Committee on
Post-1998 Drilling

report to the U.S. Science Advisory Committee
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The "US Committee on Post-1998 Ocean Drilling" met in Seattle on 14-15 October, 1993. Members of COMPOST were chosen specifically by JOI-USSAC as representatives of major ongoing ocean sciences initiatives in the US. The object of the meeting was to outline the important US scientific problems which must have access to a drilling ship. The scientific rationale for drilling was examined in outline and COMPOST, as part of this process, summarized what ODP has done and can do for the following initiatives:

* MESH [Marine Aspects of Earth System History],
* MARGINS [Processes of creation and destruction of lithosphere and temporal evolution of plate margins]
* RIDGE [Ridge InterDisciplinary Global Experiments],
* DOLCUM [Drilling Oceanic Lower Crust and Upper Mantle].
* OSN [Ocean Seismic Network] and
* Fluid Circulation and Geochemical Processes,

However, COMPOST emphasizes that as these (and other, as yet to be identified) initiatives evolve through time, the relationship of ocean drilling to them will change.

PREMISES

1. The present phase of ODP has approval for US funding through 1998, but scientific justification for continuing the program beyond 1998 must be formulated expeditiously;
2. ODP will end in its present form in 2003; ocean drilling beyond that time must reflect a new direction and a new form;
3. The role of the US as a potential major contributor in a "new era of ocean drilling" needs to be defined as soon as possible, in the context of the very real possibility that ocean drilling will be multi-platform in nature by the beginning of the 21st century.

RECOMMENDATIONS

1. Drilling is an essential tool of the marine Earth science community in the US and should continue beyond 2003.
2. The US community requires a drilling program that is global in scope and is internationally organized and funded.
3. Scientific programs in the US will in the future require access to two different types of drilling platforms: 1) a modified JOIDES Resolution-class vessel, and 2) a platform capable of deep (> 2 km) drilling.
4. The US drilling community will need a JOIDES Resolution-class capability at least to the year 2003.
5. Beyond 2003 there is a clear need for significantly enhanced capabilities beyond the JOIDES Resolution, including deep drilling and

facilities for borehole based experiments.

6. The US scientific community will not be satisfied with drilling only one or two deep holes a year, but will support deep drilling only if it has continuing access to a platform with capabilities of at least a JOIDES Resolution-class vessel. At the same time it is not clear that the US scientific community will support a large increase in the amount of funding for drilling given the legitimate demands of other major scientific initiatives.
7. The US community should actively explore alliances with industry and other Federal agencies (i.e. NOAA, USGS) to expand funding support for ocean drilling. It should also investigate the possibility non-US operation of drilling platforms as long as those vessels are operated through a JOIDES-like structure.
8. Achieving the scientific objectives discussed in this document will require a significant change in the planning of ocean drilling including a much larger component of long range planning, a more focused set of drilling goals, and a mechanism to monitor progress towards achieving these goals.

In June, 1993 the JOI BOG asked USSAC to identify the needs of the US scientific community for ocean drilling in the post-1998 time frame and related facility requirements in anticipation of a workshop on the "New Era of Ocean Drilling" planned for February 1994 in Japan. USSAC, at its June, 1993 meeting, appointed a small ad-hoc committee (COMmittee on POST 98 Drilling or COMPOST 98) to address this issue. The committee met October 14-15, 1993 in Seattle. It consisted of representatives of a number of US marine Earth scientific initiatives as well as communities represented through USSAC-sponsored planning activities.

The recommendations of this committee were shaped by the following "boundary conditions":

1. The present phase of ocean drilling has approval through 1998;
2. ODP will end in its present form in 2003; and
3. In the post-98 time frame the program could include multiple drilling platforms or non-US-operated drilling platforms.

These conditions present the US community a number of important challenges:

1. The scientific justification for continuing the program beyond 1998 must be formulated now;
2. Continuation beyond 2003 must reflect anew direction and a new form of an ocean drilling program; and
3. The role of the US in a new "Era of Ocean Drilling" needs to be defined.

In this report we present the scientific themes viewed by a large part of the marine science community in the US as being essential in our efforts to better understand Earth processes. Based on these objectives we present a series of recommendations on how the US should formulate its role in this new era.

To provide US community input USSAC selected scientists involved in the planning of several major marine Earth science initiatives. These programs are:

Program	Purpose
MESH	Global change Marine aspects of Earth System History
MARGIN	Processes of creation and destruction of lithosphere and temporal evolution of plate margins
RIDGE	Fundamental processes of ocean crustal creation
DOLCUM	Architecture of ocean lithosphere
OSN	Observation of deep Earth structure
GEOCHEMISTRY	Role of fluids in geochemical mass balance and physical processes

These initiatives are being actively supported by US funding agencies (RIDGE) or have received NSF support for initial planning efforts (MARGINS, MESH, and OSN). The scientific input from program DOLCUM and GEOCHEMISTRY reflect active planning supported directly by USSAC. The scientific objectives and program plans of these initiatives represent significant fractions of the US scientific communities.

MARINE ASPECTS OF EARTH SYSTEM HISTORY (MESH)

The objective of MESH (Marine Aspects of Earth System History) is to understand long-term natural variations in global environments, which are recorded in the ocean's geologic record. The ten-year program focuses on dynamics of the coupled ocean-climate system, including sensitivity to change over a range of timescales, responses to external forcing, and internal variability. Through generation and analysis of data and experimentation with climate models, critical environmental feedback mechanisms such as the role of ocean chemistry and the greenhouse effect will be better quantified. This will yield improved understanding of global change processes, and thus better models to predict future environmental changes on the scale of 10's to 1000's of years. This information will be critically important to policy discussions of global change, including society's attempts to adapt to future changes, or to mitigate its effects.

