Deep-Sea Drilling for Scientific Purposes: A Decade of Dreams

Marine drilling technology in the deep oceans will provide data on the history of oceans and continents.

Tjeerd H. van Andel

The development of marine geology has, in a sense, been the inverse of that of the geologic study of the continents. Classical land geology, concerned in the beginning mainly with the earth's history, has included recent geological events in its scope at a relatively late date, notwithstanding early recognition of their relevance (*1*). Marine geologists have had to content themselves with describing and interpreting the features of the present sea floor and the processes which form them. Nevertheless, investigation of the geological history of the deep ocean offers an obvious path to the study of our planet as a whole. Here, in a protected environment covering almost three-quarters of the surface of the earth, the record of geologic events on and in the crust of the earth is most likely to be preserved with minimum disturbance. Here also, according to recent concepts (*2*), major events take place in the crust and mantle which control the distribution, nature, and shape of continents and oceans.

On the continents, the combined forces of mountain building and erosion by wind and water have exposed much of the geologic record dating back at least 3.5 billion years. Even though this record is far from complete, a century and a half of observation in the field, aided in the last 50 years by commercial drilling and by geophysical studies, has reconstructed a comprehensive and detailed historical record. The results suggest convincingly that oceans and seas have been an integral part of the world from the beginning of recorded time.

The ocean floor is subjected far less intensely to erosion and deformation and is covered with an almost continuous blanket of modern sediments, so that outcrops of older rocks are rare and restricted in their occurrence. Since the marine geologist is separated from the objects of his research by thousands of meters of water, he is almost entirely dependent on remotely controlled instrumentation. Consequently, much energy has been devoted to the development of tools to penetrate the sea floor. This development has progressed from devices propelled by gravity or explosives to piston corers; but the best of these can penetrate at most 20 to 30 meters, which represents only a small slice of geologic time.

Study of the data so obtained and the piecing together of this fragmentary record by geophysical methods have permitted preliminary conclusions regarding the genesis and history of the ocean basins and their relation to the evolution of our planet. One of the more remarkable results is that evidence for a great age of the oceans, comparable to that of the continents, appears to be completely lacking. This peculiar paradox is the basis of current hypotheses regarding the evolution of the crust of the earth, and it forms a large part of the scientific justification for drilling in the deep ocean.

It is natural that the dreams of marine geologists interested in the history of the oceans have been directed toward the use of deep-sea drilling as a tool. Developments in offshore drilling technology by the petroleum industry have now reached a stage in which the hardware and know-how are available in principle to undertake drilling projects in deep water with some hope of success. Experience in water depths exceeding 1000 meters is, however, still limited.

Evolution of the Idea

The use of drilling to study the ocean was first considered seriously 10 years ago in Project Mohole, which was supported by the National Science Foundation. This project generated many of the ideas concerned with drilling projects in the sea, and it stimulated the development of some of the necessary technology. Project Mohole also produced, early in 1961, the first successful drilling and coring operation in deep water. The barge *Cuss I*, equipped with a large drilling rig, drilled five experimental holes, in depths around 1000 meters, off San Diego, and five more, in depths near 3600 meters, off Guadalupe Island on the west coast of Mexico, with bottom penetrations to 150 meters. Since anchoring in such depths is not feasible, the position of the vessel was controlled dynamically by taut-wire buoys. The feasibility of scientific deep-sea drilling was thus demonstrated (*3*).

It was then decided that Project Mohole would proceed directly to its primary objective to sample the earth's mantle. A long period of time would be required to develop the tools, systems, and drilling platform necessary to penetrate several kilometers of hard rock to a total depth of 10 to 12 kilometers below the surface of the ocean. During those several years no ocean drilling was to be undertaken by Project Mohole. In the meanwhile, however, many geologists advocated a broad investigation of the sedimentary layer of the oceans. This concept was distinct from that of Project Mohole, and its technical requirements were quite different. For a sedimentary drilling program, a vessel capable of a speedy transit between widely spaced drilling sites would be required, and the relatively shallow core holes needed to penetrate only the sedimentary layer could be accomplished with existing drilling equipment and techniques. Such a program, advocated by sediment-oriented geologists, would yield valuable technological experience and at the same time would produce data on the historical record of the deep-sea sediments.

