deep sea drilling project

ocean sediment coring program

NATIONAL SCIENCE FOUNDATION

GOVERNMENT AGENCY

National Science Foundation

PRIME CONTRACTOR

University of California, San Diego. Scripps Institution of Oceanography of the University has been delegated responsibility for management, operations, and accomplishment of scientific objectives.

ADVISORY SCIENTIFIC PLANNING BODY

Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES)—Lamont-Doherty Geological Observatory of Columbia University; Rosenstiel School of Marine and Atmospheric Science of the University of Miami; Department of Oceanography of the University of Washington; Woods Hole Oceanographic Institution; Institute of Oceanology of the U.S.S.R. Academy of Sciences and Scripps. The Bundesanstalt fuer Bodenforschung of the Federal Republic of Germany is in the process of becoming a member of JOIDES.

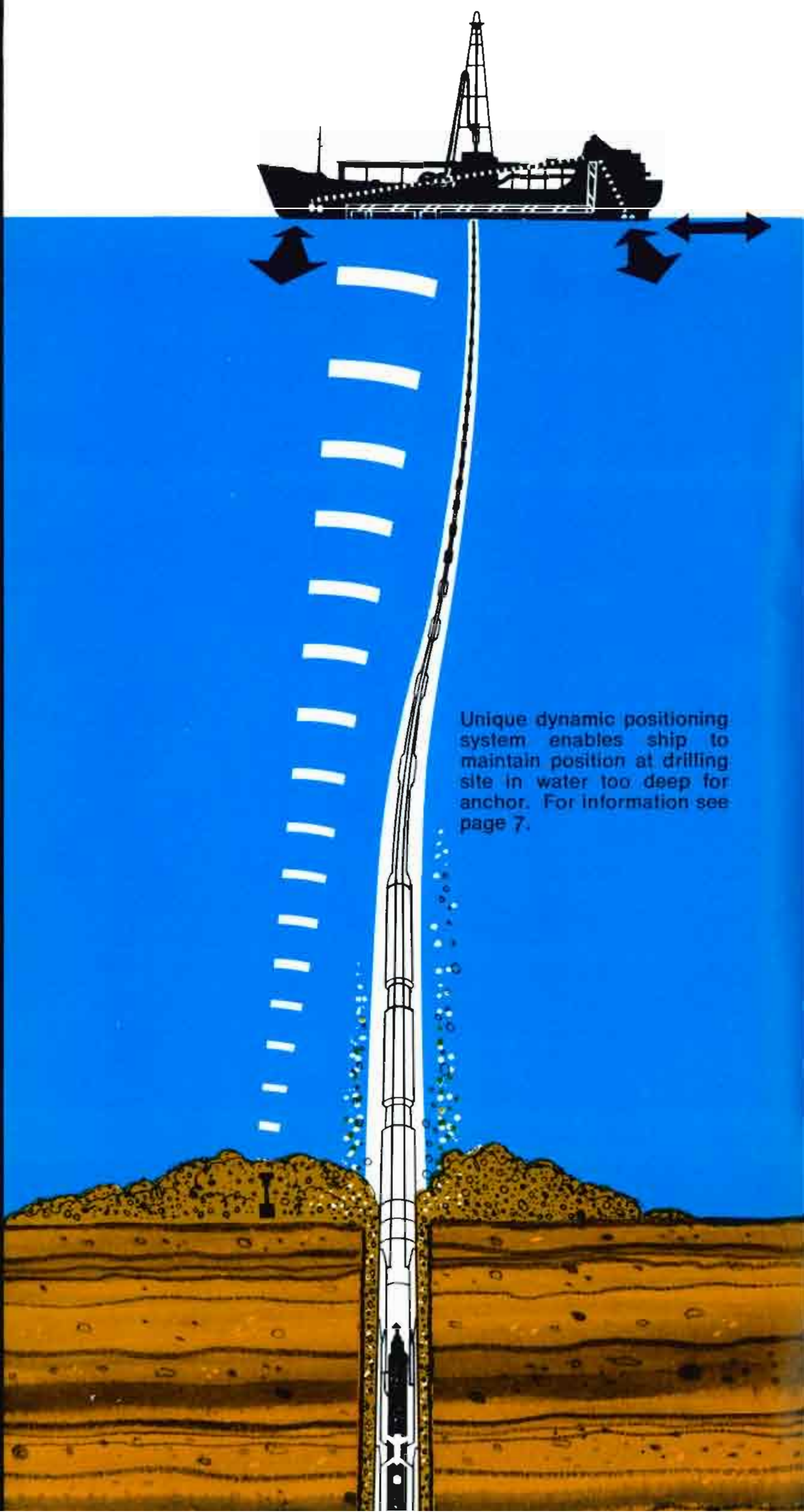
ELIGIBLE PARTICIPANTS

All qualified scientists from the academic community, government agencies, and industrial organizations, worldwide.

PRINCIPAL SUBCONTRACTOR TO THE UNIVERSITY OF CALIFORNIA

Global Marine, Inc. Responsible for design and operation of GLOMAR CHALLENGER, drilling ship for the project.

NATIONAL SCIENCE FOUNDATION—H. Guyford Stever, Director



The Deep Sea Drilling Project is a part of the National Science Foundation's Ocean Sediment Coring Program, a program to explore the crust of our own planet. Its objective is to learn about the origin and history of the earth through the study of samples obtained from previously inaccessible sites.

The immediate aim of the Deep Sea Drilling Project is to increase our understanding of the sub-oceanic crust of the earth by studying long cores of sediments taken from the ocean bottom. The ridges, rifts, and great abyssal plains that comprise the ocean basins are being systematically examined, and samples from deep under the sea floor are being obtained for careful study.

Ocean-bottom sediments come from two main sources. One, the land, contributes such products of weathering and erosion as sand, silt, and volcanic ash which are carried to the sea by streams and rivers, by the winds, or by glacial ice. The other is the steady "rain" of shells from microscopic animals and plants that live near the surface of the ocean. Throughout the ages, as they have died, their debris has dropped to the ocean floor, there to become part of the record of the earth's history.

From a study of these sediments, scientists are obtaining information about the behavior of oceanic crust. When this is combined with knowledge about the ancient history of the continents and their migration and development during the last 250 million years, investigators can better reconstruct the history of the origin, growth, and movement of the earth's crust, and extend this knowledge to the interpretation of the 4.5 billion years of earth history since the planet was formed. Besides telling us how our planet evolved and what we should expect in the future, such knowledge should help make possible better use of oceanic resources for the good of all mankind.

During the first five years of operation—beginning in the summer of 1968—the Deep Sea Drilling Project has produced information of such significance as to mark it as one of the most successful scientific expeditions of all time. In this period approximately 450 holes were drilled at about 300 sites in the Atlantic, Pacific, and Indian Oceans, as well as in many marginal seas. Sediment and rock cores were obtained from the earth's crust under water more than 20,000 feet deep. Holes have been drilled more than 4200 feet into the ocean bottom. The drilling ship has used the longest drill string (22,192 feet—well over four miles in length) ever suspended from a floating platform.

Plans call for the drilling to continue for at least two more years, both in areas of the ocean not yet investigated and in areas where more detail is sought. In addition, attempts will be made to penetrate farther below the sediment cover on the ocean floor.

Microfossil shells by which age of the sediment is determined.

The earth that we inhabit is not static, it is dynamic. Erosion is one of the dynamic processes whose results are easily seen. Earthquakes and volcanoes are also obvious evidence of a nonpassive earth and scientists have demonstrated that they occur most frequently along narrow zones that separate huge, relatively stable sectors of the earth's crust.