Within the context of the overall objectives, MESH has identified four program elements:

* Sensitivity of Climate and Atmospheric pCO2 to Ocean Circulation and Biogeochemistry Over the Past 500,000 Years (at time scales of 103 to 105 years)

Objectives

1. To use the response of the ocean to a known direct external forcing (temporal and spatial changes in the distribution of solar radiation) and to assess the role of internal forcing over the past 500 Ky. to understand how changes in ocean circulation, ocean chemistry, and biologic fluxes influenced climate and atmospheric pCO2.
2. To identify physically consistent sets of processes that control variability in ocean circulation and chemistry and to use paleoceanographic histories along with numerical models to evaluate the sensitivity and character (i.e.. quasi-linear to nonlinear internal feedbacks) of these climate-related processes.

* Extreme Climate Conditions of the last 120 Million Years

Objectives

1. Better define and characterize the times of extreme climatic conditions over the past 120 my., focusing on the stable intervals of warm climates. The highest priority is a complete characterization of the early Eocene and mid-Pliocene episodes.
2. Document and model how the climate system changed in order to effect these extremes.
3. Identify the important feedbacks within the climate system that maintained global climate in these extreme states.
4. Establish the mechanisms of climate change that brought an end to these extreme conditions.

* Climate Variability on Seasonal to Millennial Time Scales

Objectives

1. To document natural variability of key aspects of the oceanic system on decadal to century time scales, including how short-term climate variability evolves with longer term changes in climate boundary conditions.

2. To assess and use this new understanding of climate processes associated with these times scales to improve the abilities of numerical models to simulate decadal-century climate variability and sensitivity.

* Processes Controlling Abrupt Climate Change
During the Last 150,000 Years

Objectives

1. To understand the role that oceanic processes play in sudden climatic shifts that have occurred in the past;
2. To characterize and describe quantitatively the changes in ecosystems that occurred in response to these rapid climate changes, as well as any feedback processes that may reinforce or counteract the effects of these changes; and
3. To construct computer models that can quantitatively reproduce as well as predict environmental changes.

PRIORITIES AND STRATEGY

The major contribution of paleoceanography to the understanding of global climate change is the documentation of ocean geochemical dynamics. In order to accomplish that for any specific period in the geologic past requires cores from critical areas to constrain the patterns of circulation and ocean structure. Depth and latitudinal transects are especially needed to establish time series of vertical structure of the oceans to quantify and distinguish between processes acting in deep vs. intermediate water masses and surface variability. Cores are also needed from areas of high accumulation rates, such as continental margins and sediment drifts. Large volumes of sediment are required from key regions in order to achieve the goal of calibration and analyzing many proxies on the same time interval.

Within the context of MESH drilling is an important component of all elements, but the most important objective that absolutely requires drilling is the documentation of the extreme climate-dominated world. The strategy envisioned with this MESH initiative is to focus efforts at a finite number of intervals of extreme climate. The need to document the geochemical dynamics of the ocean is sufficiently large, that is unreasonable to expect any program to be able to accomplish the objectives of MESH for a larger number of specific periods of the geologic past. Thus, the MESH objectives place a specific burden on an ocean drilling program to be global in extent but also able to plan for and execute a globally coordinated drilling strategy.

NEEDS

1. Samples: Although a large archive of recovered marine sections exist, many of these are either incomplete, highly disturbed, or are from sections

with very low temporal resolution. These sections are adequate for defining the long term record, but are not adequate for the high resolution studies aimed at understanding climatic processes involving interactions of the fluid spheres. Additional drilling and sampling will be required.

This new drilling should be problem oriented, that is, guided by conceptual and mathematical models of how the oceans and atmosphere interact, and aimed at those sensitive areas of the climate system where high resolution records can be obtained. To establish firmly latitudinal gradients in the oceans, much of this new sampling must be focused in the largely under-sampled high paleo-latitude as well as tropical regions. In addition we must make a special effort to obtain samples representative of the total water column, with need especially for information on intermediate water masses (500 - 2500 m). Few such samples exist in our present collections..

To carry out this sampling program and to conduct the research it would engender requires the maintenance of an international program of scientific cooperation. The Ocean Drilling Program and the international phase of the Deep Sea Drilling Project have been shining examples of the spirit of international collective effort and scientific cooperation that few other programs can match. We must continue this effort and focus its resources to better understand our climate system through the exploration of past climatic states. This cooperation must extend across the range of our efforts from planning, to development of techniques, to sample gathering, to the undertaking of cooperative research programs. It must also include the establishment of an international data base where paleoclimatic data are safely stored and are accessible by all interested researchers.

2. Models: In the past we have frequently come up against the limits of these models in terms of expense, spatial resolution, and the realistic linkage of those different parts of the climate system that have widely different spatial scales and response times. The further development of atmospheric and ocean models, particularly linked ocean-atmosphere models, remains a high priority. The increased use of models has given us new insights into the mechanisms of climate change, the important parameters to be measured in order to evaluate the nature of climate change, and the important areas to sample in order to verify the predictions of the atmosphere and ocean models.

PROGRAM PLAN

1. Sampling: As indicated in the section on Needs, a continuation of ocean drilling is needed to collect a suite of demonstrably complete, high resolution sections from critically sensitive areas. In these geographic regions we will select areas where there is a good depth range extending up into fairly shallow water, and areas where the record is expanded by

relatively high productivity.

The sections that we collect to represent these climatic extremes will probably have several things in common: 1) To achieve the resolution necessary to evaluate climatic variability and the phase relationships of different parts of the climate system they will have sediment accumulation rates higher than 10 m/my. and permit sample resolution of at least 2 ky. Even the gains we have made in reducing the size of samples required to make a measurement can not overcome the effects of bioturbation of the sediments; and where the sediments are not bioturbated, accumulation rates are usually much higher than 10 m/my. 2) To apply many of our existing paleoceanographic proxies, carbonate-bearing sediments are required; thus, the paleodepths sampled will generally be less than 3000 - 4000 m. This is a serious restriction and points again to the need for further development of proxy indicators. 3) Assuming that any given climatic extreme lasts at least one to five my., the minimum interval that must be completely recovered at each site for each extreme sampled is 10 to 50 meters. Higher accumulation would, of course, be desirable, and target sections of 50 to 250 m would hopefully be more common. 4) Establishing an accurate chronology for each of these sections is an important and time consuming task. It will require a combination of stratigraphies that include litho-,bio-,and magnetostratigraphy. The degree to which orbital tuning can be used to refine the chronostratigraphy of these intervals is an area of very active research which shows great promise.