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This project, notwithstanding its relative simplicity, would still be too complex and costly for one individual or even one institution to initiate and manage independently. Consequently, the next few years were devoted to finding a suitable organizational form to prepare plans, and to gathering the scientific input, creating confidence, and acquiring the funds to carry them out. In all this time, there never was any lack of excellent proposals for drilling goals and sites; long unresolved was the creation of an organization that would possess the qualities needed to assume responsibility for the execution of these ideas, a problem underlying many of the struggles in the preparation and execution of "big science" projects.

Early in 1962, after a proposal of Cesare Emiliani, from the Institute of Marine Sciences, University of Miami, to charter a drilling vessel for work in the Caribbean and western Atlantic, a committee (LOCO) was formed consisting of two scientists each from Miami, Lamont Geological Observatory of Columbia University, Woods Hole Oceanographic Institution, Scripps Institution of Oceanography of the University of California, and Princeton University. The LOCO committee, realizing that a formal organization was needed, considered a nonprofit corporation of individuals or institutions, but failed to agree on its charter. Later that year, Maurice Ewing of Lamont, J. B. Hersey of Woods Hole, and R. R. Revelle of Scripps formed such a corporation (CORE), which, in February 1962, submitted a proposal to carry out a drilling program as visualized in the intermediate phase of Project Mohole. This proposal was not endorsed by LOCO and was not funded, and both groups faded away.

Subsequently, on the initiative of C. Emiliani and the late F. F. Koczy and supported by a grant from the National Science Foundation, the University of Miami carried out a moderately successful shallow-water drilling and coring program from R.V. *Submarex* on the Nicaragua Rise off Jamaica (*4*), in spite of adverse weather. Finally, in the first half of 1964, scientists from Miami, Lamont, Woods Hole, and Scripps decided to attempt once more to form an organization to initiate and carry out large drilling projects in the ocean. In May of that year, the directors of these four institutions signed a formal agreeement called JOIDES (Joint Oceanographic Institutions Deep Earth Sampling) to cooperate in deep-sea drilling. It was the intent that JOIDES should prepare and propose drilling programs based on the ideas of broad segments of the oceanographic community. It would designate one of its members to act as the operating institution for such a project and to be responsible to the funding agency for its management. This form of cooperation was chosen because of its flexibility, and because it placed the operating responsibility in the hands of an institution experienced in management. The operating institution would act in trust for the entire scientific community; all scientists actively concerned with the project would be invited to participate; samples and data would be distributed to all interested scientists without regard to affiliation. The agreement provided for an executive committee to establish policy and a planning committee to prepare plans for operations and to collect information regarding possible drilling objectives and sites (*5*). During the remainder of 1964, the planning committee compiled a list of suitable drilling sites and collected background data.

Early in 1965, there was an opportunity to use R.V. *Caldrill*, which was under charter to Panamerican Petroleum Company, and was then on its way from California to Newfoundland. The Panamerican Petroleum Company agreed to allow a brief charter for scientific purposes anywhere along the voyage. The Blake Plateau area off the southeastern United States was selected, and funds for a 1-month drilling program in April and May were made available by the National Science Foundation. Under the management of Lamont and with the aid of an *ad hoc* committee from JOIDES and from other institutions, six holes were drilled and cored successfully in water depths from 25 to 1030 meters, with bottom penetrations of 120 to 320 meters (*6*).

The success of this program and of the organization behind it stimulated plans for drilling in deeper water. A study made by the planning committee indicated that the technology for drilling in water down to 6000 meters in depth was available for reasonable cost, and that a suitable drilling ship could be found. This study also showed that much more could be learned from an immediate advance into deep water than from continued effort at shallow depths, a domain into which the petroleum industry was moving rapidly, in part for purposes of research.

The National Science Foundation in its budget request to the Congress for fiscal year 1966 asked for, and was granted, funds to initiate a National Research Program of Ocean Sediment Coring. The director of NSF had, in 1964, announced his intention of supporting such a program, conceived as distinct from and complementary to Project Mohole. Subsequently, JOIDES and Scripps together prepared a proposal to the NSF for funds for an ocean-drilling project which Scripps would manage. The nature and scope of the project were decided, and a contract between Scripps and NSF was signed in January 1967. Under the contract, a drilling program in the Atlantic and Pacific oceans for at least 18 months beginning in mid-1968 (*5*) has been planned.