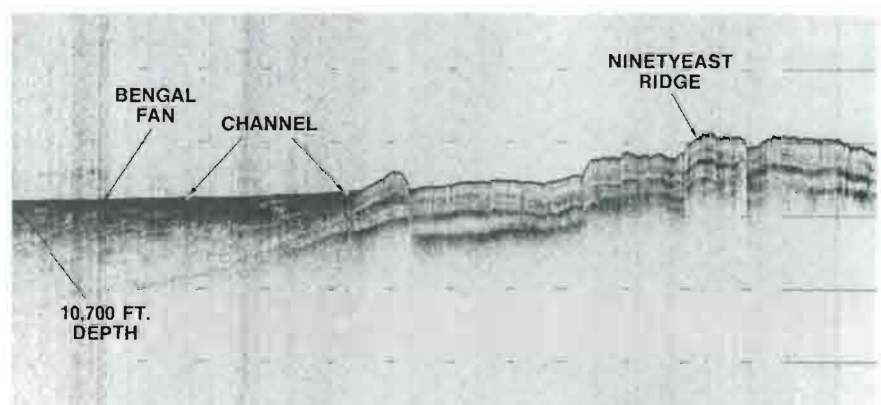
In the past 25 years geologists have given increasing attention to oceanic areas, which are far less well known than are land areas. Instrumentation was developed which permitted much to be learned about the ocean bottom without actually being able to see it or touch it. For example, profile maps of the ocean bottom were prepared by use of reflected sound waves. Preparation of these profiles required more than one million miles of traverses by surveying ships. The surveys confirmed that the oceanic areas are dynamic and subject to continual change. The investigators learned much about patterns of the earth's gravity, magnetic field, and heat flow. They also gathered much new information regarding the composition, thickness, and stratification of the sediments covering the deep sea floor and continental shelf.

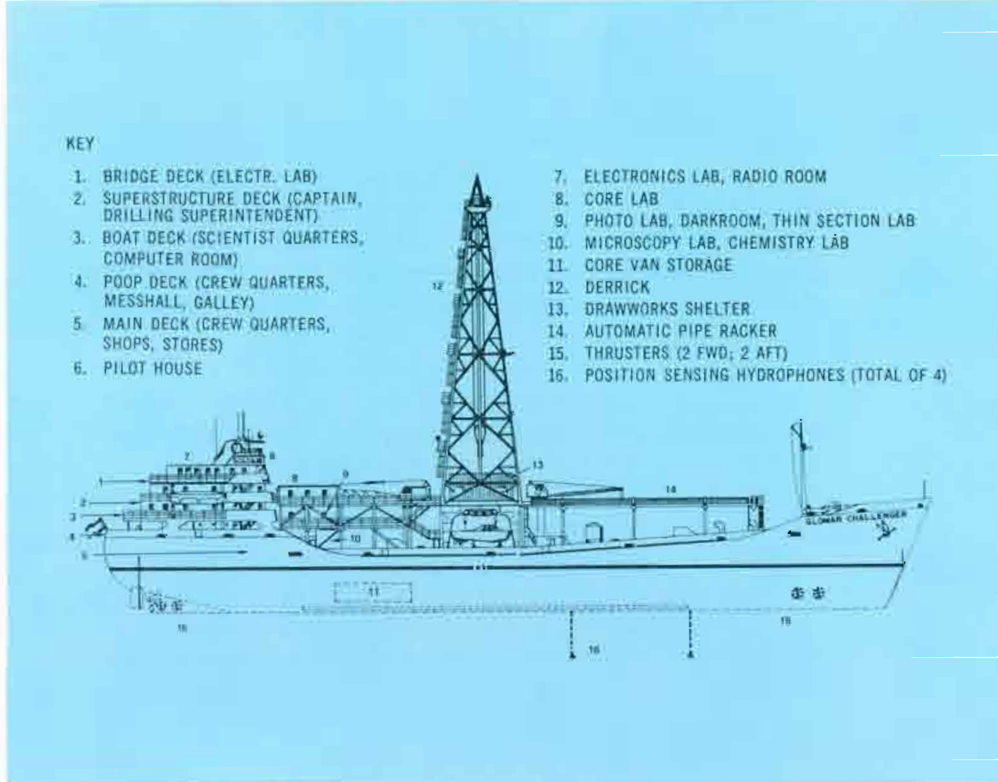
Over this same period of time, numerous new theories and hypotheses about major earth processes were proposed. These theories, for the most part, concern the magnetic field and the origin of magnetic patterns of the earth, the motions of the sea floor and the drift of continents, and the history of the temperature of the planet. They led to specific predictions that could best be checked by direct sampling of deep-sea and continental-margin sediments and underlying rocks.

In addition, during the past 10 years, the refinement of techniques based on radioactive decay of long-lived radioactive elements has made it possible to date rocks that comprise the most ancient portions of the continents. Some of these approach 4 billion years in age. They formed long before life on earth had developed to the stage represented in the earliest fossil record, and they constitute the oldest records of the history of our planet.

By providing samples of the sea bottom, the Deep Sea Drilling Project is enabling scientists to determine the validity of these theories. At the same time, the project is contributing at a rapid rate to the accumulation of fundamental scientific knowledge about our planet.

Example of sub-bottom echo profile.
Profile shows deep sea silt and sand deposits of the Bengal Fan in the Indian Ocean covering the Ninetyeast Ridge. The fan deposits are at a water depth of 3259 meters (10,700 feet). These sediments come from the Ganges and Brahmaputra Rivers and are distributed along channels that can be seen in the left part of the profile. The Ninetyeast Ridge is formed of basaltic volcanic rock with a cap of pelagic calcium carbonate ooze. Traverse is between Sites 217 and 218.





The Drilling Ship

Heart of the Deep Sea Drilling Project is GLOMAR CHALLENGER—400 feet long and 10,500 tons displacement. Her profile is unforgettable; amidships towers a 142-foot drilling derrick, its top almost 200 feet above the water line.

Aside from her unusual appearance, the ship possesses remarkable operating capabilities. She can be positioned in water too deep for anchors, and remain at a drilling site as long as desired. A dynamic positioning system that maintains the ship's position within a radius of a few hundred feet makes this possible.

When the ship reaches a drilling site, a beacon that emits acoustic signals is dropped to the ocean bottom. The pulses are received by hydrophones located in her hull. The ship's position is determined by triangulation from the difference in arrival times of the pulses at the individual hydrophones. A shipboard computer then calculates the amount of thrust required from each of the propulsion units to keep the ship precisely on station. Two main propulsion units provide fore and aft thrust and four tunnel thrusters provide lateral thrust.

Although GLOMAR CHALLENGER is remarkably stable, because of her gyroscopically controlled roll-stabilizing system, she still rolls and pitches in a heavy sea. So that drillers can effectively and rapidly control the enormous lengths of heavy drill pipe needed to probe the ocean bottom even under adverse weather conditions, the ship incorporates an automatic pipe-racking device that takes up most of the topside space forward of the derrick. More than 4 miles of drill pipe—23,000 feet—are stacked in 90-foot lengths in the pipe racker and additional storage space is available below deck. The ability to handle drill pipe mechanically is a great advantage, thereby avoiding the dangers to personnel that would be posed by manual pipe racking.

Beneath the derrick is an opening about 20 x 22 feet extending through the bottom of the ship. The drill pipe is suspended from the derrick and passes through a stress-distributing structure shaped somewhat like the flared throat of a horn. This prevents the roll and pitch of the ship from bending the pipe sharply at any one point. The lengths of pipe in the drill string are raised and lowered by winches using huge pulleys with a 1-million pound capacity.

GLOMAR CHALLENGER has living and storage facilities that permit her to remain at sea for months at a time. She has berthing for about 70 persons, including the ship's operating crew, the drilling crew, and the scientists and technicians. Living spaces, the bridge, and laboratories dominate the upper decks aft of the drilling derrick. The ship is fitted out with some of the best laboratories ever designed for the study of geological materials at sea.

Satellite navigation permits positioning the ship accurately at any time and provides precise location of the drilling sites. The ship receives daily satellite weather photographs of cloud patterns which are used in weather forecasts to increase the safety and effectiveness of the drilling operation and schedule.

