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JOIDES Lithosphere Panel
Long Range Planning Document

Executive Summary

The overall thematic objective of lithospheric drilling is to understand the origin and evolution of the oceanic crust and lithosphere, and associated magmatic, hydrothermal and metamorphic processes. Over the years, there has been a remarkable consensus within the lithospheric community on its drilling priorities. The two highest priorities have consistently been: (1) determining the structure, composition and alteration history of the oceanic crust, and (2) characterizing the processes of magma generation, crustal construction and hydrothermal circulation involved in the formation of oceanic crust. Drilling can also provide important insights into the magmatic processes associated with the onset of sea floor spreading, mid-plate volcanism, geochemical fluxes at convergent margins, the physical properties of the oceanic lithosphere, and the composition and dynamics of the mantle.

Addressing these problems during the coming decade will require a focussed, interdisciplinary drilling effort with the following four major goals:

- By 1996 drill three holes 2000-3000 m into the oceanic crust, with the prospect of extending one of these holes to Moho by the year 2000. One of these holes should be located on thin crust (e.g. proximal to a fracture zone), the others on crust formed at fast and slow spreading ridges

- Drill arrays of shallow (~300 m) and intermediate (1-1.5 km) depth holes in several locations along the mid-ocean ridge system, including fast, slow and sedimented ridge crests. One of these areas should be permanently instrumented to establish a sea floor "volcano observatory" by the year 2000.

- Complete select lithospheric "case studies" (5 over a 10-year period) of well-documented, representative features addressing magmatic and dynamic processes associated with intraplate volcanism, plate convergence and mantle evolution and heterogeneity.

- Establish a global network of sea floor geophysical stations throughout the major ocean basins in 100-200 m deep crustal holes equipped with short and long-period, broad-band seismometers and other appropriate long-term geophysical instrumentation.

Many of these objectives can be achieved using present drilling technology (shallow crustal sampling, deep drilling in exposed plutonic sections, *in situ* stress mapping). However, the long-term goals of deep crustal penetration, ridge crest drilling and sea floor observatories will require major new technological developments in drilling systems,

logging equipment and long-term borehole instrumentation. In terms of drilling systems, three major problems must be overcome: (1) penetration and sampling of young, highly fractured, extrusive basalts comprising the uppermost part of Layer 2, (2) low penetration rates, short bit life, hole instability and incomplete flushing of cuttings in deeper crustal holes, and (3) low recovery rates. Logging equipment and borehole instrumentation will need to be adapted for use in smaller diameter holes and under high-temperature (up to 400°C) conditions. Other important needs are for improved borehole sampling techniques (fluids and rock), improved utilization of drill holes for a variety of borehole experiments, and advances in data storage and retrieval techniques for long-term borehole instrumentation.

Although improved crustal drilling technology is essential to the achievement of the most important long-term drilling goals of the lithospheric community, a number of planning options exist if delays are experienced in developing this new technology. For example, if problems with young crustal drilling at the EPR can't be solved, it may be feasible to address the same thematic objectives at sedimented ridge crests where the crust is likely to be significantly altered and sealed. If drilling deep (>1-2 km) holes is not technically feasible, then more emphasis could be placed on drilling exposed lower crust and upper mantle sections near fracture zones. Finally, a higher priority could be assigned to drilling technically feasible, secondary LITHP drilling objectives until the required drilling systems are available.

The following implementation plan gives a rough estimate of the activities and level of effort that might be required to achieve these drilling objectives in coming decade:

Phase 1 (1989-1992)

- Establish detailed planning groups (DPGs) on "Drilling Deep Crust", "Ridge Crest Drilling", "Sea Floor Observatories", and others as appropriate
- Develop a long-term engineering development plan to improve crustal drilling technology, including cost estimates, manpower needs, and test-leg requirements
- Begin site survey work for at least 6 candidate sites for deep crustal drilling, 4 sites for ridge crest drilling, and 5-10 sea floor geophysical stations
- Complete 2 legs of deep crustal drilling at Hole 504B, or at another suitable deep crustal drill site
- Complete 4 legs of drilling on sedimented and unsedimented ridge crests of the eastern Pacific
- Complete one lithospheric "case study" on the nature of hot spot volcanism by drilling Loihi (one leg)
- Carry out recommended pilot experiments for the establishment of a sea floor seismic station, probably at a site near Hawaii

Phase 2 (1993-1996)

- Complete site survey work for deep crustal holes, ridge crest drilling and sea floor geophysical stations
- Complete three holes 2000-3000 m into the crust, including one hole in thin crust (1 leg/yr for four years)
- Begin first phase of Mid-Atlantic Ridge drilling; complete second phase of EPR program (1 leg/yr for four years)
- Establish 5 sea floor geophysical stations and carry out two lithospheric "case studies" (e.g. drilling a near-axis seamount and a back-arc spreading center) (1 leg/yr for four years)