Drilling in Deep Water

Commercial drilling vessels come in a wide variety of configurations, sizes, and shapes. Vessels for deep-sea drilling for scientific purposes, however, have great basic similarity because of their special requirements. Since drilling sites are widely spaced, the vessels must be self-propelled and able to operate without support at great distance from their home base and for long periods of time. Adequate space for scientific facilities and scientists is also required. The operation in very deep water also has special consequences, which tend to simplify the operation compared to commercial deep drilling near shore. The thickness of the sediment in the oceans is generally small: between 100 and 1000 meters of sediment commonly overlie the hard rock basement. Only in a few areas adjacent to the continental margins do sediment thicknesses of several thousand meters occur. The shallow penetration required in the deep sea simplifies engineering requirements.

Marine drilling systems consist of three main components, which have been tested in practice, but are being used here in an unusual arrangement and for a relatively untried operation: (i) the vessel itself, supporting the drilling rig and all facilities; (ii) the positioning system; (iii) the drilling rig and machinery.

With the exception of **D.S.** ***Cuss I***, all vessels used or planned are self-propelled ships varying in size from a few thousand to over 10,000 tons and with drilling capacities ranging from

600 to 6000 meters. In earlier vessels, drilling capacity and endurance were quite limited, as were space and facilities for scientists. On R.V. *Caldrill*, for example, scientists worked under remarkably primitive conditions. The R.V. *Glomar Challenger* (Fig. 1), planned for future operations, is by comparison spacious, well equipped, and has long range. The price of the increase in capacity is high; day costs range from $5,000 to $25,000, depending on vessel and service.

While drilling is being done the vessel must be kept near a point directly above the hole in the sea floor. In shallow water, this is accomplished by anchoring or by raising the platform on legs. In deep water, these solutions are not practical, and a dynamic positioning system is used. This system consists of a means to determine the position of the vessel with respect to the hole, and a means to correct the drift and maintain the desired position. Deviations have usually been determined with respect to anchored buoys equipped with radar and sonar reflectors or to a taut wire extending from the ship to the sea floor. In drilling operations now being planned the reference system will consist of acoustic beacons dropped on the sea floor, which are much easier to position than buoys and are not subject to stresses from wind and current. The signals of these beacons are received by three hydrophones placed in a triangle on the hull and are converted by computer into instructions to propulsion machinery. Four outboard motors placed forward and aft on both sides of the hull have been used; a combination of the ship's main propulsion with transverse thrusters placed in tunnels is planned for the future. Variations in drift and heading are anticipated by the control system on the basis of past experience, and overcorrecting must be avoided.

The drill string has a great deal of flexibility; drilling in 6000 meters of water with a conventional drill string may be compared to drilling in 100 meters with a piece of baling wire. As a result, the radius within which the vessel must be kept is a function of the depth of the water; it should be of the order of 1 to 3 percent of the depth. Obviously, maintaining position in water 5000 meters deep is far easier than staying within 5 to 10 meters in 200 meters of water.

A conventional rotary drill is used. As compared to drilling on land or in shallow water for commercial purposes, in the deep sea penetration is shallow, and the rocks are soft. As a result, since drill bits need not be changed frequently, the hole consequently is not reentered, a difficult operation under water. In shallow holes in ocean sediments, a single bit, tipped with tungsten carbide or diamonds, should suffice and should even permit some drilling in the underlying basement.