Where to Drill

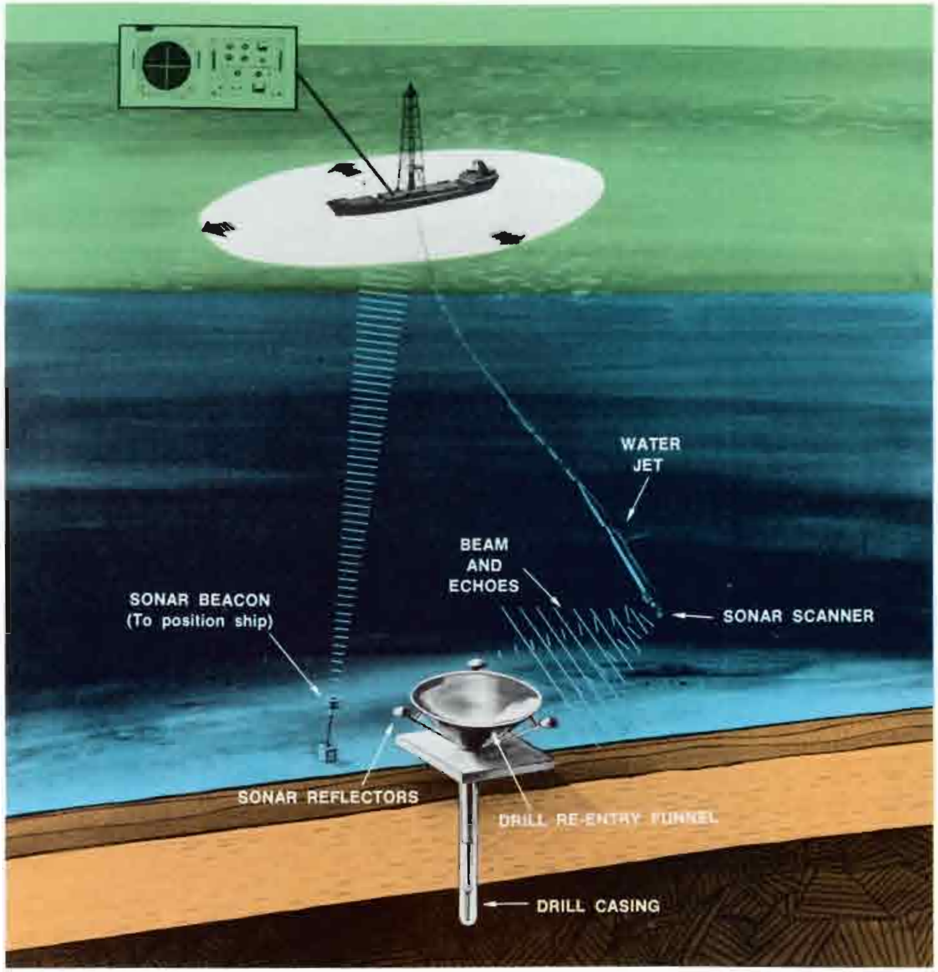
■ To obtain the maximum amount of information possible, panels of knowledgeable scientists from many different institutions are brought together to recommend a suitable drilling program to Scripps.

The sites suggested by the panels permit scientists to sample the oldest sediments in the ocean basins; to test hypotheses of continental drift, sea-floor spreading, and plate tectonics; and to recover nearly complete sedimentary columns extending from the present to the oldest sediments deposited on the original sea floor. Present plans call for increased penetration into the harder rocks beneath the sediment cover.

The Drilling Process

■ On each individual cruise, the co-chief scientists on GLOMAR CHALLENGER make the final selection of drilling sites after all recommended sites have been surveyed. Once on station, the ship is stopped and the main propulsion units are used thereafter only as required to provide additional thrust for the dynamic positioning. An acoustic beacon is lowered over the side, tested briefly, then released to fall to the bottom. After it reaches the bottom and the ship is positioned, the drill string is lowered. At the tip of the drill string is a drilling bit—any one of several kinds, depending upon the materials the scientists expect to find at the bottom. Above the bit are the core barrel, which "captures" the cores of sediment and the drill collars (heavy pipes to hold the coring mechanism and to exert weight on the bit). Once the drill bit touches bottom, the entire drill string is rotated from the drilling derrick.

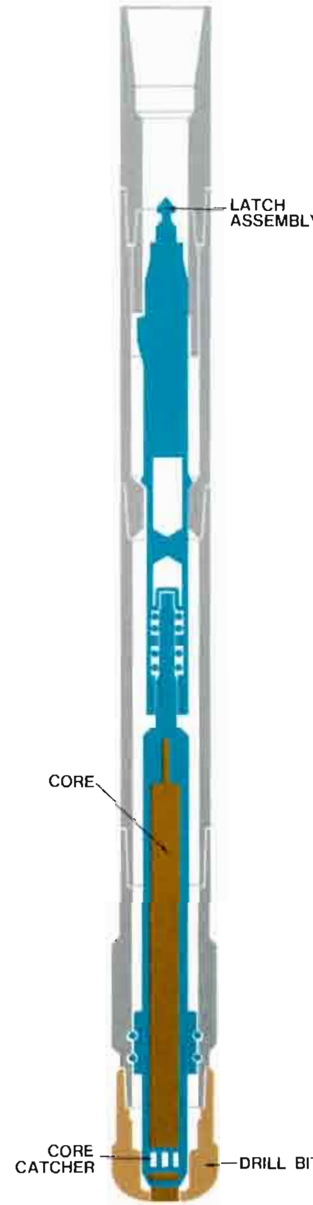
Until 1970, there was no capability for going back into the same hole after pulling the drill string out of the bottom; consequently, drilling had to be terminated after a bit was worn out. A system was developed, however, using a high resolution scanning sonar probe, that now makes it possible to re-enter the hole with a new bit. This system increases the ability to drill and recover materials from greater depths below the sea floor and to penetrate very hard rock.



Re-entering Drill Hole in the Deep Ocean Floor

This recently developed mechanism enables a drill bit to be guided into a previously drilled hole. The re-entry funnel is attached to the drill string when it is first lowered to the bottom, and remains on the ocean floor when the string is withdrawn. At the time re-entry is attempted, the drill string is relowered with a sonar scanner on the bit assembly that emits sound signals. These signals are echoed back from three reflectors spaced around the funnel. Position information is relayed to the ship and the water jet is used to steer the bit directly over the funnel.

