140th meridian west, from 6°20' North to 12°30' South, and provide a stratigraphic section of the sediments across the equatorial belt of high productivity that reaches west from the American continents. Two other sites were drilled; one southwest of Hawaii at Latitude 16°43' North, Longitude 164°10' West to provide information on the basin south of the Hawaiian Archipelago and to test a turbocorer drill that had been designed and built for the Mohole experiment; another site at 6°South, 152°52' West provides lateral control for the longitudinal section.

Chief scientific results of Leg 8 are: near-continuous coring to provide a stratigraphic section across a major sedimentological province of the Pacific Ocean; new information on lithified rocks underlying the unconsolidated sediments; and more detailed information on the problems of correlation of lithic units with reflections on the acoustic profiling records.

All of the holes drilled on Leg 8 began in thin Quaternary sediments, penetrated on upper Neogene sequence of variable thickness and composition, a largely calcareous lower Miocene and Oligocene section, and terminated in indurated Eocene sediments or in basalt (Sites 74 and 75).

Igneous rock —basalt or related rock was sampled only at the last two sites.

The sediments and rocks of this equatorial section may be divided into four lithologic units, of which we have partial information on the basal two and more complete information on the upper two.

Paleontological and biostratigraphic zoning of the rock units has been clarified for this part of the Pacific Ocean, and good samples of the Oligocene, Miocene, and Pliocene sections were obtained at most sites.

In attempting to reach basalt on Sites 70 and 71, north and south of the Clipperton Fracture Zone, nearly 15 feet of hard sedimentary rock core were recovered at each site. A total of 36 feet of lithified rock was recovered from all sites. The time taken to acquire the hard rock cores was well spent, for the limestone and radiolarite retain minute sedimentological details of texture and structure that are lost in the coring of soft sediment.

Leg IX - Tahiti to Panama, December 6, 1969 to January 27, 1970. Dr. James D. Hays, of lamont-Doherty Geological Observatory,Columbia University, was Cruise Chief Scientist, and this cruise brought to an end the initial term of the contract with the National Science Foundation for the Deep Sea Drilling Project.

Along the route from Tahiti to Panama, 17 holes were drilled at 9 sites recovering a total of 5,045 feet of core, a new record. The objectives of this leg were to study the biostratigraphy of equatorial Pacific along an east west track and wherever possible sample basement and date it by inference from the paleontological age of the overlying sediment.

Site 76 was drilled immediately north of Tuamotu Islands and Site 78 north of the Clipperton Fracture Zone about 8 degrees north of the equator. The remaining sites (77, and 79 through 84) were drilled along the east west line just north of the equator Site 84 lying just southeastof Panama.

Basalt was penetrated and recovered at 8 out of 9 sites drilled. The sediment overlying the basalt in every case showed evidence of baking indicating the basalt to be intrusive (i.e. intruded into the soft sediment rather than poured out on the sea bed as a lava flow). At the one site that failed to reach basement the bit was stopped by silicified turbidites probably of Pliocene Age.

With the exception of the first site all sites were related in that they all sampled the thick units of ooze discovered under the zone of high productivity centered along the equator. At all these sites the sediments contained abundant remains of coccoliths, diatoms, foraminifera and Radiolaria.

Four of the nine sites were continuously cored and one of the remaining five nearly continuously cored.

Leg X - Galveston, Texas, to Miami, Florida, February 13, 1970 to April 5, 1970. Dr. J. Lamar Worzel, of Lamont-Doherty Geological Observatory, Columbia University, and Dr. William R. Bryant, of Texas A & M University, were Co-Chief Scientists.

In seeking to elucidate the stratigraphic history of the Gulf of Mexico and to help resolve debates on its origin, a total of 15 holes at 13 sites were drilled inside the Florida Straits, on the Campeche Scarp, and on the Sigsbee Plain. The oldest material recovered was 135 million years old from a 1,200 foot hole on the Sigsbee Abyssal Plain near the entrance to the Florida Straits.