The need to focus the drilling program is well illustrated in an example. The sampling strategy for the early Eocene extreme warmth interval would global sampling strategy. A rough approximation suggests that more than 15 legs are required to study an episode of extreme warmth. Actual drilling programs can address more than one problem and achieve more than one specific goal with a single suite of sites.

2. Critical Analyses: Some critical analyses have already been mentioned in the Needs section above. These involve the development and use of proxy measures of specific parts of the climate system - for example, the concentration of greenhouse gases in the atmosphere. The more we can separate specific elements of the climate system and the more clearly we can identify circulation pathways within the fluid spheres, the more clearly we will understand how that system has worked in the past.

With a surprisingly small number of sections from the early Eocene, for example, we have been able to establish a fairly clear idea of the unusual nature of this extremely warm climate and its associated low latitudinal temperature gradient . We will have to greatly expand the quantity and improve the quality of these sections in order to adequately document the extremes of both the high northern and high southern latitudes and to clearly demonstrate climatic and oceanographic conditions of the lower latitudes. We should also strive to recover sections with relatively high rates of accumulation in order to better characterize the variability of the climate system during this warm interval.

The climatic variability of the marine environment and its link to other elements of the climate system (such as the seasonal extremes of climate on land) is one of the critical analyses that need to be carried out. Other such critical analyses include : 1) the establishment of the vertical structure of the oceans, particularly as it pertains to density driven circulation and mixed layer thickness; 2) the role of the Arctic Ocean in the early Eocene climate; and 3) the patterns of surface circulation, particularly in terms of poleward heat transport and regions of divergence.

3. Model Experiments: As emphasized in the Needs section and implied in the Critical Analyses section, modeling must be an integral part of our research on climatic extremes. This includes geochemical box models, energy balance models, and general circulation models of the atmosphere and oceans. Focusing on the dynamics of warm climate intervals lends a special relevance to this research in terms of the anthropogenic green-house warming that we now face. It is through these quantitative models that we come to realize what critical measurements are yet to be made, how the many feedbacks in the system act to give us the composite climate, and where we need to look to provide necessary input to such models or to check their output.

MARGINS

OBJECTIVES

To develop an understanding of the physical and chemical processes that drive the formation, evolution and destruction of margins --convergent, divergent, and translational. These are the

- processes manifest in the
- mechanics of large faults
- strength of the lithosphere
- magmatic construction of continental crust
- material fluxes through margins
- dynamics, eustacy and the margin stratigraphic record

PRIORITIES AND STRATEGY

Mechanics of very large faults: One of the outstanding problems in lithospheric mechanics that still thwarts investigators is the weakness of very large fault structures. These major, localized deformation zones accommodate a large proportion of the strain at continental margins along subduction zone thrusts, major transforms and normal detachment faults. These structures apparently move at resolved shear stresses far less than required to cause failure based on simple Coulomb theory. We currently lack a verified theory to account for the processes that give rise to these structures, and it can be reasonably stated that absent an understanding of these structures we cannot understand margin evolution.

Theories have been developed to account for fault slip that involve strong gradients in pore fluid pressures between the fault rock and surroundings. Resolution of part of the apparent low-stress faulting paradox may be achieved by drilling an "active" system, to directly address the mechanics of the displacement surfaces themselves. However, low-strength faults are widely conjectured to have evolved from high-strength faults, so the time/space history of fault development is essential to understanding its mechanics. We, therefore, need to integrate scientific drilling of an active system into studies of the evolutionary history of such faults. These studies would include designing drilling experiments to establish fault zone properties at locations where total strain and strain rates differ, and perhaps include regions of seismogenic faulting and aseismic slip (creep).

Strength of the lithosphere: An even more basic question involves the strength of the lithosphere in relation to the magnitude of available tectonic forces. Strength of the lithosphere can be estimated by integration of the "yield stress envelope," commonly used to describe rheology. The magnitude of tectonic forces can be estimated by consideration of "slab pull" and "ridge push" phenomena. When compared, the forces available are simply insufficient to rupture the lithosphere. A closely related issue involves vertical partitioning of strain during deformation. Mounting evidence suggests that strain occurring in the upper crust during extension, as measured by fault geometries, may be much larger than that implied to have taken place in the lower crust and upper mantle based on geophysical observations. One possibility is that the rheology of the lower crust is nearly fluid and hence very weak -- the jelly sandwich model of lithospheric rheology.

Scientific drilling has a central role in addressing problems of lithospheric strength and strain partitioning if it concentrates on 3-D experiments, monitoring and borehole geophysics, as well as coring. For example, stress measurements provide the only direct way to estimate the size and orientation of forces acting on the lithosphere. The nature of the lower crust cannot reasonably be inferred from surface observations, either by geological mapping or by geophysical measurements. Coring lower crustal rocks is desirable, but unless it is seriously proposed that drilling will routinely intersect the deepest levels of continental margins, the most appropriate route to understanding the lower crust is to develop a strategy that integrates in situ measurements of rock properties around and beneath drill holes by borehole geophysical techniques including VSPs and borehole electrical experiments, coupled with surface experiments measuring similar parameters. One critical aspect is the role of fluids in controlling the deformation of the lower crust. This will require carefully executed fluid sampling and monitoring programs in deep levels of appropriate boreholes.