DRILLING PIPE AND CORE BARREL



Rhyolites from Lord Howe Rise. Leg XXI

Analysis of Cores

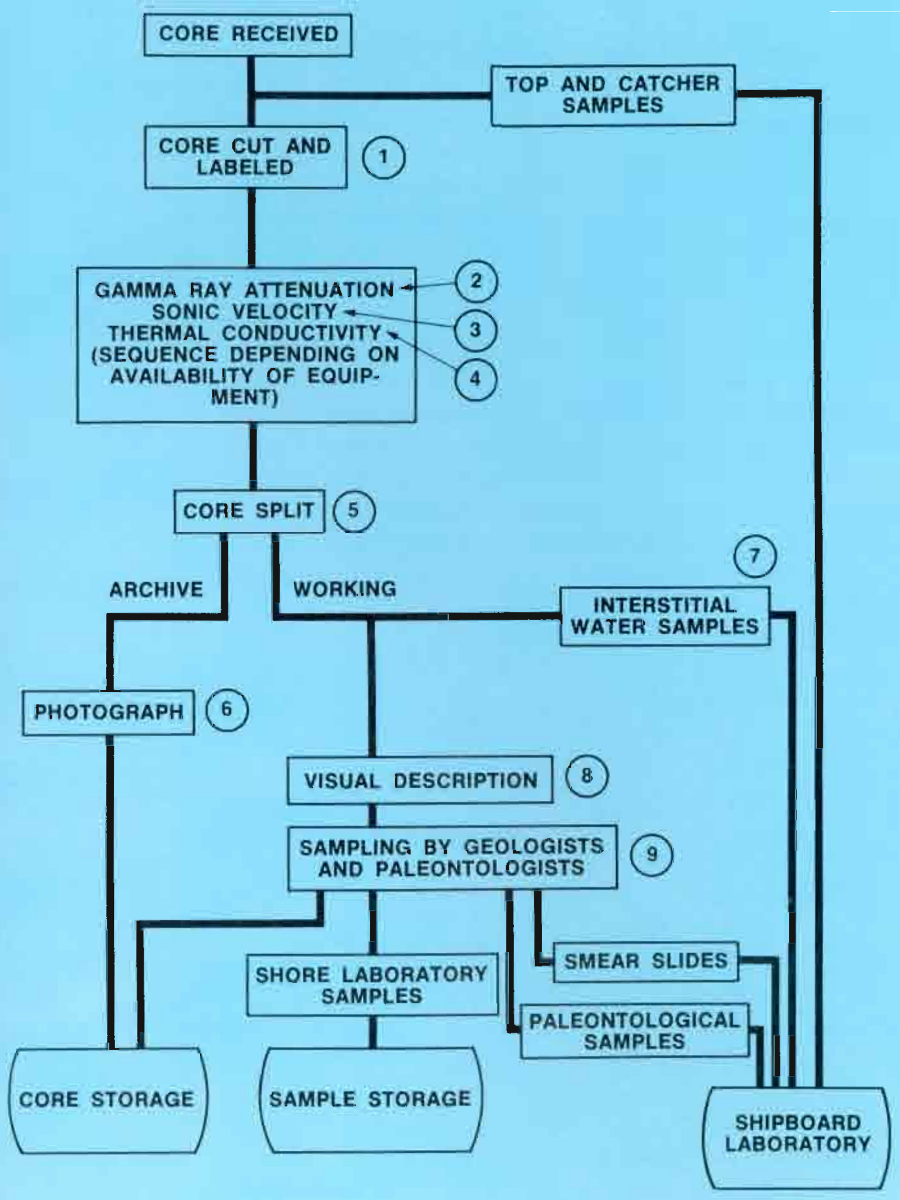
■ To the scientist the real sense of excitement starts when the cores come aboard. It is like finding himself for the first time in a library of a civilization previously lost. These samples tell the story of ancient oceans, climates, mountain building, volcanic eruptions, currents, organisms, evolution, and movements of the sea floor and continents. Distribution of minerals indicates the proximity to land masses and volcanic centers. Sequences of fossils show evolution and distributions of areas of high organic productivity related to prior current systems in the ocean. The preservation or dissolution of certain types of minerals, largely in the form of skeletons of small organisms, indicates earlier distributions and characteristics of water masses in the oceans. Structure and composition of the rocks beneath the sediment can tell how the floor of the ocean is made at the ridge crests.

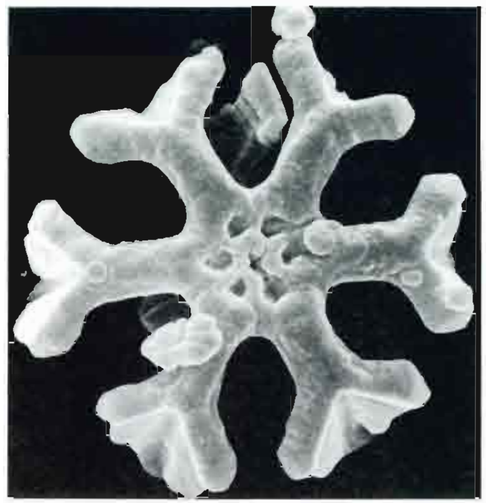
The samples also aid in interpreting the data from geophysical measurements. Scientists use them to test theories, proving some, disproving others, and proposing new ones. Each sample brings us a step closer to the ultimate goal of reconstructing the earth's history.

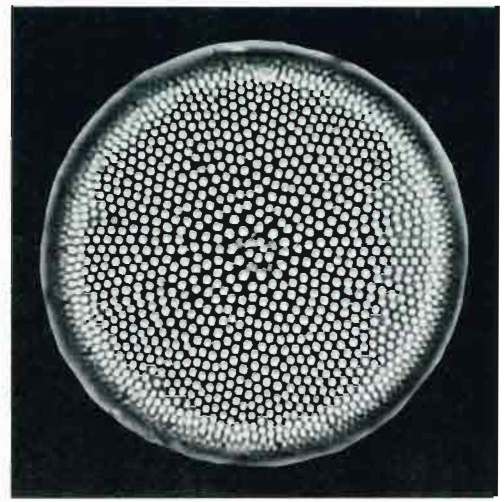
Each core receives immediate study on board ship. Of prime importance is determination of its geologic age. The first analysis is by paleontologists, who report the sample's age through studies of microfossils. Geologists then study the cores by microscope to describe their composition, grain size, and general mineralogy. They describe bedding (layering), structure, and color (by comparison with standard color charts). The cores are documented photographically because many properties, including color, will change in storage. Many samples are taken for additional study on shore. Then these exceedingly valuable cores are carefully packaged and placed in cold storage aboard GLOMAR CHALLENGER until they are shipped to permanent core repositories in the United States.

When the samples of the cores reach the laboratories on shore, the scientists there perform many other studies. In a computerized and automated X-ray diffraction laboratory, the cores are analyzed for their detailed mineralogy. Preliminary chemical analyses include determination of the carbon content and composition of the interstitial solutions (those trapped within the sediments). In addition, the paleontological age determinations are refined.

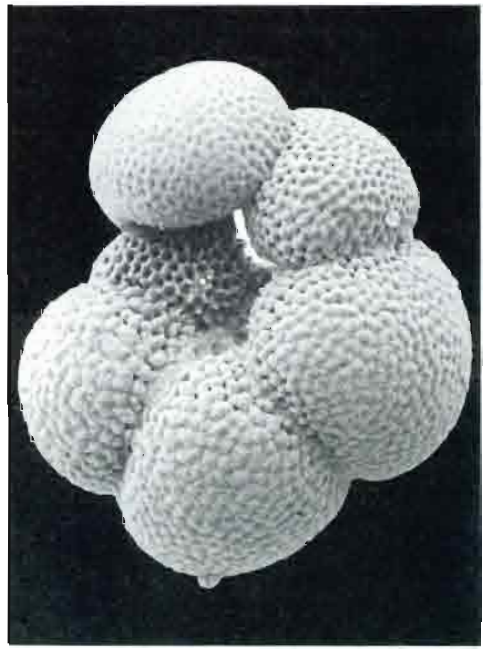
When the initial analysis that is performed uniformly on all the cores is finished, the material is stored in refrigerated repositories. Samples of the core material are made available by Scripps' curators to qualified scientists who request them for individual research investigations. It is expected that DSDP samples will be used for decades to come and will compose a permanent reference for marine geology. Scientists from about two dozen countries around the world have participated in the cruises or in the study of core material.

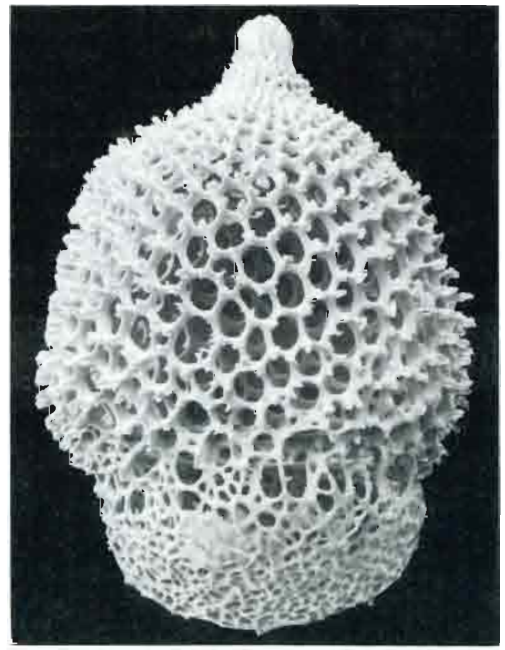






Enlarged photomicrographs of typical calcareous and siliceous microfossils upon which the age of cored sediments is based. Immediate, precise identification of these minute plants and animals is one of the primary functions of the shipboard scientific party.