Biostratigraphically, the most significant achievements were (1) the recovery of pelagic sediments representing almost the entire Cenozoic and much of the Late Cretaceous deposition; and (2) the recovery of well-preserved radiolarian assemblages from Late Cretaceous to Miocene in sediments that can be very well dated in terms of the planktonic foraminiferal and calcareous nannofossil zonation schemes. The co-occurrence of siliceous fossils with calcareous microfossils in sediments ranging in age from about 30 million to 100 million years ago is a particular interest because such a long sequence of this type is probably unique. The recovery of these sediments will do much to clarify the age relations between the two groups of fossils.

Of geological significance were (1) sequences of pebbly, very coarse, graded sandstones extending back to Middle Miocene time. These are the coarsest terrigenous sands yet recovered from the deep water in the Gulf of Mexico, indicating evidence of very strong turbidity currents, and (2) cherts which were encountered with increasing frequency, thickness, and density eastwards along the Campeche Scarp and across the deep-water approches to the Straits of Florida. This "chert gradient" shows promise of providing evidence useful for studying chert formation and the history of the cherts widely encountered in the north and central Atlantic Ocean.

Natural gas, predominantly methane, was encountered in all holes drilled in the deep basin. It was apparently of biogenic origin and appeared to have reached its maximum concentration at about 300 feet sub-bottom penetration.

It is concluded that the Gulf of Mexico is essentially the same now as it was 100 million years ago. It was established that the Gulf of Mexico was a deep-water basin since at least Late Cretaceous (Santonian)time and possibly, at least in the southeastern portion, since Cenomanian time.

Leg XI - Miami, Florida to Hoboken, New Jersey, April 8, 1970 to June 1, 1970. Mr. John I. Ewing of Lamont-Doherty Geological Observatory, Columbia University and Dr. Charles D. Hollister of Woods Hole Oceanographic Institution were Co-Chief Scientists.

The principal objectives of Leg XI were to:

1) recover the oldest, inplace material above the oceanic crust and thereby attempt to date the age of the sea floor in the western Atlantic, (2)gain additional information to delineate faunal stratigraphy and interpret the paleoenvironmental history of the north Atlantic, 3)determine processes involved in the construction of massive accumulations of sediments that now form the continental rise and other oceanic ridges.

Fifteen holes were drilled at eleven sites in the eastern north Atlantic; one site (98) in the Northeast Providence Channel, two sites (99 and 100) southeast and north-Blake-Bahama Outer Ridge; three sites (102,103 and 104) on the crest of the Blake-Bahama Outer Ridge; one site (105) between the Hatteras and Sohm Abyssal Plains, one site on the lower continental rise (106) and two sites on the lower continental slope (107,108).

Scientific highlights of the cruise included:

1) recovery of the oldest deep sea sediment to date (upper middle-lower upper Jurassic - 150-160 m.y.b.p.) from two sites, 100 and 105. Both holes penetrated through basalt, providing good contacts with this and the overlying shallow water limestone. The consistent recovery of these Jurassic limestones in contact with supposed oceanic basement suggests that the north Atlantic at this location began to form 170 million years ago - 100 million years later than originally supposed.

2) nearly continuous coring at Site 105 through over 1,000 feet of lower Cretaceous and upper Jurassic sediments bearing nonnoplankton, benthonic foraminifers, radiolarians, dinoflagellotes, ostracods, pollen and spores presented an unparalleled opportunity to study the taxonomy, biostratigraphic zonation and paleoecology of these fossil groups.

3) recovery of significant mineraliferous and metaliferous sediments from Site 105. Here a spectacular sequence of Mid-Tertiary zeolitic clay beds was recovered. These brilliant red, yellow, brown, olive and orange colored layers contained a variety of minerals including zeolites, micas, quartz, siderite, pyrite, rhodocrosite, sphalerite, amphiboles and iron-manganese micro-nodules. A thin veinlet of native copper was discovered, approximately 45 feet above contact with basalt.

4) observation of a persistent major disconformity between middle Tertiary and middle Cretaceous sediments. This unconformity, observed in three sites (99,100 and 105), represents a time span of approximately 70 million years for which there is no sediment record suggesting large scale deep sea erosion.

5) recovery of Cretaceous detrital reef sediments overlain by open marine deposits from Site 98 in the Northeast Providence Channel indicating that Cretaceous sedimentation occurred in a shallow fore-reef environment followed by gradually deepening

and more open marine conditions. These observations support the concept of a slowly subsiding Bahama block whereupon the upward growth of adjacent reefs has kept pace.