Magmatic construction of continental crust: Growth of continents has long been thought to be largely associated with magmatism at convergent margins but it is becoming clear that very large volumes of magma are brought to the earth's surface in other settings. Simple volume estimates of flood basalt provinces on land and beneath the oceans (so-called Large Igneous Provinces), and the information available on the timing of outpouring for many of them, imply magmatic fluxes of extraordinary proportions in intraplate and divergent margin settings. For example, creation of the Ontong-Java Plateau may have involved production of magma over a few million years equivalent in output to the entire mid-ocean ridge system at that time.

Decompression melting of an unusually hot mantle during extension can deliver considerable volumes of melt to the surface, which may give rise to high-velocity "underplated" layers recognized beneath the continental slope of many so-called "volcanic" margins. Mounting evidence, however, suggests that margins with volcanic characteristics have also formed without the heat source provided by a hotspot. We therefore lack a theory that can adequately explain the spatial and temporal aspects of melt generation and migration needed to account for even our most basic observations.

It becomes critical then that we establish the nature of the so- called underplated layers and determine the time-scales involved in igneous construction in various plate settings. In many instances, only the uppermost surface of these constructions can be sampled, giving us just the "last gasp" of the constructional process; this may very well seem of short duration. Assessing the nature of the deep underplated sequences is probably not a problem that can be resolved by direct sampling, since the depths involved (more than 15 km) are too great to achieve from any ODP drilling platform. Therefore we will need an integrated science strategy that will geophysically sense the nature of units beneath the maximum depth of actual penetration. This may involve seismic experiments that aim to observe shear wave birefringence as a guide to the crystal orientation, and perhaps as a strain marker for lower crustal units. For example, in-hole shear wave seismic sources would be extremely valuable, as they can be combined with p-wave observations to estimate the presence of fluids in the crust.

Material fluxes through margins: The great distance between model predictions and observations is equally expressed in convergent settings, where the boundary structures are very different. Models of mantle flow,

melt generation and migration for mid-ocean ridge settings are capable of predicting some basic petrological characteristics of ridge basalt. Similar models for convergent settings provide only crude predictions of magma distribution. Despite many years of study, a number of essentially zeroth order questions remain. These include:
How does heat and mass transfer associated with subduction of oceanic lithosphere lead to production of magmas? In particular, what is the role of slab fluids in triggering melting in the overlying mantle? What is the nature of the mantle wedge and its role in arc magmatism? How does the downgoing slab evolve as it penetrates into the asthenosphere?

One of the key missing pieces of information is a constrained estimate of mass balances and material fluxes at convergent margins. We know that material enters the convergent boundary along the subducting slab, but the fate of that material is very poorly understood. Some fraction of the material is flushed back to the ocean, some is scraped off the descending plate and accreted to the edge of the continent. Only ocean drilling can investigate the partitioning of material near the site of subduction.

Dynamics, eustacy and the margin stratigraphic record: Continental margins are the Earth's principal locus of sedimentary accumulation. Margin sediments provide one of the best proxies for global sealevel history and record variations in past terrestrial climates, the history of vertical motions of the lithosphere, ocean circulation, geochemical cycles, organic productivity and sediment supply, and are a principal recorder of lithospheric deformations. Margins provide long records of variations in the solid Earth-ocean-atmosphere system essential to evaluating models for today's global changes. Yet, processes responsible for erosion, transport, accumulation and preservation of margin sediments represent a complex, dynamic system that is still incompletely understood. An understanding of erosion is, for instance, a necessary prerequisite to understanding sediment supply. Other important interacting factors include changes in accommodation space due to tectonic subsidence and uplift, global sea- level (eustatic), and the rate of sediment supply through time.

ODP can rightly claim a leadership role in many aspects of the study of sedimentary processes. For example, drilling will allow both snapshots of stratigraphic systems at critical times of change and monitoring of prisms themselves, to assess evolving parameters like diagenesis and deformation. The response of margin stratigraphy to sealevel changes in terms of the development of seismic sequences has become almost a paradigm. ODP investigators are leading the investigation into the mechanism by which the response occurs by seeking an understanding of relationships among stratigraphy of sedimentary sequences, processes that form stratification at all scales, and geologic events that trigger these processes.

NEEDS

It is tempting to recite a panoply of technological advancements that would allow ODP to make more rapid progress toward achieving the research goals outlined above. It might be easier to say that what is needed is "whatever it takes to drill, sample and log deeper." For example, if even simple measurements such as temperature are to be made at very deep levels the technological problems quickly become very serious and the estimation of other parameters will be a significant challenge. However, as important as this is the need to re-orient the basic strategy of ODP to one in which the results of scientific drilling - not just cores, but the results of experiments conducted in the borehole - are seen as one component of an integrated study of the problem being addressed. This goal goes well beyond the need for adequate site survey information, the primary purpose of which is to see that a hole is properly sited. We need to establish drilling as part of a long-term, multi-disciplinary approach that integrates underway surveys, seafloor geological sampling and monitoring, numerical modeling, and a range of other approaches, together with scientific drilling at an early stage in the development of scientific strategies. Drilling has often been considered the ultimate tool for which all other studies provide preparatory information. While it may be the case that study of the cored rock provides the essential information for the analysis of some classes of problems addressed by ODP, this is not the case for tectonic problems in general and the study of margins in particular.