150 TO 200 MILLION YEARS AGO

80 TO 120 MILLION YEARS AGO

Hypotheses of Continental Drift, Sea-Floor Spreading, and Plate Tectonics

CONTINENTAL DRIFT

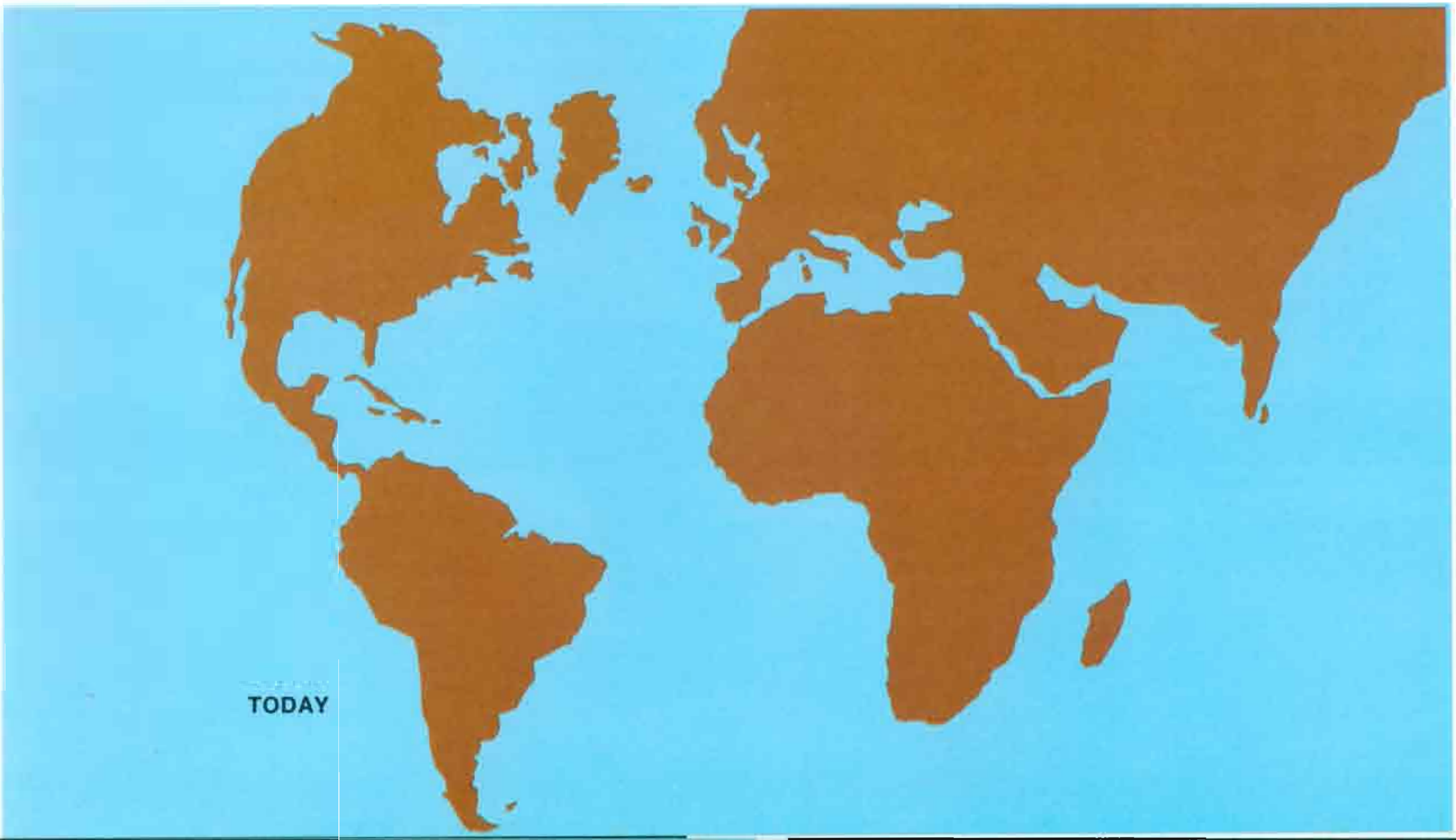
Perhaps the most important single scientific accomplishment to date of the Deep Sea Drilling Project has been the verification of hypotheses of continental drift and sea-floor spreading.

The idea of continental drift occurred to men generations ago when maps were developed that enabled them to observe the remarkable jigsaw-puzzle fit that can be made of the Atlantic coastlines of Africa and South America. But it was not until 1885 that Eduard Suess suggested that all the southern continents had once been joined together as a supercontinent that he called "Gondwanaland," and it was another 30 years before Alfred Wegener proposed in detail the hypothesis of continental drift in his book, "The Origin of Continents and Ocean Basins." In the following years, two main variants of the hypothesis evolved: (1) there had been a single supercontinent; (2) there had been two continental masses, Laurasia in the north and Gondwanaland in the south.

The evidence was not clear cut, and many scientists were not convinced. Until the 1940's, the arguments centered around the shapes of coastlines, paleontologic correlations (similarity of fossils), and general resemblance of rock types on opposite sides of the Atlantic Ocean. An example of this type of evidence is the discovery that ancient glacial deposits called "tillites," roughly 250 million years old, occur in Antarctica, Australia, South America, Africa, and India. A unique fossil plant, suggestive of a cold climate, was found in rocks associated with these tillites. Studies of rocks of the same age in other regions of the earth indicated that warm temperatures also occurred during this period. The inference was drawn that the southern continents at one time were indeed joined and were near the south rotational pole.

Interest in the drift hypothesis, which had flagged for lack of conclusive evidence, was revived in the 1950's by research in paleomagnetism, the study of the direction and intensity of rock magnetization. Rocks become magnetized—that is, the atoms become aligned in the direction of the earth's magnetic field—at the time the rocks cool (if they are igneous rocks) or at the time iron-rich particles settle in water (if they are sedimentary rocks). Thus, locked into the rocks is a record of the earth's magnetic field at a particular time. Measurements have shown that the earth's magnetic field has reversed itself numerous times throughout geologic time and that the position of the magnetic poles has changed with respect to the continents. For a given geologic period, the indicated positions of the poles are not the same from continent to continent, suggesting that the continents have shifted their relative positions.

The paleomagnetic studies spurred further field research and gradually new supporting evidence for continental drift was found. Typical of this kind of evidence



is the discovery of: (1) a series of rocks in the states of Bahia and Alagoas in Brazil that are nearly identical in composition, structure, and age (dated by radioactive methods)to rocks in Gabon in West Africa; and (2) sedimentary rocks in Antarctica, about 200 million years old, that contain small fossil amphibians and reptiles found also in the other "Gondwanaland" continents. (Conceivably, plants of the earlier glacial age might have been able to travel across the seas, with the seeds being airborne or waterborne, but the small animals could not have crossed the water barrier).

SEA-FLOOR SPREADING

One of the difficulties with the continental drift concept was the failure to determine a reasonable mechanism for explaining the movement of the continents. Also, there was no clear picture of what might be happening to the oceanic crust as the continents moved. Both difficulties are overcome by the new concept of sea-floor spreading.