6) recovery of rapidly accumulated hemipelagic mud containing a variety of minerals, floral and faunal assemblages from sites straddling the Blake Bahama Outer Ridge (102,103,104). Biogenic and mineralogical constituents of these thick sediment accumulations indicate they may have been derived from a northerly source and that the entire Outer Ridge system may have been built by accumulation of northerly derived sediments penecontemporaneously and subsequently shaped by a comination of gravitational movement and bottom current action.

7) coring of thick sections of Tertiary and Quaternary sequences in sites 102, 103 and 104 provided sediments spanning two major stratigraphic boundaries - Miocene-Pliocene and Pliocene-Pleistocene. In addition, the thick Pleistocene sections offer unusual opportunity for paleontologists to study and establish relationships between planktonic foraminifers, nannoplankton and dinoflagellates to climatic changes.

New records established on Leg XI were:

1) Oldest deep sea desiment recovered to date - 160 million years b.p.

2) Most basalt recovered - 42.7 feet.

3) Most hard formation recovered - 509 feet

4) Deepest penetration (686 ft.) and most core recovered (246 ft.) with a turbocorer

5. Deepest penetration of ocean floor - 3,332 feet.

Leg XII - Boston, Massachusetts to Lisbon, Portugal, June 19, 1970 to August 11, 1970. Dr. Anthony S. Laughton, of the National Institute of Oceanography, Surrey, England, and Dr. William A. Berggren of Woods Hole Oceanographic Institution, were Co-Chief Scientists.

Thirteen holes were drilled at a total of nine sites in the North Atlantic. Three sites in the Labrador Sea (111,112 and 113), two in the Reykjanes Ridge area (114 and 115), two in the Rockall area (116 and 117) and two in the Bay of Biscay (118 and 119).

Scientific Highlights:

1. Evidence for mid-Pliocene (3 million years B.P.) glacial activity in high latitudes. The contact between glacial and preglacial sediments was cored. It is believed that this is the first time this contact has been sampled in the deep ocean.

2. Indications in the fossil record that prior to 3 million years ago the pattern of the Gulf stream differed so that a branch of this warm current flowed into the Labrador Sea.

3. Direct evidence that two topographic highs, a seamount northeast of Newfoundland (Orphan Knoll) and a plateau northeast of Ireland (Rockall Plateau) are probably continental fragments left when Europe, Greenland and Canada broke apart over 100 million years ago.

4. A large part of the turbidite sediments of the Bay of Biscay which have been deposited over the last 65 million years, appear to have accumulated 10-12 million years ago and may be a result of the active phase of mountain building in the Alpine Orogeny.

Other important achievements:

1. Largest amount of core ever retrieved by the Challenger during an Atlantic leg.

2. The most northerly latitude (60°North) that a deep sea drilling vessel has ever attempted to operate.

Leg XIII - Lisbon, Portugal and return, August 13 to October 6, 1970. Dr. William B. F. Ryan, Lamont-Doherty Geological Observatory and Dr. Kenneth J. Hsü (Eidg. Technische Hochschule) were Co-Chief Scientists.

Glomar Challenger left Lisbon at midnight on the 13th of August and returned in the morning of the 6th of October. The principal objectives of this Thirteenth Leg of the Project were to investigate the tectonic and sedimentary histories of the Mediterranean Basin and their relevance to such fundamental problems as mountain-building and the origin of small ocean basins. Rocks of many different kinds, ophiolites, basalt, obsidian, andesite, tephra, meto-sandstone, semi-schists, algal limestone, dolomite, pelagic oozes, sapropels, evaporite, flat-pebble conglomerate, detrital gypsum, nodular anhydrite, and even rock salt were recovered from some of the 200 cores retrieved from 28 holes at 15 sites.

One of the most impressive findings was the evidence for compressional tectonics in the eastern Mediterranean Basin. In the Hellenic Trough (Hole 127) Lower Cretaceous, limestones and dolomites were penetrated and the hole terminated in flat-lying Middle Pliocene pelagic ooze. At Site 130 in the Levantine Basin, evidence was found that the Mediterranean Ridge there was formerly a part of an extensive Nile Abyssal Plain as recently as the Middle Pleistocene.