CRUSTAL ACCRETION PROCESSES AT OCEANIC SPREADING CENTERS (RIDGE)

The goal of the RIDGE program is to understand the complex and interrelated magmatic, hydrothermal and tectonic processes involved in the formation of new oceanic crust and lithosphere. The major scientific problems RIDGE is addressing are:

* Global structure and fluxes - to characterize the tectonic structure, geo- chemistry, biology and energy fluxes of ocean ridges on a global scale
* Crustal accretion variables - to access the key variables that effect the crustal accretion process and develop quantitative, testable models of magmatic, tectonic and hydrothermal process operative at oceanic spreading centers
* Hydrothermal processes at ridges - to quantify the flux of seawater through oceanic crust at ridges, its effects on the chemistry and physical properties of oceanic crust, and the processes that lead to the formation of polymetallic sulfides
* Mantle flow and melt generation - to constrain the nature of mantle flow and melt generation beneath oceanic spreading centers

* Temporal variability of magma-hydrothermal systems - to understand the variability of active sea floor magma-hydrothermal systems on time scales ranging from days to decades

ODP can make important contributions to both the US RIDGE program and the international InterRidge initiative in ridge crest research. Drilling is viewed as one component of a broader, longer-term investigation of mid-ocean ridge processes that will involve detailed surface geological mapping and sampling, geophysical experiments, and concurrent monitoring of volcanic activity, hydrothermal output and water column chemistry at "sea floor observatories". The emerging ability to identify and locate volcanically active sections of the mid-ocean ridge through long-distance acoustic monitoring will offer exceptional opportunities in the coming years to target both drilling and related studies in those areas where magmatic, tectonic and hydrothermal processes are currently most active. Much can and has been learned by studying fossil magmatic and hydrothermal systems, especially in ophiolites, however because these systems reflect the time-integrated history of many different processes acting over millions of years many fundamental questions remain unanswered. A full understanding of the processes accompanying the formation of oceanic crust will require in situ observations of an active magma-hydrothermal system on the sea floor.

Drilling can make many unique contributions to these studies. In particular, drilling provides the only method of directly sampling the sub-seafloor components of active ridge crest magmatic and hydrothermal systems. Drill cores, fluid samples, and in situ physical properties measured in these holes will address critical questions such as:

* The lithostratigraphy, composition and alteration history of "zero-age" crust
* The porosity and permeability structure of the crust above an active crustal magma body
* The time/space variations in physical properties of the fluids circulating within an active hydrothermal system
* The relationship between magma emplacement and eruption and the state of stress and deformation of the surrounding crust
* The feedback loops linking the evolution of magmatic, hydrothermal and tectonic systems at ridge crests

Ridge crest drill holes can also serve as sites for the emplacement of sub-seafloor instrumentation to monitor these processes (e.g. the CORK) and will be an integral part of any long-term RIDGE observatory effort. The results of drilling in Middle Valley suggest that the drill holes themselves will perturb the equilibrium of an active system and, by monitoring this disturbance and its subsequent recovery, much can be learned about the properties of these systems.

The highest priorities for drilling at ridge crests include: (1)Drill a deep (1-2 km) hole in "zero-age" crust through the entire extrusive and sheeted dike section to the top of an axial magma chamber. This crust need not be hydrothermally active. (2) Drill into a large, polymetallic sulfide deposit of an active hydrothermal system and extend the hole into the high temperature reaction zone 1-2 km below the seafloor. (3) Drill arrays of shallower (~100-500 m deep) holes into an active magma-hydrothermal system as part of a RIDGE observatory.. All of these holes should be drilled in the context of long-term instrumentation and monitoring of the ridge axis as envisioned by the RIDGE sea floor observatory. If drilling "zero-age" crust at unsedimented ridges remains technically unfeasible, these holes should be drilled using conventional technology at a sedimented ridge crest.

NEEDS

The long-term success of ridge crest drilling depends critically on the availability of new technology to drill and retrieve core and sample fluids in young, fractured rock. The temperatures expected in ridge crest drill holes may be in excess of 400°C, and all drilling subsystems will have to be modified to handle these exceptionally high temperatures. We must also learn to better exploit the drill holes for in situ experiments and for long-term monitoring (e.g. CORK). Close coordination of this drilling with RIDGE and InterRidge will be vital.

THE STRUCTURE, COMPOSITION, AND ALTERATION OF THE OCEAN CRUST AND MANTLE

OBJECTIVES

* Obtain a direct knowledge of the three dimensional architecture and composition of the ocean crust and upper mantle (structural, igneous and metamorphic) and how these change through time.
* Determine how the architecture of the ocean crust and shallow mantle varies with spreading rate, magma supply, and varying patterns of mantle flow beneath the ridges.
* Determine the origin of the major seismic boundaries in oceanic crust and shallow mantle.
* Quantitatively balance themagmatic and chemical fluxes between the mantle, crust and hydrosphere. Test the ophiolite model for oceanic crust.

PRIORITIES

Drilling can make a number of unique contributions to understanding the fundamental architecture of the oceanic crust:

* Drilling, supplemented by logging data, is the only way in which long vertical sections of the lower crust and mantle can be obtained where the key stratigraphic relationships between different igneous, structural and metamorphic units can be determined.
* Drilling is the only way to ground-truth models of oceanic crust and shallow mantle structure and composition and determine the geological significance of major seismic interfaces such as the layer 2/3 boundary and Moho.
* Drill holes provide the only way of determining the in-situ physical properties of oceanic crust and shallow mantle including critical parameters such as temperature, permeability and porosity.
* The physical and chemical evolution of oceanic crust and shallow mantle is a subseafloor process that can only be addressed by drilling
* Drilling, in many cases, provides the only way to sample crustal or mantle rocks off-axis
* Ocean drill holes provide in-situ laboratories for ongoing active and passive geophysical measurements of the properties and behavior of the ocean crust and shallow mantle.

STRATEGY

Ocean drilling has two fundamental goals: (1) direct sampling of in-situ ocean crust, and (2) establish single and multi-hole laboratories for both active and passive direct measurements of the physical properties and behavior of the ocean crust.

Sampling: There are three strategies for obtaining samples of the entire oceanic crust and studying its alteration history: (1) drilling single deep holes though the entire crustal section to Moho, (2) drilling partial sections of the lower crust and upper mantle with multiple shallow penetration holes (<1 km) in tectonic windows into the ocean crust (offset-section drilling), and(3) drilling off-axis multiple hole transects to sample hydrothermal sediments and ocean crust. In all cases, these should be carried out in the context of detailed geological and geophysical studies, including those being conducted by programs such as RIDGE and InterRidge.