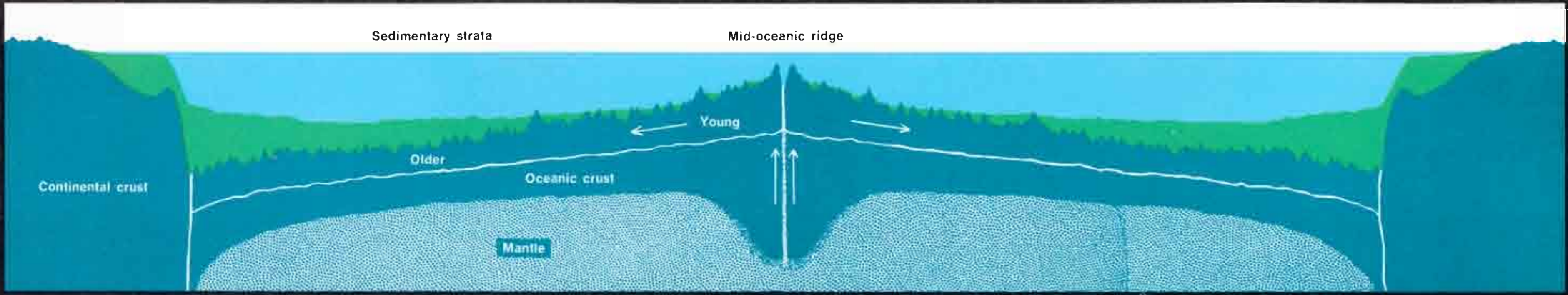
About 20 years ago, the Mid-Atlantic Ridge was shown to be part of a worldwide ocean ridge system which typically contains a central rift valley that is a common site of earthquakes. About 10 years ago, long linear magnetic anomalies (bands of rocks of alternating magnetic polarity) were found on the sea floor. These anomalies are parallel to the ridge system and symmetrical on either side. From these and other lines of evidence, it was deduced that volcanic material is brought up in the center of the ridge and moves away on either side as newer lava rises along the rift. As the lava cools, it is magnetized and retains the polarity of the earth's magnetic field at the time of its solidification.

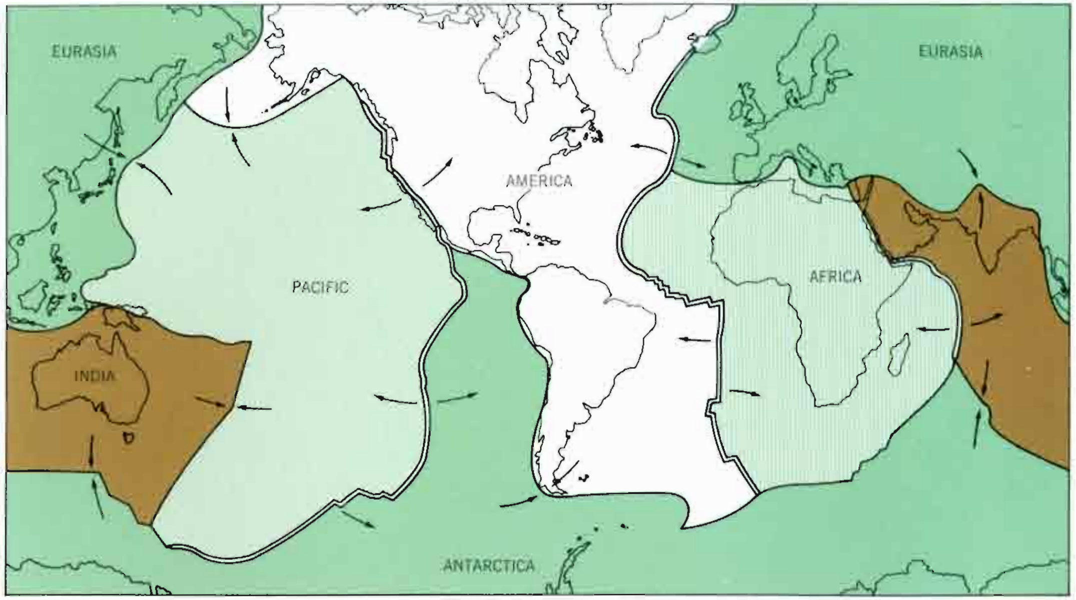
Because the earth's field is known to have reversed itself at intervals during geologic time, the linear anomalies are believed to be the record of these reversals, and the anomalies and the ocean floor get progressively older away from the ridge.

Based on the well-documented reversals of the past few million years, a magnetic time scale has been worked out for the anomalies of the ocean floor. The scale suggests that the oldest parts of the ocean floor, i.e., those parts that are farthest from the ridge, are probably less than 200 million years in age, and that the spreading from

Generalized Ocean Cross-Section

Molten rock is believed to be rising continually along the central portions of the oceanic ridges, cooling, and moving slowly aside, resulting in progressively older ocean floor away from the ridge.





Mosaic of plates forms the earth's lithosphere, or outer shell. According to the recently developed theory of plate tectonics, the plates are not only rigid but also in constant relative motion. The boundaries of plates are of three types: ridge axes, where plates are diverging and new oceanic floor is generated; transforms, where plates slide past each other; and subduction zones, where plates converge and one plate dives under the leading edge of its neighbor.

the ridges is taking place at rates of about 1 to 10 centimeters a year.

Since we know that the continents have rocks as old as 3.5 billion years, what has happened to the older oceanic crust? Apparently it moves down again into the mantle in the deep oceanic trenches, such as those around the western Pacific. The whole process had been likened to a conveyor belt. New crust is formed at the ridge, moves aside, and is carried away to the trench areas where it moves downward and is destroyed.

Destruction of Crust

Evidence indicates that the ocean floor is constantly renewed at the oceanic ridge crests and destroyed by assimilation into the mantle or into continental rocks, where ocean trenches exist at seismically and vocanically active zones near continental borders.

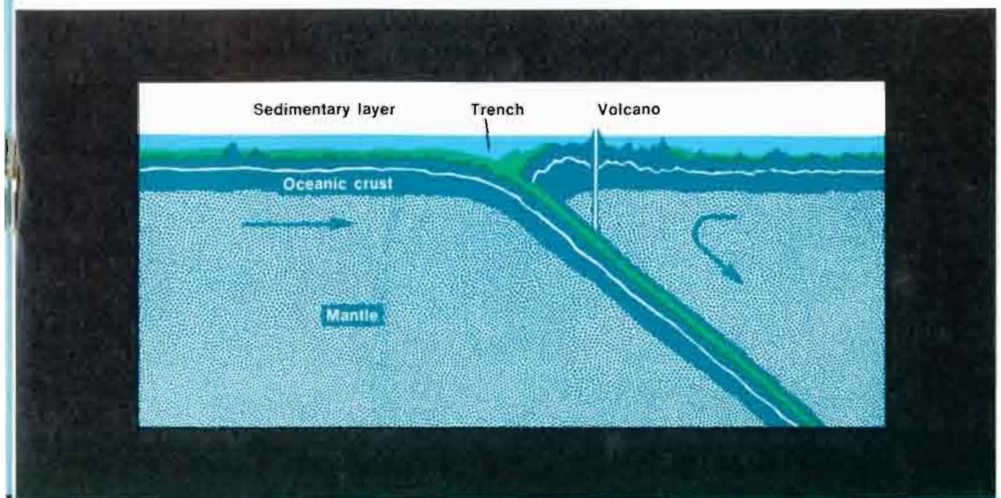


PLATE TECTONICS

Scientists have recently begun to view the crust of the earth as being made up of a relatively small number of large stable plates that shift positions and size by separating from each other, running into each other, or by sliding by each other. The separation process takes place at oceanic ridges and is called sea-floor spreading. The converging takes place mostly at the deep sea trenches and is called subduction. The boundaries of the plates are the active earthquake zones of the world. As oceanic crust migrates on its long journey from a spreading axis to a deep oceanic trench where it plunges into the mantle, sediments accumulate and provide the historical record which is being recovered and interpreted by scientists involved in the Deep Sea Drilling Project.