Evidence for rifting or extensional tectonics was also present . The similarity of stratigraphical succession at Site 105 recovered by the Leg XI scientific team, adds an almost superfluous confirmation of the symmetrical spreading of the Atlantic. However, the location of this site west of Portugal does suggest that the Iberian Block may have moved with Africa during a portion of the early phases of the opening of the Atlantic. The discovery of oceanic basalt under Upper Miocene sediments at Site 121 in the Alboran Basin might be indicative also of a rifting origin for this narrow seaway which separates Spain from Africa. Finally, at our last drill site (134) we wxplored the boundary fault which separates the subsided edge of the Corsica-Sardinia micro-continent from the Balearic oceanic crust, and sampled in a series of five holes a basement terrane under an eroded fault scarp consisting of meta-gray-wackes and phyllites lithologically similar to those of Lower Paleozoic age on the west coast of Sardinia, some 45 miles east of the drill site.

Long standing disputes concerning the age of the evaporite rocks which underly the Mediterranean Basin and the nature of the prominent subbottom acoustic reflectors under the Mediterranean, have been resolved. We have indisputable evidence of a late Miocene age for the salt at Site 134 in the Balearic Basin, where we actually discovered fossil-bearing marine sediments intercalated in layered halite. The rock salt is apparently the facies of an Upper Miocene evaporitic sequence whose upper surface everywhere seems to correlate with the M-Reflector. The only major surprise was in the Nile Cone region at Site 131, where the prominent subbottom reflector previously identified as Reflector M, turned out to be a cemented sandstone of young Quaternary age.

Associated with some of the evaporites are diatomaceous muds containing at certain levels diatom species indicating the temporary occurrence of a fresh or brackish surface layer within this ocean basin. Another astonishing discovery is the sudden Lower Pliocene transgression, which drowned the evaporites simultaneously in the Ionian, Tyrrhenian, and probably also all other deep Mediterranean basins. This transgression coincides with the Miocene-Pliocene boundary as defined by stratotypes in Italy; the contact was cored at Site 132. Samples from this site may eventually provide a useful reference section for Mediterranean biostratigraphers.

All Quaternary and some Pliocene pelagic sections include tephra layers, as witness of intermittent volcanism throughout the last few million years. The virth and evolution of the western Mediterranean are assuredly connected in some way to these volcanic activities.

Leg XIV - Lisbon, Portugal to San Juan, Puerto Rico, October 9 to December 1, 1970. Dr. Dennis E. Hayes of Lamont-Doherty Geological Observatory and Dr. Anthony C. Pimm, Staff Geologist for Deep Sea Drilling Project at Scripps Institution of Oceanography, were Co-Chief Scientists.

Seven sites were drilled along the continental margin off West Africa and three along the northeast coast of South America. Total steaming distance for this cruise was 10,025 Kilometers.

The main objectives were to study the structure and processes of sedimentation along the Atlantic continental margins. Particulary to compare results from this Leg with those of Leg XI; to investigate a piercement structure presumed by many to be a salt dome; and to determine the sedimentary and structural evolution of the Ceara and Demerara Rises.

Some Comments on the Preliminary Results of this Leg:

1. Basalt was recovered at three sites (136,137,138) in the eastern North Atlantic and the depth of each can be correlated with the depth of the acoustic basement reflector. Sediments overlying the basalt at Site 136 indicate a minimum age for the basalt of about 110 million years. If, sea-floor spreading has been symmetric in the North Atlantic, the inferred age of the crust at Site 136 (110 million years) is anomalously young when compared with that at Site 105 of Leg Eleven(155 million years). One possible explanation for the apparent age discrepancy is that the western Atlantic basin is underlain by oceanic crust of a small proto-Atlantic Ocean.

2. Unconformities, representing sedimentary hiatuses in the Early to Middle Tertiary sections are inferred for Sites 135, 136, 138 and 140. Similar unconformities are indicated for the western North Atlantic from the records of Sites 99, 101, 105 and 106. The interrelation and geographic extent of these unconformities is not yet known.

3. Several sites, all shallower than 4500 meters (136, 139, 140, 141), show an upper chalk or marl ooze sequence of Quaternary to Neogene age resting on a non-calcareous clay with silt and sand of Early Neogene and Paleogene age.