Drill Hole Laboratories: Drill hole laboratories allow in-situ measurement of the physical properties of the ocean crust by well logging, and how these evolve with time as hydrothermal fluxes vary. Offset vertical seismic borehole experiments and hole to hole seismic and other geophysical measurements in multi-hole laboratories allow in-situ measurements at appropriate scales of the physical properties of the ocean crust and shallow mantle at all levels where structure and igneous, metamorphic stratigraphy is already known to provide a basis for interpretation and extrapolation of geophysical data in other areas of the ocean crust.

PLAN

Post 1998 drilling priorities are listed below. The philosophy behind these priorities is one of drilling fewer, but deeper holes than has been the case in the program to date. They involve a commitment to a multi-year, multi-leg, and, in some cases multiple hole drill strategy. The program is designed to build towards a post-2002 drilling program which will directly address the three dimensional architecture of the ocean crust and its evolution with time.

1. Obtain a complete cross-section of the ocean crust in offset sections preferably at one location on the global ridge system, or, if logistically necessary, by composite drilling at different locations on slow spreading ridges.
2. Do the same for crust created at a fast-spreading ridge.
3. Drill a multi-hole laboratory in a tectonic window where the seismic properties and other physical characteristics of the lower ocean crust can be directly determined both along and across an isochron.
4. Drilling a multi-hole off-axis transect out to crust ~10 Ma age in order to investigate the variation of the physical and chemical properties of the shallow (<1 km) crust with age
5. Drill a 2-3 km deep hole into igneous basement in a supra-subduction zone setting to test the hypothesis that most ophiolites form in this region.

Post 2002 drilling priorities are listed below with a shift in philosophy of drilling a few really deep holes, but much more numerous shallow holes (~500 m).

1. Drill a total penetration of an intact section of "normal" ocean crust at a slow-spreading ocean ridge at to obtain the composition and physical properties of the crust and shallow mantle to 1 km below Moho ~10 Ma .
2. The same in crust formed at a fast spreading ocean ridge.
3. Determine the along strike variability of the oceanic mantle and lower crust in tectonic windows for representative ridge sections of ocean crust formed at a slow spreading ridge segment using short offset 500-1000 m penetrations along an isochron.
4. The same in crust formed at a fast-spreading ridge.
5. Deep penetration of major ocean seamount and oceanic plateaus to 6km.

NEEDS

Conventional rotary drilling techniques have proven successful in drilling to depths of up to 2 km into old oceanic crust and, through offset drilling in tectonic windows, into lower crustal (gabbroic) and upper mantle sections exposed on the seafloor near ridge crests. This drilling has already yielded important results at Hole 504B on the structure and alteration history of the sheeted dike and extrusive section, and at Hole 735B and at Sites 894 and 895 for the lower crust and mantle for crust formed at both slow and fast spreading ridges. Thus, the present technology, with improved ability and techniques for casing holes is adequate for shorter penetrations in many key environments. Improved bit designs to enhance recovery, and the ability to diamond core would provide the crucial ability to obtain high recovery in highly fractured rock which typifies both the shallow ocean crust and some key tectonic windows.

Drilling to crustal depths greater than 2 km in the year 2002 and beyond will require a different technology and platform than presently exists. Most importantly a riser system capable of operation at abyssal depths. Also needed will be improved downhole instrumentation for measuring physical properties and sampling fluids in small diameter holes at high temperatures. Deep crustal drilling will require a platform dedicated to or capable of commitment to multiple legs at a single site for one or more years.

[Image]OCEAN SEISMIC NETWORK (OSN)

OBJECTIVES

A uniformly distributed network of approximately 128 very broadband (3 mHz to 10 Hz) seismic observatories must be established around the Earth at a spacing of approximately 2000 km. This distribution is necessary for unaliased tomographic studies of the large-scale structure of the Earth and for studies of earthquake sources. Because of the lack of islands in some ocean basins, this goal cannot be achieved unless the capability to operate broadband, four-component (including a hydrophone) seismic observatories on the ocean floor is developed. Even in areas where small islands are available, seafloor observatories are preferred because island stations are generally positioned over anomalous regions of the upper mantle. Two major issues must be considered:

* The ODP is essential to OSN since it is possible that an installation in a cased hole in igneous basement is the only way to record high fidelity broadband inertial motions on the seafloor.
* From the standpoint of the OSN program the US must retain the leadership role in ODP. At the moment the US has the leadership role in the international OSN and GSN programs and we wish to retain that role.

The prioritized scientific objectives within the OSN program are:

- Global Earth structure

An important goal of seismology is to obtain more detailed representations of the Earth's internal heterogeneity. We believe that only if instruments are deployed on the ocean floor will it be possible to greatly improve the tomographic models on a global, rather than on a regional basis. The lack of coverage by seismic instruments in the oceans leads to inaccuracy in seismic models, particularly in the Pacific region and in the southern oceans. This shortage of information is particularly regrettable since the oceans, in general, but the Pacific in particular, contain the most significant global tectonic process - the fastest spreading ridges, the most active hot spots, the oldest ocean floor, and the majority of subduction zones. The ability to determine how these surface manifestations of mantle convection express themselves at depth will be of crucial importance in understanding the dynamics of the Earth as a whole. Even a small number of instruments on the ocean floor can considerably enhance our ability to determine deep Earth structure, since they provide control points of the mesh of intersecting paths. Placing instruments in a sparsely sampled area does not only provide a proportionate number of additional paths, but it also enhances the value of all the other available data which are sensitive to the structure of the undersampled region.