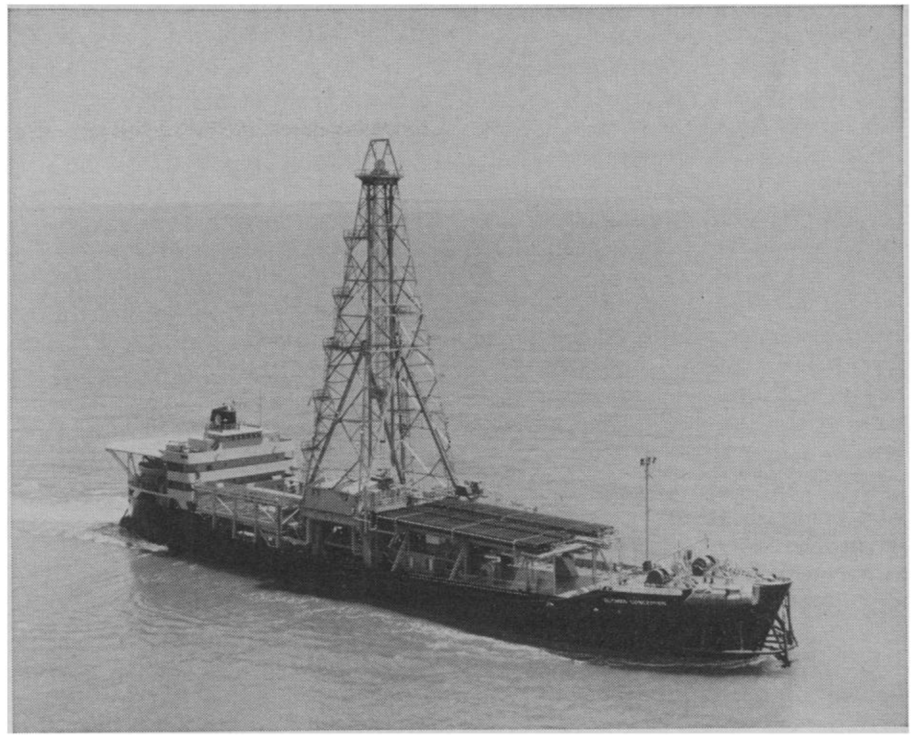

Fig. 1. The R.V. *Glomar Conception*, a drilling vessel belonging to Global Marine Inc., and sister ship of R.V. *Glomar Challenger*, the drilling vessel to be used for the Deep-Sea Drilling Project in the Atlantic and Pacific oceans.

In commercial deep drilling, high-density drilling fluid is circulated from the pumps, through the pipe, into the hole, and back to the ship through a riser pipe in order to wash out drill cuttings and maintain a stable condition in the hole. In shallow penetrations, drilling can be accomplished with seawater, without complete circulation; the water is flushed out on the sea floor, and the costly and time-consuming installation of the riser pipe can be eliminated. Hence, a deep-ocean drilling operation for scientific work as described here is adequately served with a simplified system at low cost; this gain, however, is partially offset by the cost of operation on the high seas. An additional advantage of the simple system is that, in case of approach of bad weather, the hole can be quickly abandoned.

The coring operation, the most important step in the entire procedure, is carried out with core barrels fitted inside the drill pipe. These barrels are pumped down with the drilling fluid and latched in place automatically. After the core has been taken by rotating or punching, a wire line with a catch is used to retrieve the barrel. Cores varying in length from 6 to 12 meters with diameters from 2 to 6 centimeters can be obtained without reentering the hole.

The motions of the vessel can affect the operation of the drilling equipment. Severe roll and pitch make handling of the pipe impossible, even though automated systems are used, and they place excessive stress on the drill string just below the vessel. These motions can be reduced significantly by devices for stabilizing the motion of the vessel (antiroll devices) and by proper positioning of the vessel with respect to wind and sea, but in all open-sea operations loss of time because of weather is inevitable. Heaving of the vessel tends to pump the drilling fluid in the string, and it bounces the bit on the bottom, which damages both hole and tools. This is counteracted by the use of bumper-subs: spring-loaded, telescoping sections of drill pipe just above the bit, which will accommodate heave up to several meters. However, an inevitable consequence is that the vertical distance from the ship to the bottom of the hole cannot be determined from the length of drill pipe to better than 3 to 6 meters. Since additional uncertainty is introduced by the fact that the vessel is not usually precisely above the hole, the precise depth of the core remains unknown within relatively large limits.

In a shallow hole in pelagic sediments, where 1 meter may represent as much as 1 million years of time, these inaccuracies are serious. They can be reduced in part, but not entirely, by measuring certain physical parameters of the rock continuously in the open hole by well-logging, and subsequent comparison of this log with measurements of the same parameters on the core. Although this has never been done in deep-sea sediments, such parameters as the variations of natural radioactivity may permit correlation between core and well log.

