SCIENTIFIC GOALS OF THE ADVANCED OCEAN DRILLING PROGRAM

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Summary

The Advanced Ocean Drilling Program (AODP) is planned as a follow-on to the highly successful Deep Sea Drilling Project (DSDP), which will cease drilling in November of this year. Intellectual resources which are being utilized in planning the research program include the plate tectonic theory, results of the DSDP, recommendations of the Conference on Scientific Ocean Drilling and the initial planning document of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES).

The major areas of scientific interest include the origin and evolution of oceanic crust, the tectonic evolution of continental margins, the origin and evolution of marine sedimentary sequences and the causes of the long term changes in the earth's atmosphere, oceans, cryosphere, biosphere and magnetic field. In particular the Program seeks information leading to a more complete understanding of the following areas:

1) process of magma generation and oceanic crustal formation;
2) configuration, chemistry and dynamics of hydrothermal systems;
3) early rifting history of passive continental margins;
4) dynamics of forearc evolution;
5) structure and volcanic history of island arcs;
6) response of marine sedimentation to fluctuations in sea level;
7) sedimentation in oxygen-deficient oceans;
8) global mass balancing of sediments;
9) history of ocean circulation;
10) response of the atmosphere and oceans to variations of the planetary orbits;
11) patterns of evolution of microorganisms; and
12) history of the earth's magnetic field and magnetic reversals.

Present plans envision a ten year program beginning in October 1984.

Introduction

A new scientific ocean drilling program is being planned as a follow-on to the highly successful Deep Sea Drilling Project (DSDP) which ends in November 1983. The DSDP provided the verification of the hypothesis of seafloor spreading and continental drift as well as the first reconnaissance of the earth's crust beneath the sea floor. In contrast, the Advanced Ocean Drilling Program (AODP) is aimed at answering specific questions arising from the DSDP and will adopt a problem focused approach in reaching its scientific objectives.

In general, the scientific goals of the Program are to improve our fundamental understanding of the physical, chemical and biological processes which determine the geological history, structure and evolution of oceanic sediments and crust. Specific objectives to reach these goals are presently in the planning stage. Major areas of scientific interest include the origin and evolution of oceanic crust, the tectonic evolution of continental margins, the origin and evolution of marine sedimentary sequences and the causes of the long term changes in the earth's atmosphere, oceans, cryosphere, biosphere and magnetic field.

The AODP is international in scope and participation in both the planning and anticipated research activities. In order to plan the detailed scientific objectives of the program, several sources of information are being utilized including the plate tectonic theory, results from the DSDP, recommendations of the Conference on Scientific Ocean Drilling (COSOD) and the initial planning document of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). The refinement of the plate tectonics theory is heavily indebted to the drilling results, cores and other scientific data obtained by the DSDP since the inception of drilling in 1968. The recommendations contained in the aforementioned two reports also are directly related to the plate tectonic theory and the cumulative results of over fourteen years of drilling and coring on the DSDP.

Intellectual Sources

Plate Tectonic Theory

All of the work being planned bears upon the general tenents of the plate tectonic theory. Primarily, the generation of new oceanic crust at the spreading centers within the world ocean coupled with the cooling, thickening and movement of that crust away from the spreading centers as large rigid plates. As the oceanic crust moves away from the spreading centers it subsides and thickens by the accumulation of sediments on top of it. Eventually the oceanic crust, and often the overlying sediments, are destroyed by being subducted beneath another crustal plate or pasted onto a continental land mass.

One line of evidence for this continual cycle of oceanic crustal regeneration, movement and eventual destruction is that the oldest oceanic crust encountered appears to be less than 180 million years old. The present ocean basins are relatively young and are believed to represent only the latest of many cycles of oceanic crustal formation and destruction. If we can understand the processes taking place as part of
this present cycle, we will be able to understand the previous cycles. The ocean floor has become the laboratory for understanding the dynamic processes which are continuously changing the shape of the earth.

Deep Sea Drilling Project Results

In the early years of drilling, the DSDP verified the hypothesis of sea floor spreading and continental drift. Results of the DSDP demonstrated how the sediments which accumulated over the oceanic crust became progressively thicker and older as distance from the spreading centers increased. DSDP cores confirmed the ages of the sediments and underlying oceanic crust in most areas of the world ocean. Once the basic hypothesis was confirmed, the DSDP was aimed at broadening our knowledge of the geology of the world ocean and our understanding of how the mosaic of different spreading centers, crustal plates and sedimentary sequences fit together within the concept of plate tectonics. A fairly comprehensive reconnaissance of the earth's crust beneath the sea floor has been accomplished throughout the life of the project. By the end of Leg 91 (February 20, 1983) the R/V Challenger had drilled 1019 holes at 596 sites and recovered 18,460 cores while traversing 665,488 km across the world ocean.