- Oceanic upper mantle dynamics and lithosphere evolution

At the present time, no broadband seismic stations are available to record earthquakes with pure oceanic propagation paths. While the most active seismic regions on Earth lie within oceanic regions, surface wave studies of oceanic upper mantle and lithosphere structure rely entirely on stations located on continents or those located on islands. Pure path studies conducted with seafloor stations will greatly enhance the resolution available for studying the upper mantle. It is axiomatic now that seismic anisotropy can be used to map flow in the upper mantle. The degree of lithosphere thinning and the mechanisms of lithosphere thinning can be studied in much greater detail with seafloor observations than with observations at great distance on heterogeneous continents. There is an ongoing debate regarding the depth extent of heterogeneity at mid-ocean ridges. Given a model of pressure-release heating at a mid-ocean ridge, it is likely that melting and associated heterogeneity are relatively superficial. However, new studies of shear wave multiples provide strong evidence for the continuation of the heterogeneity to the core-mantle boundary. Pure path surface wave studies and studies of oceanic shear wave multiples are important in resolving this issue.

* Earthquake source studies

Major faults extend along the coastlines of North and South America and Japan and significant expenditures have been made in establishing stations on the continents and islands to monitor this activity. Unfortunately, this monitoring is severely biased to one side of these major faults and oceanic observations are lacking. Permanent ocean stations are clearly needed to reduce this bias. Ocean floor stations are needed to improve source locations (particularly depth), focal mechanism and rupture process determinations. These measurements are critical to studies of the depth of the seismic decoupling zone, the depth extent of outer rise events and the rheology of the oceanic lithosphere. Nearfield data, in particular ocean floor recordings, are needed to improve the resolution of the source mechanisms of events not caused by faulting but by slumping or magmatic injection.

Other , lower priority objectives include:

* Oceanic crustal and lithosphere structure

* Tsunami warning and monitoring

* Sources of noise and propagation of noise

PLAN

The holes drilled for the OSN must penetrate the overlying sediments and extend approximately 100 m into basement. The holes must be cased into basement and grouted.

STRATEGY

Efforts to improve the design and performance of the ocean seismic observatories must continue for many years. It is also crucial that operational OSN observatories be installed as soon as possible so that useful data can be distributed to the community and the value of these new observatories can be evaluated and recognized. For these reasons, the OSN Steering Committee has recommended a phased approach to the establishment of OSN:

Phase 1: Primary pilot experiments (1994-1996)

Phase 2: Installation of five to seven prototype operational observatories by OSN and international partners that would be used for further instrument and system development, and at which additional auxiliary experiments could be carried out to enhance understanding of site selection, system performance and reliability issues. We anticipate that Phase 2 could begin in 1996.

Phase 3: Routine emplacement of the remaining 10-15 planned stations distributed to complete an even global distribution of broadband stations.

FLUID CIRCULATION AND GEOCHEMICAL PROCESSES

OBJECTIVES

To understand processes of fluid circulation at mid-ocean ridges, ridge flanks, subduction zones, and passive margins, in order to evaluate the role of these processes in geochemical mass fluxes. These processes and the accompanying fluxes are important for heat loss from the Earth, formation and evolution of the oceanic crust, formation of hydrothermal ore deposits, support of biological communities, control of seawater chemistry, mass transfer between the exosphere (atmosphere, oceans, and sediments) and endosphere (deep crust and mantle), long-term storage of volatile elements and compounds, and processes at convergent margins, including magma generation, volcanism, and backarc spreading.

PRIORITIES AND STRATEGY

Mid-Ocean Ridge Axis: Along the axis of the mid-ocean ridge system, heat associated with volcanism causes seawater to circulate convectively through the oceanic crust. This seawater becomes heated to high temperatures and reacts with crustal rocks, recrystallizing them and exchanging with them chemically. The heated and altered seawater exits the seafloor as hot springs which deposit polymetallic sulfide ore minerals. Because the springs are rich in hydrogen sulfide and other reduced compounds, they also support biological communities that are based on chemosynthetic production of organic matter. The heat flux carried by the circulating seawater is sufficiently large to play an important role in crystallizing and cooling the oceanic crust, and hence in determining crustal structure. The accompanying chemical fluxes are large enough to influence the composition of seawater.

Priorities are:

* To quantify the seawater flux through mid-ocean ridge axes and its effects with depth on the chemistry, mineralogy, and physical properties of the oceanic crust
* To determine the conditions under which large polymetallic massive

sulfide deposits form in and on the oceanic crust, at both unsedimented and sedimented ridge axes.

These objectives can best be accomplished by drilling as deeply into layer 3 as possible on relatively young crust. The crust need not be hydrothermally active at present but should be as young as possible. Good core recovery and logging are essential. Sidewall coring should be developed to ensure that representative samples are recovered. It is critical to drill into that zone within the crust which has acted as the source of ore metals for polymetallic sulfide deposits. An additional key strategy is to drill a group of closely spaced holes into an active hydrothermal system. The holes should be instrumented for long-term monitoring of pressure, temperature, flow velocity, and fluid composition.

Mid-Ocean Ridge Flanks: Thermally driven circulation of seawater continues through the crust of mid-ocean ridge flanks, to ages of tens of millions of years. The heat loss and probably the chemical fluxes as well are greater on the flanks than at the axis. The important objectives are:

* To characterize the thermal and chemical regimes under which progressively older crust is altered by the circulating seawater
* To quantify the effects of this process on the chemistry, mineralogy, and physical properties of the oceanic crust with age, including both sediments and basement rocks. Key parameters include crustal age, basement relief, and thickness of sediment cover.

These objectives can be accomplished by drilling deeply into layer 2 in a variety of regimes defined on the basis of the above parameters. Additional preferred targets are basement highs that may have protruded through the sediment cover for long periods of time and acted as conduits for fluid flow. Good core recovery, logging, and measurement of physical properties such as permeability (preferably in situ)are essential. Much can be learned about the composition of fluids in basement from profiles of sediment pore water composition, even without deep basement holes, as long as the sediment column is completely cored and basement is at least penetrated.