Several hours elapse between the withdrawal of one core barrel and the arrival at the bottom of the hole of the next one. During this interval, a thick layer of caved sediment may accumulate at the bottom, or the bottom may be scoured, so that ill-defined gaps exist between successive cores. Moreover, the coring process tends to be more effective in certain types of sediment than it is in others and more efficient at depth than near the surface where the deposits are soft. Thus, expected recoveries from the core vary from 40 to 80 percent of the total interval that is cored.

Consequently, even when an attempt is made to core a hole continuously, the cores ultimately obtained will have gaps and uncertainties. Advanced designs incorporating increased experience will improve this situation, but a complete record such as marine geologists expect from their usual sampling tools is not likely to be obtained.

Some Ocean-Drilling Targets

In 1946, Kuenen (*7*) estimated by various independent methods that the average thickness of sediment in the ocean should be approximately 3 kilometers, if one assumes that the age of the earth is 2 billion years. The average thickness was later found to be about 10 percent of this figure, and it is now known that the earth is more than 4 billion years old. Thus, the record of ocean sediment must be incomplete, or it does not reach farther back than a few hundred million years. Independent estimates based on sedimentation rates, sediment thicknesses, and consolidation lead to the latter conclusion (*8*). This is in agreement with the fact that nearly all of the older rocks recovered from the ocean floor date from the Tertiary or the Upper Cretaceous, a very few from the Lower Cretaceous (*9*). Even if the underlying sediment is included by extrapolation, this still terminates the record somewhere in the early Mesozoic or late Paleozoic, or 200 to 300 million years ago. Direct instead of extrapolated data regarding the age of the oldest sediment in the oceans are of great value in confirming this strange observation. Drilling in the oldest parts of the oceans, for example, the western Atlantic and Pacific, would supply such information while at the same time shedding light on the conditions prevailing at that time.

In a different vein altogether, Hess postulated in 1962 (*2*) that convective flow in the mantle, an old concept, might be a major factor in shaping the floors of the oceans. This hypothesis, recently expanded by Vine (*2*), states that a hot mantle current rises to the surface under the mid-ocean ridges, and spreads laterally from there to the continental margins where it submerges and completes the convection cell. This hypothesis explains many of the morphological and geophysical features of the ocean floor, and offers a mechanism for the process of continental drift.

This concept also explains how old deep-sea deposits are removed continuously from the oceanic realm by transport toward the continents where they are submerged under the continental mass. It thus accounts for the absence of an ancient oceanic record. In consequence, the lower part of the sedimentary sequence should increase in age from the mid-ocean ridges to the continental margin. This fact can be established by drilling a series of holes across the mid-oceanic ridges in the Pacific and Atlantic.

The combined sea-floor spreading and continental drift hypotheses, although far from completely accepted, have stimulated much imaginative research and speculation. A major contribution to testing this line of thought can be made by using deep-sea drilling.

A different group of problems deals with the history of the oceanic circulation and the closely related climatic