4. Several sites (135, 136, 137, 138, 144) show a striking variety of Cretaceous lithologies. These include clay, siliceous mudstone, chert, black shale, limestone, and chalk/marl ooze. Pyrite is abundant in the Cretaceous section at Sites 135, 137, 138 and 144. Well developed cyclic sequences of carbonaceous material, dolomitic clay and silt, and siliceous mudstone occur in Sites 138 and 140.

5. A piercement structure was drilled north of the Cape Verde Islands but gave no evidence of salt or evaporite concentrations. A highly altered basalt was recovered at 300 meters subbottom, clearly establishing that the structural feature has an igneous origin.

6. A prominent reflecting horizon that underlies most of the Ceara Abyssal Plain at subbottom depths ranging from 300 to 1000 meters is caused by a series of thin alternating chalk/marl ooze and turbidite layers deposited in the Late Miocene or Early Pliocene. The major portion of the Ceara Abyssal Plain sediments lie above the reflecting horizon and have probably been deposited since the Early Pliocene. The generally undisturbed character of the reflector abutting the flank of the Ceara Rise indicates the major uplift of the Rise was pre-Early Pliocene.

7. Marine sediments were deposited on the Demerara Rise prior to the inferred separation in the Late Cretaceous of South America and South Africa.

8. A good succession of Cretaceous nannoplankton was recovered and should be valuable in establishing a world-wide biostratigraphic subdivision of the Late Mesozoic.

Leg XV - San Juan, Puerto Rico to Cristobal, Canal Zone, December 5, 1970 to February 2, 1971. Dr. N. Terence Edgar, of Scripps Institution of Oceanography, and Mr. John B. Saunders, of Texaco Trinidad Inc., were Cruise Co-Chief Scientists.

By drilling and sampling sediments and rock below two to three miles of water, the shipboard scientists on Leg XV identified fossils of animals and plants that have remained buried for 75-85 million years. These fossils were entombed in sediments that lie on basalt, or cooled magma, that represents the final stages of development of the crust beneath the Caribbean Sea. In comparison, the oldest part of the North Atlantic Ocean is about 180 million years old and that of the continents is about 3,500 million years.

This curious age-relationship is explained by scientists using the now popular concept of continental drift or sea-floor spreading. According to this theory the continents of North and South America were once attached to Europe and Africa and about 180 million years age they pulled apart and drifted westward leaving a young ocean crust in their wake. Curiously, when the continents are "fitted" back to their original position, before the breakup, South America overlaps where the Caribbean should be. Thus scientists conceived of the Caribbean crust as either being formed when the continents broke up or as a fragment of even older crust from the Pacific Ocean that was wedged between the Americas as they moved westward.

The scientists, therefore, envisage South America tearing apart from the Greater Antilles (Haiti, Dominican Republic, Puerto Rico, Virgin Islands) and a new crust slowly developing. Geologists have recorded long periods of great volcanic activity in the Greater Antilles and Northern South America, at this time, with a slow return to quiescence about 80 million years ago. Similarly, in the Caribbean basins, the final stages of crustal development were completed about 75 million years ago, after which the sediments that were deposited during the ensuing millions of years contain an ever decreasing amount of volcanic ash and debris. Finally the lands and seas were quiet; the formation of the Caribbean crust was completed and it became stable and inactive. Since the end of Cretaceous (65 million years ago), volcanicity in the Eastern Caribbean has been confined to the extreme eastern edge where the volcanoes of the Antillean Islands are still active. The reasons for this limited activity is envisaged as the interaction of the Caribbean crustal plate with the Atlantic plate - both are moving westward but the latter is moving faster than the former and is being forced down below it, creating a line of weakening and melting. Ash from the frequent Tertiary eruptions drifted over great areas of the sea and is now to be found as repeated thin layers within the sediments.

The scientists also point out the possibility that older sediments may be buried below the basalts in which case the interpretation would be modified considerably. A virtually complete section of rocks for the past 85 million years was recovered in the Caribbean for the first time. Paleontologists on board examined the microscopic animals and plants to build up a record of their development over the past 85 million years. The refinement of their zonation will be of value for use throughout the pantropical belt wherever marine sediments are exposed at surface or reached by the drilling bit.