TESTING THE HYPOTHESIS

The hypothesis of sea-floor spreading provided a plausible explanation of the observed features and of the mechanism by which the continents are being carried away from or toward one another. But the explanation had to be tested. If the hypothesis is valid, then the sediments overlying the lava "basement" should be thin at the ridge, and thicken progressively away from the ridge. Seismic profiling of the oceans suggested that this is true, but conclusive proof had to await the Deep Sea Drilling Project's GLOMAR CHALLENGER. Not only should the sediments thicken away from the ridge, but those immediately above the basement should be progressively older with distance from the ridge.

Several of the cruises were designed to test this hypothesis in the Atlantic, Pacific, and Indian Oceans as well as in some of the marginal seas. The results were highly satisfactory.

In the Atlantic, the sedimentary cover near the ridge is indeed thin and comparatively young. It thickens and the bottom part gets progressively older toward the continents. The most ancient rocks found are close to the edge of the continental rise and are about 150 million year old.

In the Pacific, the pattern is more complex. The ridge is not centered as in the Atlantic; rather it is in the eastern part of the Pacific and actually seems to go under part of the North American continent, from the Gulf of California to about Cape Mendicino, western-most point in California. But here again the sediments are thinnest and youngest near the East Pacific Rise and get older and thicker to the west toward the trenches. As in the Atlantic, the oldest sediments found were about 140 to 150 million years in age. However, in the Pacific, it has not yet been possible to penetrate to the basement in the area of the oldest sediments.

Thus, drilling by GLOMAR CHALLENGER has established that the present ocean basins are relatively young—no more than 200 million years old—and have been shaped by the process of sea-floor spreading. Indeed, the project and other investigations have provided such strong evidence in support of continental drift, sea-floor spreading, and plate tectonics that they must now be considered as established theories.

Scientific Accomplishments of the Deep Sea Drilling Project

■ In addition to helping confirm hypotheses of sea-floor spreading, continental drift, and plate tectonics the Deep Sea Drilling Project has also produced many other significant results such as:

(1) Determination of latitudinal motion of certain areas of the oceanic crust. The floor of the Pacific is moving northward beneath the equator; older equatorial sediments are found progressively farther north from the equator. Similarly, sediments in both the eastern Indian Ocean and on the Australian continent appear to have been nearer the south pole at one time and to have moved northward subsequently.

(2) Determination of vertical motions of the oceanic crust, both uplift and subsidence. Rockall Bank, in the North Atlantic, has been slowly sinking. Ninetyeast Ridge in the Indian Ocean is now a mile below sea level. It was formerly at sea level as evidenced by deposits of coal and shallow-water shells. Submarine plateaus west of Australia have a complex history of up and down motion. The floor of the ocean subsides as it becomes older and moves away from the spreading centers.

(3) Proof that lime (calcium carbonate) dissolved in deep water of the ancient oceans just as it does today. If the present-day oceans could be drained, it would be possible to see that all the shallower areas, such as the tops of seamounts and the ridge areas, would be white with lime, whereas most of the deep areas would have rusty, red-brown clay. The depth interval through which this change takes place is quite small. This phenomenon, when observed in the sediments, helps interpret up and down motions of various areas of the sea floor through time.

(4) Discovery of sediments that are suitable as sources and reservoirs for oil and gas, and of information leading to a broad evaluation of the resource potential of the sea floor.

(5) Proof that parts of the deep Gulf of Mexico are underlain by salt, some of which has been forced up into salt domes, such as the Sigsbee Knolls. Oil and gas were discovered in association with the Sigsbee Knolls, the first demonstration of the occurrence of hydrocarbons in deep-sea conditions. This discovery is having a profound impact on geological thinking and technological development for exploration and exploitation of deep-sea petroleum resources.

(6) Recovery of sediments rich in metals—mostly iron and manganese, but also containing copper, zinc, and lead. These metal-rich sediments occur just above the original igneous rock floor of the ocean. This discovery may have economic implica-

tions and may help scientists explain certain kinds of ore formation.

(7) Proof that the Mediterranean Sea basin was nearly dry and empty during the period from about 10-5 million years ago during which thick layers of salt accumulated. About 5 million years ago, the basin abruptly filled again and has remained a sea since then.

(8) Discovery of evidence concerning the past deep circulation of water in the oceans. Much of the deep ocean water of the past contained oxygen, much as it does today, indicating a gross circulation bringing oxygen from the surface to the bottom. At the present time, the ocean's "bottom water" is formed in high latitudes as cold, dense water that sinks and flows along the bottom. However, prior to 80 million years ago, the North Atlantic did not receive cold and oxygenated bottom water.

(9) Proof that Antarctica has been glaciated for at least the last 20 million years and presumably has maintained its position near the south pole for at least that long. There is evidence that the Antarctic ice cap suddenly receded to its present extent about 5 million years ago.

(10) Discovery of major gaps in the sedimentary record that result from submarine erosion or non-deposition. Many of these hiatuses are probably related to major changes in oceanic currents, an example being the establishment of the Antarctic Circumpolar Current after Australia separated and moved away from Antarctica.

(11) Discovery of numerous layers of volcanic ash, indicating periods of volcanic activity in the past.

(12) Demonstration of the widespread occurrence of chert (flint) in deep sea sediments and the important presence of land-derived material transported by turbidity currents far out into the ocean basins.

(13) Penetration, recovery, and identification of distinct layers within the sediment that reflect sound and can be traced long distances by geophysical surveys (see page 4).

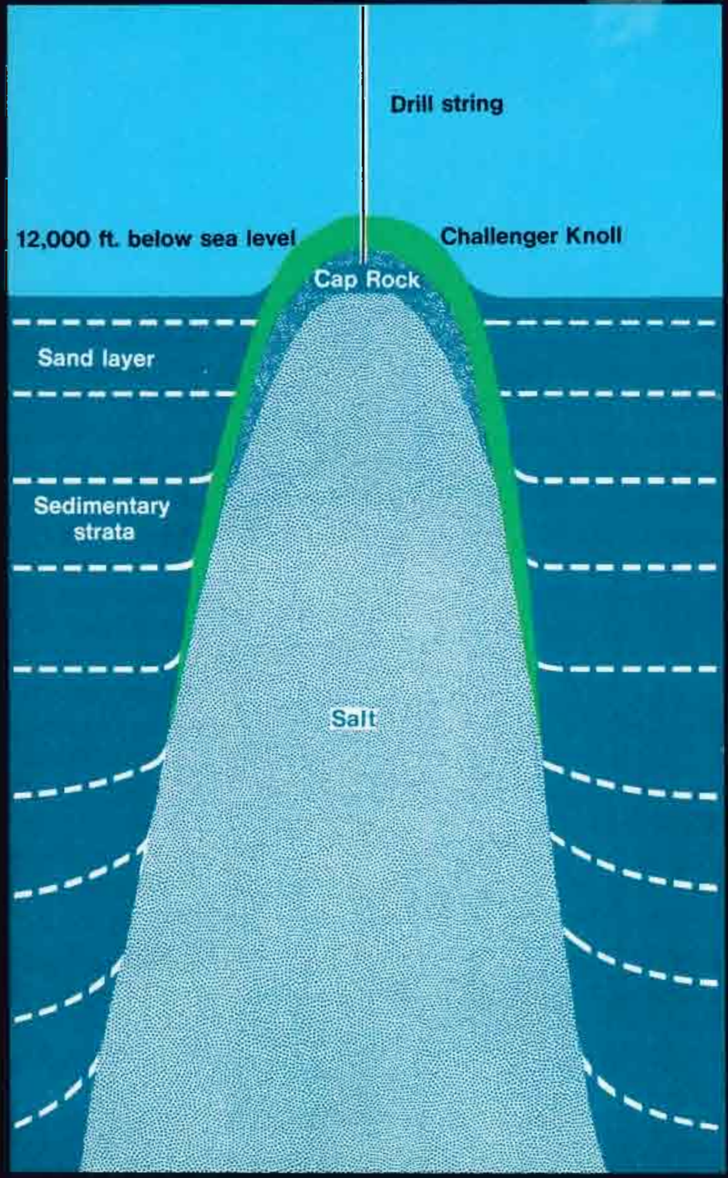
(14) Proof that many minerals form by chemical action in deep-sea sediments after deposition.