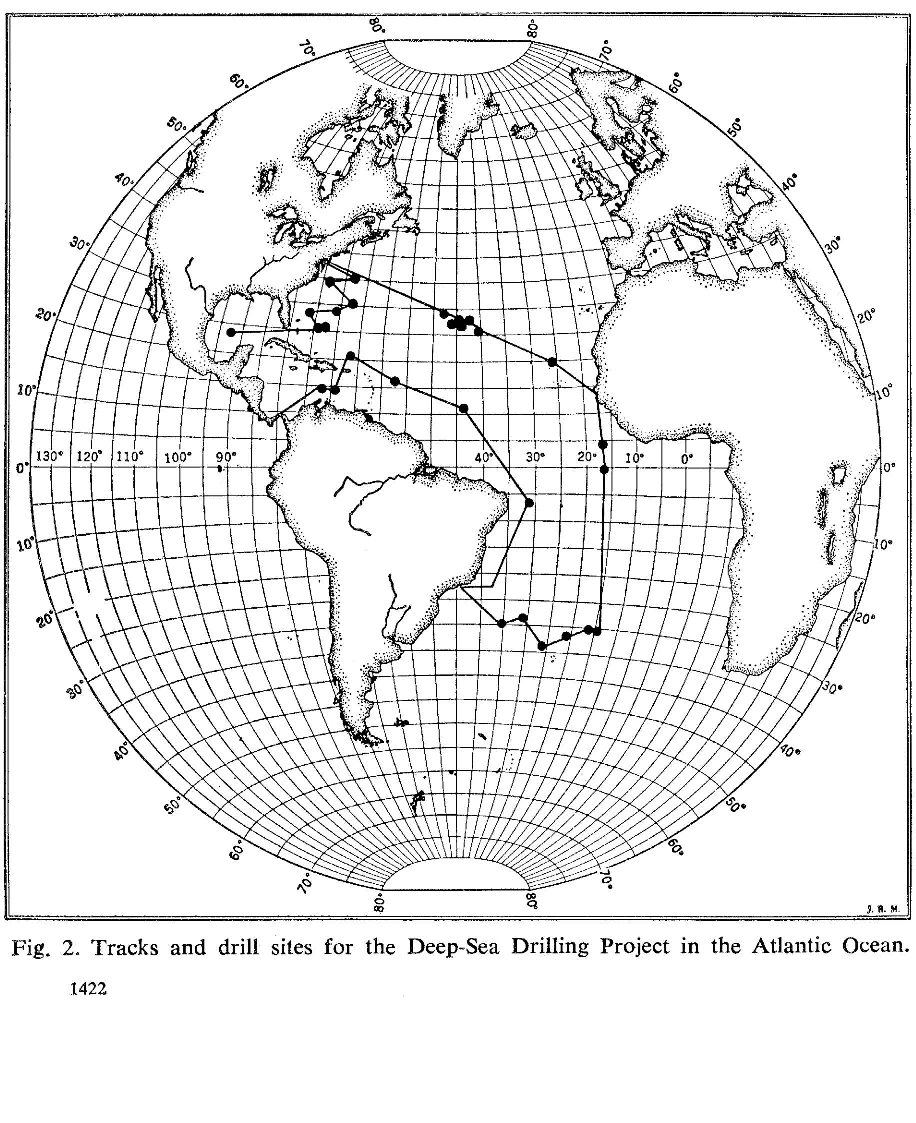

Fig. 2. Tracks and drill sites for the Deep-Sea Drilling Project in the Atlantic Ocean.

history of the earth. In both the Atlantic and Pacific, the oceanic circulation consists of a westward-flowing equatorial current with northward and southward return flow around a northern and a southern central water mass. This circulation system, driven by the planetary winds, strongly affects the nature of the pelagic sediments, especially in the Pacific where disturbing influences of sea-floor topography and adjacent continents are minimized. A thick layer of highly fossiliferous carbonates marks the path of the equatorial current, while the sediments under the north and south Pacific central water masses consist of slowly accumulating, nonfossiliferous clays. Sparse evidence (*10*) indicates that the boundaries between these sediment provinces have migrated back and forth during the Tertiary in response to changes in intensity and distribution of currents and water masses. Similar relations probably obtain in the regions of eastward return flow at high latitudes. Drilling the complete sediment sequence along a north-south profile in the central Pacific should greatly improve the understanding of the history of ocean circulation since the Cretaceous, and of the related climatic evolution of the earth.

The last 100 million years have been a period of major evolutionary change in marine life and of large changes in the composition of the pelagic fauna and flora. Bramlette (*11*) has drawn attention to such a major change occurring at the end of the Mesozoic and suggests that it may have been caused by a reduction in the nutrient supply, which, in turn, was the result of the deeply eroded state of the continents at that time. Recently, it has been suggested that abrupt evolutionary changes, including wholesale species extinctions, may have been caused by increased cosmic-ray activity during reversals of the earth's magnetic field (*12*). A detailed biostratigraphic record based on reasonably continuous samples of pelagic sediments extending back into the Mesozoic would contribute otherwise unobtainable data for understanding these aspects of the history of life. An important corollary is the improvement that might be achieved in the use of planktonic fossils for biostratigraphic correlation and age dating. The existing biostratigraphic time scale is based almost entirely on sediments deposited in near-continent environments and now exposed on land. These formations are often disturbed and discontinuous, and the correlations from one continent to another are highly controversial. Good stratigraphic sequences in true pelagic environments placed strategically between continents would go far toward resolving these difficulties.