A totally different problem was investigated by the scientists on Leg XV when they drilled a hole in the deep closed basin - the Cariaco Trench - off the north coast of Venezuela. The sediments span the time interval of the last Ice Age (Pleistocene) in North America and it was hoped to establish a series of warm and cold periods to match the glacial and inter-glacial periods known from the north. Preliminary work on the ship, using temperature sensitive small marine organisms, shows that such fluctuations do exist and further work on these should delineate the changes of climate.

Another aspect of work in the Cariaco Trench was the examination of geochemistry of the sediments in this rather peculiar closed basin. Geochemists were on board especially to do this, making it the first major geochemical program in the deep ocean. This is a first stage in the understanding of the chemical changes that take place in marine sediments over long periods of time - an understanding that is necessary for our future utilization of the resources of the deep oceans.

Leg XVI - Cristobal, Canal Zone to Honolulu, Hawaii, February 5, 1971 to March 30, 1971. Dr. Tjeerd H. van Andel and Dr. G. Ross Heath both of Oregon State University were Cruise Co-Chief Scientists.

The scientific objectives of Leg XVI were twofold:

The first was to test the hypothesis recently developed by scientists from Oregon State University and Lamont-Doherty Geological Observatory that the present-day Carnegie, Cocos, Coiba, and Malpelo Ridges, high-standing blocks of sea floor surrounding and within the Panama Basin, are parts of formerly single, ancestral Carnegie Ridge which was split lengthwise relatively recently by the development of an east-west rift zone. Rifting began in the east, so that the eastern blocks have drifted successively farther north than the western blocks, while the present-day Carnegie Ridge has remained stationary. As successive pieces of the drifting northern part of the ridge reached the Middle America Trench, they were pulled down into it, and sealed its eastern end. Isostatic compensation has subsequently elevated the Isthmus of Panama, which throughout Tertiary time had been the site of an open waterway between the Atlantic and Pacific Oceans, and parts of Costa Rica.

The cores taken on Leg XVI in the Panama Basin area —— on the Coiba, Carnegie, and Cocos Ridges —— show that this hypothesis is most probably correct. The hole drilled on the Carnegie Ridge shows essentially unchanging sedimentation from the bottom of the hole to the top —— a uniform sequence of equatorial-type calcareous/siliceous oozes. The holes drilled on the Coiba and Cocos Ridges, on the other hand, show changing sedimentary facies as the deposits become younger. The oldest deposits at both sites are equatorial-type oozes; upward, less fossiliferous sediments are encountered, probably deposited when the blocks drifted under the less productive waters north of the equator; and yet further upward volcanic ash and terrigenous materials become increasingly abundant, indicating approach to sources of land-derived sediment in Central America. Thus, the path of the ridge fragments across 400 miles of ocean floor can be traced in the Panama Basin cores.

In addition to their significance in the reconstruction of the tectonic history of this part of the ocean floor, the Panama Basin cores will prove valuable for bio-stratigraphic studies of planktonic microfossils, and for paleoclimatic studies of the last 14 million or so years of earth history. This is mainly by virtue, of the unusually high rate of sedimentation in the Panama Basin area; rates as high as 11 cm per thousand years were encountered.

The objectives of the second part of Leg XVI were to further investigate the depositional, tectonic, and paleo-oceanographic history of the eastern Pacific area, a regional study begun on Deep Sea Drilling Project Legs V, VIII, and IX. The history of this area, as recorded in the changing facies of pelagic sediments, is determined by the interrelations of four factors:

(1) Regional depth of the calcite compensation depth, or that level in the water column below which all skeletal calcium carbonate is redissolved.

(2) Movement of the ocean floor, which is continuously created at the crest of the East Pacific Rise, down the flank of the Rise from depth above to depths below the calcite compensation depth.

(3) A northward component to the overall motion of the East Pacific floor. The main significance of this factor is that strata deposited under the equatorial high productivity belt, generally thicker and more calcareous than sediments north or south of this belt, are continuously moved to higher northern latitudes, where biological productivity is low and sedimentation relatively slow. Also, areas previously south of the equator, where surface productivity is also low, gradually move to positions under the equator. Thus, by tracing the thick belt of equatorial sediments it is possible to determine the rate and direction of motion of the east Pacific floor.