Subduction Zones: Volatile elements and compounds are delivered to subduction zones mainly in the form of carbonate sediment and as interstitial water in sediments and basement. Carbonate and bound water taken up during alteration of the crust at the ridge axis and flanks are also subducted. As the subducted crust is heated the volatiles are driven off in stages, depending on the site they occupy within the crust; they then ascend through the overlying mantle and crust, where they are believed to be involved in magma generation and other processes.

Priorities are:

- To determine the mass fluxes in subduction zones, especially those carried by fluids, so as to quantify mass transfer between the exosphere (atmosphere, oceans, and sediments) and endosphere (deep crust and mantle).
- To determine the fate of various materials introduced into subduction zones, especially volatile elements and compounds in the oceanic crust.
- To determine the role of these volatiles in processes within forearc, arc, and backarc regions of subduction zones, including dewatering, decarbonation, formation of gas hydrates, magma generation, volcanism, and backarc spreading.

These objectives can be accomplished by drilling transects of moderately deep holes across a variety of subduction zones, from seaward of the trench to the arc and backarc. Sites of fluid upwelling within these regimes should be identified and targeted for drilling for recovery of pore waters. Temperature-pressure regimes vary drastically from one subduction zone to another, depending on convergence velocity, angle of subduction, crustal age, and whether subduction is steady-state or not. Study of fluid compositions across a variety of subduction zones should therefore yield information about the progressive devolatilization of the subducting slab.

Passive Margins: Passive margins are sites where large volumes of sedimentary material with associated volatiles accumulate over long periods of time. Eventually most passive margins become active margins, as convergence and subduction are initiated.

Priorities are to determine mass fluxes within thick sedimentary piles along passive margins; in particular, how much of the material that is buried in this environment is stored long-term, and how much is remobilized and returned to the oceans? What is the fate of this material when a passive margin becomes active, by initiation of subduction or by collision?

These objectives can be achieved by drilling deeply into a variety of passive margin environments, distinguished on the basis of sediment type, age, and thermal conditions.

NEEDS

- More deep holes in other environments, e.g., in crust formed at slower and faster spreading rates than at Hole 504B, and in younger crust
- A better way to sample hot fluids from boreholes and from basement
- A way to sample intervals that yielded poor core recovery by conventional methods. In particular, it is likely that the most highly altered and metasomatized layers are being grossly undersampled. These layers must be sampled in order to obtain accurate bulk compositions

and to ground-truth the geochemical logs. Development of a sidewall sampler could solve this problem.
- Better ways to identify fluid flowpaths by geophysical methods
- Better ways to identify and sample gas hydrates
- Better ways to sample fluids and to monitor their composition in situ
- Better ways for measuring permeability and flow velocity
- More long-term monitoring of pressure, temperature, fluid composition, and other parameters important for fluid flow

Clearly there is significant scientific interest in the continuation of ocean drilling beyond the present program. However, there is a strong perception of the US community that to advance Earth sciences beyond the present phase of ocean drilling requires improvement in four areas:

APPROACH/STRATEGY

New advancements will come with three changes in our scientific strategy. First is the need to drill significantly deeper in a number of geologic environments. Secondly the scientific objectives require the careful planning for multiple holes in these geologic settings. Holes are needed to provide complete three dimensional images. This is especially true in complex tectonic regions but is also true for paleoceanographic settings where a more complete picture of the vertical as well as horizontal structure of the past oceans need to be delineated. Finally, drilling to collect core material will still need to be emphasized but carefully planned and executed borehole experiments, including the use of holes as in situ laboratories must be an integral part of an ocean drilling program.

TECHNOLOGICAL NEEDS

We highlight five areas where technological developments and facilities are essential to achieve the scientific objectives outlined in this report:

- Deep Drilling:
    - 4.0 km (water depth), 3.0 km (penetration)
    - (max. 6.5 km water depth, 2.0 km penetration)
- Controlled Circulation System-- hot, high pressure, recirculation, continuous fluid monitoring.
- Ability to penetrate and recover fractured rock
- Laboratory Facilities at sea
- Downhole Instruments
    - Packers, fluid samplers and other tools (including high temperature tools) that measure in situ rock and fluid properties. Low-power borehole broadband seismometers, long-term seafloor battery and recording packages, recovery technologies for station refurbishment, and long-distance telemetry are technologies which

and the necessary scientific staffing associated with reduced capabilities is not in the best interest of the scientific objectives of ocean drilling. Plan 3 with a multipurpose ship augmented by a larger deep drilling platform will provide the scientific community a much more cost effective program although the ships will require a significant funding augmentation.

RECOMMENDATIONS

Based on the scientific objectives outlined in this document we present in this section a series of recommendations on how the US should formulate its role in the "New Era of Ocean Drilling":

1. Drilling is an essential tool of the marine Earth science community in the US and should continue beyond 2003.
2. The US community requires a drilling program that is global in scope and is internationally organized and funded.
3. Scientific programs in the US will in the future require access to two different types of drilling platforms: 1) a modified JOIDES Resolution-class vessel, and 2) a platform capable of deep (> 2 km) drilling.
4. The US drilling community will need a JOIDES Resolution-class capability at least to the year 2003.
5. Beyond 2003 there is a clear need for significantly enhanced capabilities beyond the JOIDES Resolution, including deep drilling and facilities for borehole based experiments.
6. The US scientific community will not be satisfied with drilling only one or two deep holes a year, but will support deep drilling only if it has continuing access to a platform with capabilities of at least a JOIDES Resolution-class vessel. At the same time it is not clear that the US scientific community will support a large increase in the amount of funding for drilling given the legitimate demands of other major scientific initiatives.
7. The US community should actively explore alliances with industry and other Federal agencies (i.e. NOAA, USGS) to expand funding support for ocean drilling. It should also investigate the possibility non-US operation of drilling platforms as long as those vessels are operated through a JOIDES-like structure.
8. Achieving the scientific objectives discussed in this document will require a significant change in the planning of ocean drilling including a much larger component of long range planning, a more focused set of drilling goals, and a mechanism to monitor progress towards achieving these goals.