Many other problem areas such as those related to marine volcanism, the diagenetic change of sediments with time and burial, the history of the major topographic features of the ocean floor, and the history of the continents as reflected in the sediments shed into the oceans could be cited. The brief listing of major issues presented above, however, may suffice to justify the strong motivation for deep-ocean sediment drilling.

The Deep-Sea Drilling Project

The scientific goals described here form the core of the program of the Deep-Sea Drilling Project at Scripps Institution of Oceanography, under contract from the National Science Foundation as part of its National Ocean Sediment Coring Program. The project has signed a subcontract with Global Marine Inc., of Los Angeles, to provide and operate R.V. *Glomar Challenger*, now under construction, for approximately 18 months beginning in July of this year. First operations are expected to take place in the Gulf of Mexico, the Atlantic, and the Caribbean. With the advice of several panels formed under the auspices of JOIDES, a proposal for drilling objectives and for sites was prepared (*5*); the proposed sites and cruise tracks are shown in Figs. 2 and 3. After consideration of further advice and a review of the schedule, in the spring a final drilling program will be established, which will include a large portion of the proposed program; a detailed discussion of this program and its scientific justification can be found in (*5*).

Under the mandate from the National Science Foundation, the project will mobilize its drilling operation, drill the sites, prepare an initial description of the cores for publication, and preserve and store the core material and data before its distribution for research purposes. The initial description of the core is designed to record characteristics of perishable sediment and to pro-

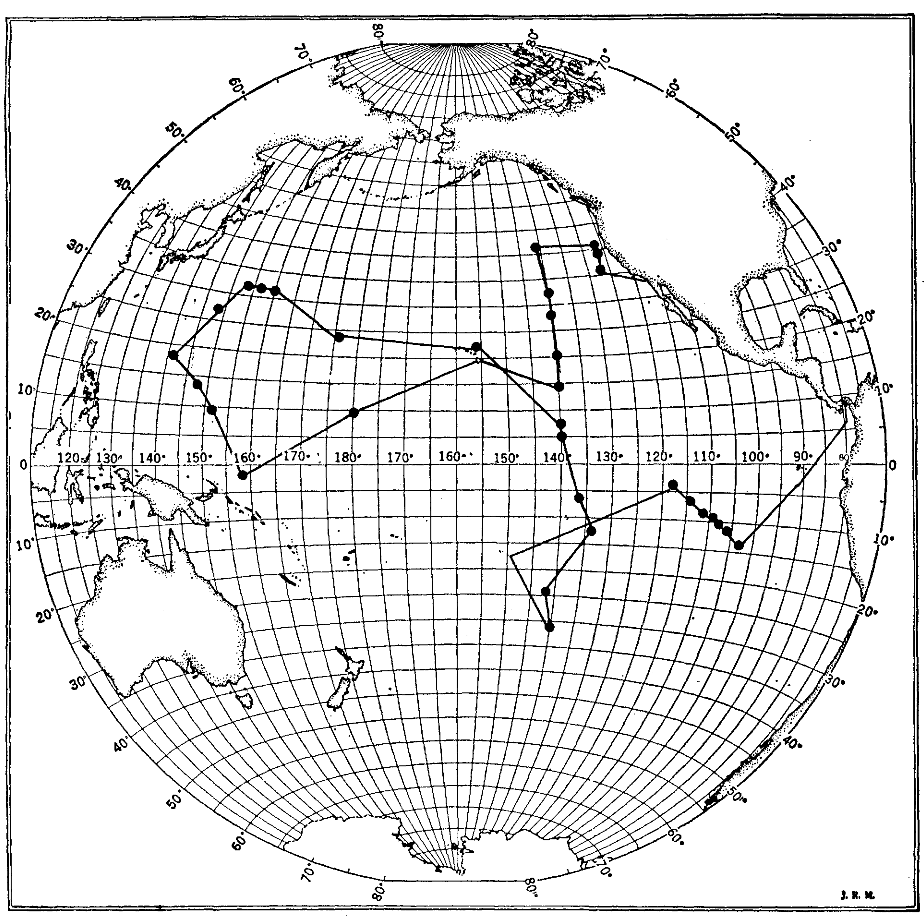

Fig. 3. Tracks and drill sites for the Deep-Sea Drilling Project in the Pacific Ocean.

vide enough descriptive information to permit scientists to define research programs and to select their samples economically and efficiently. Reports should be available approximately 4 to 6 months after the termination of each segment of the drilling cruise. The project welcomes all inquiries and suggestions for additions and improvements in the program (*13*).