(4) The width of the equatorial high productivity belt, which is probably determined by the intensity of overall oceanic circulation. The last factor has been shown to be related to major changes in global climate.

The five holes drilled in the second half of Leg XVI, together with the findings of other cruises of the Deep Sea Drilling Project support the existence of the northward movement of the Pacific. With increasing age in the cores, the zone of thickest and most calcareous sediment moves progressively to the north. Sediments representative of the Eocene equatorial zone (approximately 45 million years old), for example, are now located more than 1,000 nautical miles north of the equator.

Since the pattern of ages of sediment immediately above basement gives a measure of the rate of movement of the ocean floor away from the ridge crest where it was created, it was one of the primary objectives of Leg XVI to drill through to basement and recover the oldest sediment at each site. This was accomplished at each site. The basement ages obtained on Leg XVI in general support a very rapid motion for the block between the Clarion and Clipperton fracture zones, first deduced by the Leg IX scientists; the rate is approximately 8 cm per year, or 30 feet per century.

The findings of Leg XVI were not without surprises, however. At the last site drilled, in an area where the predicted basement age on the basis of the above spreading rate was approximately 62 million years (Paleocene), a section bottoming with sediments of Late Cretaceous age (Campanian, or nearly 80 million years old) was cored. It is likely that this age discrepancy may require substantial changes in our views of the older history of the Pacific Ocean Basin.

Leg XVII - Honolulu to Honolulu, April 4, 1971 to May 25, 1971. Dr. Edward L. Winterer, Scripps Institution of Oceanography, and Mrs. John I. Ewing, Lamont-Doherty Geological Observatory, were Cruise Co-Chief Scientists.

Scientific objectives:

1. To see how fast and in which direction the Pacific Ocean crust has moved. It is known that, like the Atlantic, the crustal plates of the Pacific Basin have moved by continuous spreading away from a mid-oceanic line of sub-sea mountains in a fashion similar

to two diverging conveyor belts. Scientists calculate oceanic age and spreading rate by determining the age of tiny fossils in the sediments just above the "basement rock". In the Atlantic, drilling to "basement" on earlier DSDP legs has shown the ocean to be about 150 million years old and presently increasing in width at the rate of about an inch a year. Drilling of nine selected holes to "basement" on Leg 17 will allow the opportunity to gauge better the rate of movement of Pacific crust, its probable maximum age, and where the oldest rocks may be.

2. To determine a time history of ocean currents, climate changes, and geographic movements of ocean plates. Again, focus will be on tiny fossils collected in continuous long sediment cores. The type of animals and plants that can live in a particular area of ocean water depends largely on temperature, salinity and availability of certain necessary mineral salts, so that the different open ocean areas are populated by different assemblages of small creatures. When these creatures die, their hard parts settle vertically to accumulate on the bottom. Subtle change in fossil assemblage in a given core, then, can indicate either 1) changes in water characteristics in that area with time (i.e. changes in ocean current patterns and climate zones), assuming the piece of ocean floor has stayed put, or 2) changes in latitude of the piece of ocean floor (due to ocean floor spreading) from beneath one water mass to beneath another. Actually, it is known that both relative movements are occurring - it will be the exciting and difficult job of Leg 17 scientists to separate the two.

3. To study sub-sea sound-reflecting zones. Geologists can, from a study of these rocks and sediments, tell something about types of sediment accumulation and sub-sea rock forming processes. These zones are important clues to regional geologic processes and in some cases can tie histories at several drill sites together. The Project's proven capability to re-enter the same drill hole is vital to these studies.

4. To study the origin of sub-sea mountains. This area of the ocean has many discrete mountains rising from the sea floor, some breaking the surface (atolls and islands), some completely submerged (seamounts). The number of these features is particularly high in this one area, and this is somewhat puzzling. Leg 17 finds should add evidence toward solving the problem.

Scientific findings:

The Pacific sea floor has been moving northward across the Equatorial belt of great biological productivity. This northward motion of the oceanic crust was shown on earlier expeditions of DSDP to have persisted for at least the last 30 million years. Earlier magnetic studies on seamounts in the Pacific suggested that as much as 1,800 miles of northward movement has occurred in the past 100 million years and that the results of this cruise lend support to the idea of long-continued northward motion.