Results of the DSDP are primarily contained in the Initial Reports series of volumes. These volumes, one for each Leg, describe in detail the scientific results of that leg, descriptions of the cores, preliminary results and conclusions. The 98,075 m of core samples recovered through Leg 91 are retained within repositories at Scripps Institution of Oceanography and Lamont-Doherty Geophysical Laboratory for present and future scientific study. The Initial Reports, cores, data banks, and numerous other professional reports and papers represent a wealth of material to draw upon for planning the scientific objectives of the AODP as well as other individual science projects.

Recommendations of COSOD

The Conference on Scientific Ocean Drilling (COSOD) was held at the University of Texas at Austin on November 16-18, 1981. The objective of COSOD was to discuss future scientific drilling programs to succeed the DSDP, problems and scientific objectives. General recommendations of the Steering Committee stated that a world-wide program of long-term drilling is an essential component of research in the earth sciences and that drilling must be part of a larger scientific program including adequate support for problem definition, site surveying, geophysical experimentation and sample analysis. Also recommended was the integration of continental and marine geology through scientific drilling programs and the continuation and expansion of international cooperation.

In addition to the general recommendations, twelve scientific areas were identified at the COSOD as having the highest priority for ocean drilling. These areas are:

- Processes of magma generation and crustal construction at mid-ocean ridges.
- Configuration, chemistry, and dynamics of hydrothermal systems.
- Early rifting history of passive continental margins.
- Dynamics of forearc evolution.
- Structure and volcanic history of island arcs.
- Response of marine sedimentation to fluctuations in sea level.
- Sedimentation in oxygen-deficient oceans.
- Global mass balancing of sediments.
- History of ocean circulation.
- Response of the atmosphere and oceans to variations of the planetary orbits.
- Patterns of evolution of microorganisms.
- History of the earth's magnetic field.

These areas have become the focus for planning the scientific goals of the AODP.

Planning Document of JOIDES

In April 1982, JOIDES produced an initial plan for 8 years of scientific ocean drilling. The plan was prepared by the JOIDES Planning Committee and JOIDES Advisory Panels. The plan reflects the recommendations of the JOIDES Advisory Panels as presented in a series of White Papers prepared over the previous year. The White Papers, accompanying the planning document, define the state of knowledge, problems effectively addressed by ocean drilling and a proposed drilling program for each of the subject fields within the responsibility of each Advisory Panel. The plan integrates the areas recommended by COSOD as highest priority for ocean drilling into a broad comprehensive program for meeting the scientific objectives. The objectives, and proposed drilling programs to meet those objectives, are organized under similar general categories to those utilized in the COSOD report for consistency. These categories are:

- Origin, evolution and tectonics of ocean crust.
- Origin and evolution of marine sedimentary sequences.
- Tectonic evolution of continental margins.
- Causes of long-term changes in the oceans, atmosphere, cryosphere, biosphere and magnetic field.

The plan also includes a discussion of downhole measurements and experiments as well as potential drilling schedules.

This plan was prepared as a "straw man" for the detailed planning of the scientific objectives of the AODP and synthesizes the existing data as well as focusing on the problems to be attacked. This document is being fully utilized in the continuing detailed planning of the science program for the AODP.
New Directions

Within the final years of the DSDP, a shift in emphasis occurred in several areas. The Project began to focus on:

- Solution of specific problems derived from the plate tectonic theory rather than a global reconnaissance of the sea floor.
- Use of drill holes to monitor on-going processes rather than just for acquiring core samples.
- Unification of our understanding of continental and marine geology, within the framework of plate tectonics, rather than a concentration solely on the marine environment.

These shifts in emphasis represent the new directions in which the AODP will proceed in order to obtain the aforementioned general scientific goals.

The shift to a problem focused approach is the natural outgrowth of an improved understanding and acceptance of the plate tectonics theory. Drilling objectives are now planned to gain a more detailed and quantitative understanding of the mechanisms of plate movement and the formation and destruction of oceanic crust. This quest focuses attention on the edges of plates, that is, the mid-ocean spreading centers and continental margins. Related to the interest in spreading centers is the desire to better understand hydrothermal circulation in these regions.