The Deep-Sea Drilling Project is the first large scale expression of the dreams described in this article. It is close to reality, and a new chapter on deep-sea drilling can soon be written.

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13. Inquiries may be directed to Project Manager, Deep-Sea Drilling Project Building T-16, Scripps Institution of Oceanography, Univ. of California, La Jolla 92037. In preparing this article I have been helped by my colleagues in various JOIDES committees, in particular by C. L. Drake and W. R. Riedel. Contribution from Scripps Institution of Oceanography.

Relevance in Testing

College entrance testing programs should be changed to meet new student needs and new educational patterns.

William W. Turnbull

Few agencies have survived since the turn of the century in America unless they have had a notable capacity for change. This proposition is true of agencies working in the field of education, as in other fields. Sir Eric Ashby has noted (*1*) that, in order to survive, educational institutions must be both sufficiently stable and sufficiently responsive—not an easy job! The College Entrance Examination Board, which has been a notably stable institution since 1900, has at the same time been no stranger to change. The appointment in 1967 of a Commission on Tests to undertake a fundamental reexamination of the College Board's testing programs demonstrates that the 1960's, and indeed the second half of the century, are likely to see the Board continuing as an institution responsive to changes in the social and institutional context in which it operates. In this article I speculate on some of the forces that may exert powerful effects in postsecondary education and on the College Board's programs in coming years.

The author is executive vice president of the Educational Testing Service, Princeton, New Jersey. This article is based on an address presented in New York City on 17 October 1967 at a meeting of the Commission on Tests of the College Entrance Examination Board.

The Board has not been merely the mirror of change. It has also served as a powerful agent of change in its own right. The Educational Testing Service Annual Report for 1961–62 (*2*) makes the following points.

> . . . during the lifetime of the SAT [Scholastic Aptitude Test], more opportunities for higher education have been opened up for more students than ever before in this country. In the 1930's, the availability of the SAT provided the additional method needed for identifying able students sufficiently well to justify the award of very large national and regional scholarships. Since then, the SAT and other tests similar to it have contributed to the effective selection of scholarship students in many colleges throughout the country.
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> Another interesting development is the change that has occurred in the undergraduate bodies of colleges that have used the SAT over the last two or three decades. In the Ivy League colleges, for instance, the undergraduate body of the 1920's was a homogeneous one with respect to socioeconomic background and a heterogeneous one with respect to intellectual ability. Today the picture is almost reversed—undergraduates in these colleges come from widely varying socio-economic backgrounds and possess a generally high intellectual ability.
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> A third development worth noting is the fact that at colleges where the SAT has been used as part of the admissions process for the last twenty or thirty years, the academic failure of enrolled students has been reduced to a minimal level.
>
> Surely more than coincidence is involved in the fact that these developments occurred during the lifetime of the SAT. Obviously, many other elements have also contributed to expanding opportunities for higher education, to better identification and encouragement of able students, to better guidance, and to reduction of the academic failure rate at many colleges. The SAT, however, has played its part. And the net effect has been the lifting of many of the earlier restrictions to higher education in this country.

These points are worth developing a little further. It has frequently been said that 10 or 20 years ago the most selective eastern private colleges and universities drew 80 percent of their freshmen from 150 or 200 secondary schools. Now, to fill 80 percent of their first-year places, they draw from upward of 500 schools. This movement has, of course, been fueled by the strong desire of institutions of higher education to broaden the composition of their student bodies. It has been made possible, however, by the nationwide availability of examinations designed to allow a good student anywhere to show to advantage, and to be considered favorably whether or not his school is known to the college.

For a time, perhaps, the influx of students from distant schools into prestigious Eastern colleges, made possible in part by use of the testing system, posed some problems for the independent secondary schools that could no longer be confident that their own students would find ready admission to the colleges that would surely have accepted them in an earlier day. In the