The time from about 80 to 110 million years ago was an era of great volcanic activity in the Central Pacific. During part of the Cretaceous Period (70 to 130 years ago), not only did lava pour out into the deep ocean floor, but many undersea volcanoes built themselves up close to sea level where reefs could flourish. At some place the cores obtained show evidence of repeated episodes of volcanism millions of years after earlier outbursts.

The last hole was drilled in Horizon Guyot, about 620 miles West of Honolulu. It is one of the many flat-topped seamounts of the Central Pacific. The cores showed conclusively that the top of the seamount was formerly at or above sea level and has since subsided to its present depth of about 5,000 feet.

The sediment cores also focus attention on the as-yet unexplained dearth of sediments representing the early part of the Tertiary Period from about 50 to 70 million years ago. So widespread is this phenomenon in both the Atlantic and Pacific that it probably represents a world-wide change in ocean circulation patterns. The deep sea sediments deposited just after this unusual era are rich in silica in the form of flints and beds of chert. These cherty layers are observed as prominent reflecting horizons in seismic records and can be traced over major parts of the world's ocean basins.

The mid-Cretaceous volcanism makes it very difficult to make out any clear pattern of crustal ages in the Central Pacific between the Hawaiian Islands and the Marshall Islands. Near the Equator, ages increase regularly to the West in the same way predicted by previous drilling results with sediments as old as 135 million years now documented at one of the sites. But farther North, the apparent crustal ages are much too young to fit the previously predicted pattern. Whether this represents the covering over of an old pattern by younger volcanism or a change in the pattern itself is not yet clear.

Leg XVIII - Honolulu, Hawaii to Kodiak, Alaska, May 29, 1971 to July 19, 1971. Dr. LaVerne D. Kulm of Oregon State University and Dr. Roland von Huene of United States Department of the Interior, Geological Survey were Cruise Co-Chief Scientists.

Several scientific objectives were pursued by Leg 18 scientists. One of the more important was to examine the tectonic relationships and sediments where oceanic crust is thrust under the continental margin. Two opportunities for this study were afforded, one by drill sites off the Oregon Coast and the other by drill sites in the Gulf of Alaska. The approach in both cases was to drill paired holes one being in flat lying sediments reposing on oceanic crust near the continental margin and the other on large structures developed at the foot of the continental slope.

From cores taken off the Oregon Coast it was determined on the basis of microfaunal assemblages that tectonic uplift occurred on the lower continental slope at about the same time a landward dipping acoustic discontinuity developed in sediments above the oceanic crust. Such synchroneity of events is to be expected where oceanic crust impinges on the leading edge of the continental margin. In the Gulf of Alaska, soft, flat-lying sediments occur in the Aleutian Trench. On the landward site of the trench, sediments of the same age are deformed and well-consolidated. Further work may determine whether the latter sediments were deposited on the ocean floor, seaward of their present position, and whether the passing of the oceanic crust beneath the continent is responsible for their induration and structural alteration.

One Leg 18 objective of importance to the paleontological community was establishing a high latitude biostratigraphic section in the Gulf of Alaska. To do this required the drilling of a transitional biostratigraphic section which would tie-in the high latitude forms to low latitude types.

Varvelike structures were encountered at several sites in the Northeast Pacific. Some are definitely drilling artifacts, while others may be contourites.

Another significant scientific objective was to fill in the 140° West Longitude biostratigraphic traverse begun on Deep Sea Drilling Project Legs V, VIII and XVI. The site selected was on the plate segment between the Murray and Molokai fracture zones and coincided with Anomaly 8 of a proposed secondary spreading center (Malahoff and Handschumacher in press) in a magnetically "disturbed zone".

Drilling results indicate an age near 32 to 37 million years at total depth which is greater than the 29 million years expected for Anomaly 8. This suggests that anomaly identifications in this area are still not clear. Stratigraphically, a series of "red clays" rich in zeolites was encountered above the oceanic basalt. Near the base of the section a thin nannofossil ooze of Early Oligocene age is developed. It is similar in age, fossil assemblage and stratigraphic position to one encountered at Site 3 on Leg V. Interestingly enough the nannofossil ooze does not rest directly on basalt but is separated from it by a thin layer of dark red clay. This clay resembles the magmatic exhalate rich material found on previous legs in this region of the Pacific Ocean.