Much interest also exists in the sediments overlying the oceanic crust. The extensive coring program of the DSDP has developed large data and sample bases which are now being utilized to focus on specific problems and/or geographic regions which will improve our understanding of the oceanographic and biologic processes controlling the formation of ocean sediments.

The use of drill holes to monitor on-going processes is the result of a better understanding of the geological processes related to the plate tectonic theory. It is now possible to specify the properties that best can be measured in the hole and design equipment specifically for those measurements. In this manner the hole becomes an in-situ laboratory for observing and measuring various physical and chemical parameters within the crust and overlying sediment as well as monitoring changes in those properties as they occur. Far greater emphasis is planned, within the AODP, for downhole experiments and measurements than was possible within the DSDP. Included are plans for long term monitoring experiments utilizing instrumentation packages left in the drill hole long after the departure of the drilling vessel.

The recognition that continental and marine geology are an intellectual whole also is derived from a clearer understanding of the plate tectonic theory. The oceans represent the area where new crust is created and the continents appear to have evolved through geologic time from that crust in some yet poorly understood manner. In order to gain a better understanding of the relationship between continents and the sea floor more emphasis is necessary on the study of sea floor processes and crustal lithologies. These studies will aid in interpreting the complex lithology, stratigraphy and structures encountered on the continents in ophiolites as well as in the exotic terrains along the Pacific Ocean margins. More emphasis also will be placed on transects across the boundaries of continents and the ocean in order to obtain a better understanding of the transition zone. The thrust toward a clearer definition of the relationships between continental and ocean crust implies closer working relationships between continental and marine geologists throughout the AODP.

Some Specific Objectives

The necessary brevity of this paper prohibits any attempt at a detailed treatise on the scientific problems to be addressed within the twelve high priority areas. The reader is referred to the two referenced documents for excellent accounts of the state of knowledge in each area, what the major unanswered questions or problems are and how they might be attacked through ocean drilling. The following paragraphs are meant only to highlight a few of the areas for future research and some of the pressing problems and questions.

Magma generation and crustal construction. The basic question to be answered is what is the character and composition of the deep portion of the oceanic crust. Geophysical and geological research over the past few decades has yielded a generalized model of oceanic crustal formation and structure. It appears that the process of formation begins with primary magma generation in the mantle. These magmas rise to shallow levels beneath the spreading center axes, coalesce into pockets of various sizes and shapes and undergo processes of mixing and differentiation before eruption onto the surface of the sea floor or crystallization in place. The accreted material becomes the upper portion of the oceanic crust and the material that crystallized in-place is believed to form the lower part of the oceanic crust. The generalized model of oceanic crustal structure assumes a relatively thin basaltic lava cover grading into a complex of sheeted dikes at depths of about 1 km. The sheeted dike complex is about 1 km thick and underlain by the in-place crystallized material believed to consist of gabbroic rocks grading with depth into cumulate ultramafic rocks. The gabbroic-ultramafic layer of the crust overlies the mantle and varies in thickness from 2 km to 5 km.

The mineralogical and petrological nature of the lower crustal layers has been postulated by comparison to the structure and "stratigraphy" of ophiolite complexes which are thought to be slabs of representative oceanic crust tectonically emplaced onto the continents. Other clues have been the sound velocity structure of the oceanic crust and its distinct horizontal zonation as well as rock samples dredged from the base of transform faults along the mid-ocean ridges (spreading centers).

DSDP drilling has penetrated through the basaltic lava crust at one location in the eastern Equatorial Pacific Ocean and substantiated the presence of what appears to be a sheeted dike complex. Deeper drilling as part of the AODP, will continue the nature of the sheeted dike complex and reach the gabbroic layer. The Program will provide a test of the ophiolite model, calibrate the seismic structure, elucidate the magmatic processes and improve our
understanding of the formation and character of the lower oceanic crust and how it is linked to the dynamics of the magma chambers. Other questions to be addressed include the nature and geometry of magma chambers, whether they are steady-state features and the relationships between their geometry and the rate of crustal spreading at the ridge.

Hydrothermal circulation at mid-ocean ridges. The presence of hydrothermal circulation in oceanic crust near spreading centers and its associated hot springs on the sea floor has been a major scientific discovery in the past few years. Hydrothermal circulation appears to cool the crust near the ridge axis forming convection cells with narrow upwelling and downflowing limbs. Of potential economic significance, as well as scientific interest, are the massive deposits of polymetallic sulfides around the hotspring vents. Very little drilling has been done in or around these hydrothermal convection cells.