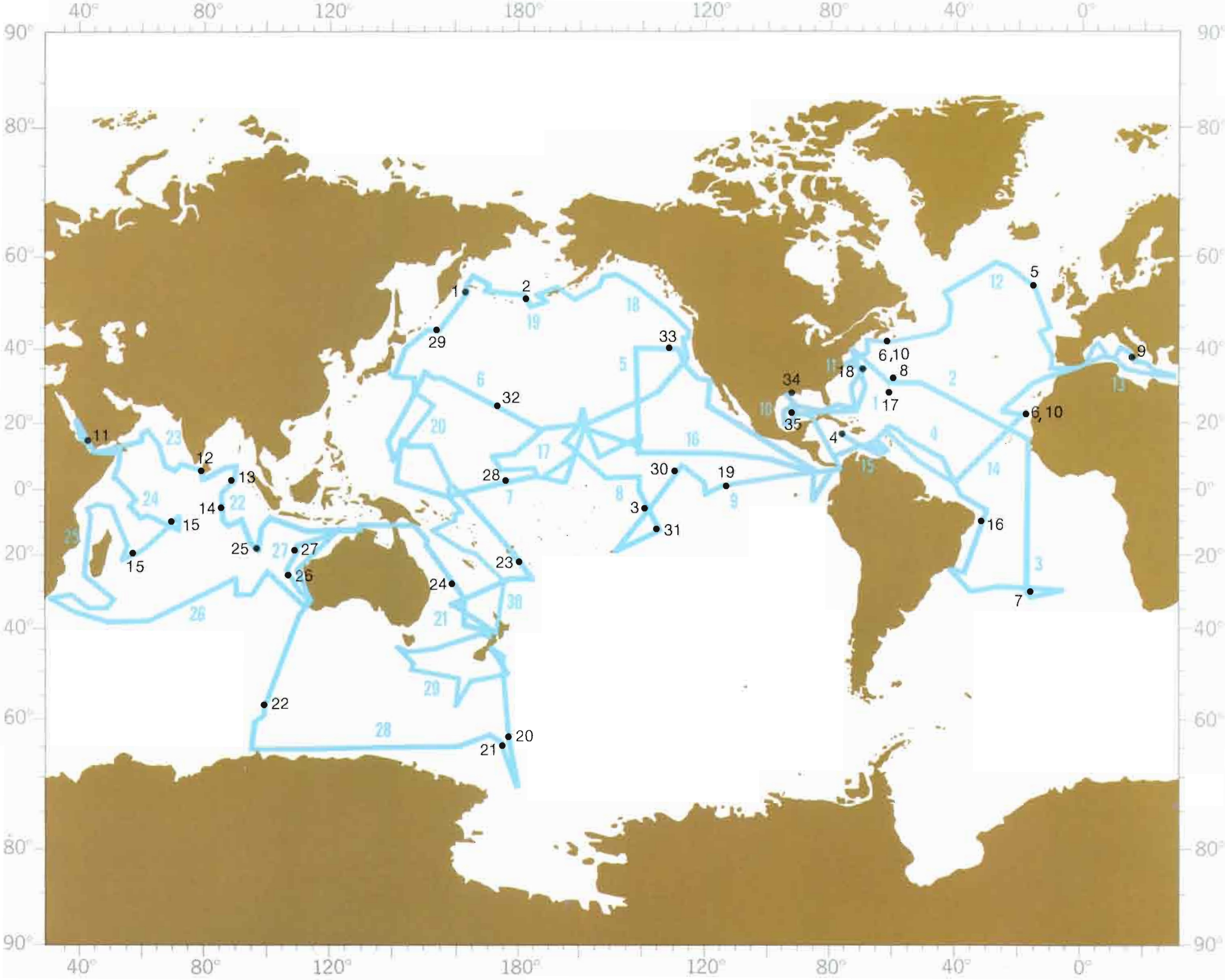
(15) Recovery of material from throughout the world's oceans that vastly increases our knowledge of the time significance of oceanic microfossils.

(16) Determination of rates of accumulation of various types of deep-sea sediment at hundreds of locations.

Salt Domes

A core taken from one of the Sigsbee Knolls in a deep part of the Gulf of Mexico showed that the Knolls are salt domes. One core contained oil. This unexpected discovery was the first demonstration that oil exists in some parts of the deep ocean.

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90° 80° 60° 40° 20° 0° 20° 40° 60° 80° 90°
1 2 29 32 33 5 6,10 18 8 17 34 35 4 9 6, 10 11 12 13 14 15 15 25 27 26 24 23 28 30 19 3 31 16 7 22 20 21
12 18 19 6 5 11 1 2 10 16 17 20 8 9 7 15 4 14 13 3 23 24 22 25 26 27 21 30 29 28

1. Subtropical fossil assemblages now near Aleutian Islands
2. Sediments crushed against Aleutian arc
3. Floor of Pacific moving northward beneath equator, older equatorial sediments now found north of equator
4. First operational re-entry
5. Rockall Bank slowly subsiding
6. North Atlantic began to open as notch in continent 180 million years ago. Spreading rate from Mid-Atlantic Ridge established as 1.4 cm/year
7. Verification of the paleomagnetic time scale
8. Identification of major sound reflecting Horizon A as 60 million year old chert layer
9. Mediterranean Sea nearly dry and empty during a period of 10-5 million years ago. Filled abruptly 5 million years ago
10. Outside edges of Atlantic are oldest portions
11. Early rifting history in Red Sea similar to North Atlantic 180 million years ago
12. India moved northward across Indian Ocean relatively rapidly and collided with Asia forming Himalayas
13. Continental sediments carried by underwater mud flows (turbidity currents) far out into ocean basin
14. Ninetyeast Ridge now a mile below sea level; above sea level in past
15. Sea floor spreading from Mid-Indian Carlsberg Ridge
16. South Atlantic began to open as notch in continent 150 million years ago. Spreading rate from Mid-Atlantic Ridge established as 2.0 cm/year
17. Widespread occurrence of chert (flint)
18. Layers of metal-rich sediments
19. Spreading of sea floor from East Pacific Rise, youngest part of Pacific Ocean floor
20. Antarctica has had glaciers and has been near south pole for at least past 20 million years. Ice cap receded to about present extent 5 million years ago
21. Metamorphic rocks, marble and gneiss, beneath sediments of Ross Shelf
22. Australia began separating from Antarctica about 55 million years ago
23. Deep water of past contained oxygen, like today
24. Widespread major gaps in antarctic sedimentary record may be related to Antarctic Circumpolar Current starting after Australia separated from Antarctica
25. Deepest water drilling—20,483 feet. Longest drill string—22,192 feet
26. Oldest (early Cretaceous) dated sediments from Indian Ocean; oceanic floor moving northward
27. Complex up and down motion; Broken Ridge above sea level 60 million years ago, now almost 1 mile below sea level
28. Sea mounts form as volcanoes and then become extinct as they slowly subside
29. Oldest part of Pacific Ocean is northwest sector
30. Floor of ocean subsides as it moves away from ridge
31. Metal-rich bottom layer of sediments
32. $CaCO_3$ dissolution in deep water
33. Abyssal hills irregularities on volcanic surface
34. GLOMAR CHALLENGER keel laid October 19, 1967, and launched May, 1968. DSDP started August 11, 1968
35. Oil and gas on Sigsbee Knolls salt domes

THE GLOMAR CHALLENGER

After 5 years of operations (August 1968-August 1973)

- About 450 holes drilled and cored at about 300 sites
- Over 400,000 feet of aggregate penetration
- Over 165,000 feet of sea-floor cored
- Nearly 100,000 feet of core recovered—stored at Lamont-Doherty Geological Observatory and Scripps Institution of Oceanography
- Over 150,000 nautical miles travelled by GLOMAR CHALLENGER

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