Some of the questions to be addressed within the AODP are the nature of the hydrothermal flow and flow path systems, the vertical and horizontal extent of the cells, the duration of individual hotsprings and the nature of the metallogeneses at mid-ocean ridges.

History of passive continental margins. Sediments which have accumulated along the passive margins record the history of the tectonic movements of the margin during initial continental rifting and subsequent drifting. It is important to isolate and study these horizontal and vertical movements in order to verify and amplify our understanding of the plate tectonic processes during continental rifting. The stratigraphy of these margins reflect many complicated post-depositional processes, such as eustatic sea level changes, which interact during margin evolution. The observed stratigraphy must be corrected for these processes in order to isolate the effects of the tectonic movements. Another problem is the vast thickness of these sediments in many areas. The lowermost sedimentary deposits recognized on seismic profiles, that record the history during rifting, are beyond the depth that has been reached by DSDP drilling in most areas.

By being able to drill deeper, a more comprehensive section of these deposits will be available for study. Some of the questions to be addressed will include the form of the tectonic movements present during early rifting, how these movements vary across a margin, what rheological models best describe the response of the lithosphere to extension at rifting and the role of vertical and lateral heat conduction at the margin.

Structure and evolution of forearc regions. The original model for the subduction of one plate under another at active margins has had to be expanded due to recent seismic work and DSDP drilling. In the original model sedimentary material overlying the oceanic crust is scraped off the downgoing plate and accreted to the overlying plate during convergence. Recent discoveries demonstrate that many active margins accrete very little material while other margins appear to be undergoing tectonic erosion. Margins where there is accretion from the downgoing plate construct an accretionary wedge on the overlying plate in the forearc region and demonstrate abundant evidence of long-term uplift whereas non-accretionary forearcs show substantial subsidence.

It is suspected that thrusting, particularly in subduction zones, is affected by overpressured pore fluids. The rate of fluid migration out of the sediments is believed to be one of the primary controls on the mechanical behavior of subducted sediments. Questions to be addressed by the AODP include how are pore pressures distributed in a subduction zone; what is the relationship between geometry of the subduction beds, rock composition and fluid migration pathways and how does pore pressure influence tectonism in subduction zones.

Other questions. Within the remaining top priority areas for drilling the following questions represent some of the problems to be attacked.

- How does deep sea sedimentation respond to fluctuations in sea level?
- Which hiatuses or breaks in the stratigraphic record of marine sedimentation represent sea level changes and which represent tectonic upheavals?
- What are the best estimates of world sediment mass and composition balances in space and with time?
- How do patterns of ocean circulation respond to changing ocean boundaries as continental masses shift position?
- How have marine organisms evolved through geologic time?
- What is the nature of the magnetic field during a reversal of polarity?

Schedule
The Program is presently envisioned for ten years of drilling beginning about October 1984. The interim period between the cessation of DSDP drilling (Nov. 1983) and the start of the new drilling operations will be spent in active detailed planning of the science objectives for the whole Program, field surveys of prospective early drilling sites, planning of the first legs and the acquiring and outfitting of a sophisticated drilling vessel.

Tentative plans for the first year of drilling call for a sequence of 6 legs beginning in the Gulf of Mexico and then proceeding in turn to the Bahamas, a Barbados transect, the mid-Atlantic Ridge, the Labrador Sea and the Norwegian Sea. Some of the problems to be addressed on these legs include:

Leg 1 - micro-plate tectonics, salt diapirs, paleoenvironments;
Leg 2 - effects of sea level changes, carbonate platforms;
Leg 3 - mechanics and processes of subduction;
Leg 4 - ocean crust formation, fracture zone geology;
Leg 5 - passive margin sedimentation, paleoenvironment;
Leg 6 - anoxic sediments and paleoenvironment.

During the second year of drilling, the vessel will tentatively be drilling in the Mediterranean Sea, off
Northwest Africa, the Equatorial Atlantic, the Venezuela/Colombia Basins, the Costa Rica Rift and the Peru Trench. From there the vessel will continue south with a leg of drilling in the Chile Trench followed by drilling in the Weddell Sea off Antarctica in December 1986 and January 1987. These initial plans may be modified during the detailed planning but represent the primary areas of interest which can be reached within the first 28 months of the Program.

References