Phase 3 (1997-2000)

- Extend one crustal hole to Moho (6 legs/yr over four years)
- Complete second phase of MAR drilling (2 legs)
- Establish a sea floor volcano observatory (in conjunction with RIDGE) on a volcanically active part of the mid-ocean ridge system
- Complete a global network of sea floor seismic stations and carry out two lithospheric "case studies" (e.g. a regional geochemical mapping program and an *in situ* stress experiment along an accretionary plate boundary) (1 leg/yr for four years)

In this scenario, approximately 3 legs of drilling would be required per year over the next decade to complete the four long-term drilling goals outlined above (the equivalent of about 1 leg/yr for deep crustal drilling; 1 leg/yr for ridge crest drilling; and 1 leg/yr for establishing sea floor geophysical stations and carrying out selected lithospheric "case studies"). However, LITHP's interest in sea floor seismic stations and *in situ* stress measurements clearly overlap that of TECP, and at least some other lithospheric drilling could be carried out in conjunction with the programs of other thematic panels. Thus the amount of <u>dedicated</u> LITHP drilling required to achieve these four goals is probably about 2 1/2 legs per year over ten years.

Although lithospheric drilling objectives exist in all the major ocean basins, most are concentrated in the central and eastern Pacific and Atlantic Oceans. Many of the highest priority objectives also require multiple drilling legs at single site or in the same area. Thus it is critical that the drillship be scheduled so that it can reoccupy drill sites at intervals of 9-12 months. All of these considerations suggest that the circumnavigation philosophy that has driven the first eight years of ODP planning is **not** the optimal strategy for lithospheric drilling. Instead, ship scheduling should be planned around long-term, thematically prioritized drilling goals like those outlined above.

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I. Overview of Scientific Objectives of the First Phase of ODP

COSOD I - The COSOD I Report in 1981 identified a variety of problems related to the origin and evolution of the oceanic crust and lithosphere that can be addressed by drilling. The two highest priority ocean crustal problems agreed upon at this conference were:

- Processes of magma generation and crustal construction operating at mid-ocean ridges
- Processes of hydrothermal circulation in the ocean crust

In addition, the COSOD I Report also discussed a number of other important lithospheric problems that could be studied by drilling. These included: (1) the compositional heterogeneity of the mantle and mantle evolution, (2) the aging and evolution of the oceanic crust, (3) the formation of overly thick crust, (4) the role of transform faults, (5) processes operating in young ocean basins, and (6) island arcs and backarc basins. The need to drill at least one hole as deeply as possible into Layer 3 was specifically noted in the conference report.

At COSOD I the role of "natural laboratories" in future crustal drilling was emphasized. As defined in the conference report, the natural laboratory concept includes: "arrays, or clusters of holes, some deep, some relatively shallow, grouped together in fours or fives in particularly critical (active) parts of the ocean floor . . . . They would be used for the emplacement of sophisticated instruments, some during the drilling period, and others for long-term monitoring after the drilling had ceased. Within each each laboratory complex, one hole would be targeted for deep penetration to allow sampling from hitherto unreached levels in the ocean crust." The need for improved drilling technology was also recognized, including the development of techniques for drilling in areas with little or no sediment cover.

LITHP White Paper - The JOIDES Lithosphere Panel (LITHP), following on the recommendations contained in the COSOD I Report, prepared a White Paper in 1986-87 which outlined a series of specific recommendations on the drilling strategies, priorities and technical development required to address these broad thematic objectives. The panel identified as its two most important long-term drilling objectives the completion of one or more deep holes into the lower oceanic crust, and the establishment of a suite of drill holes to investigate magmatic and hydrothermal processes at both fast and slow spreading ridges. It was noted that neither of these objectives could be attained with existing ODP drilling systems, and a major, long-term effort to improve crustal drilling technology was urgently needed. However, the LITHP White Paper also identified other shorter-term drilling objectives (e.g. drilling old oceanic crust, flexural moat drilling, and convergent margin drilling, including geochemical reference holes) that were feasible with present drilling technology. The White Paper suggested the most productive approach to lithospheric drilling was one which included these shorter-term objectives, coupled with a parallel engineering development effort to achieve the longer-term goals of the deep crustal and ridge crest drilling.

II. Scientific Achievements of ODP to Date

A. *Present status in achieving thematic objectives*

The progress to date in achieving the major lithospheric drilling objectives outlined above has been frustratingly little. This is attributable, in part, to the technical difficulties of drilling in young, highly fractured basaltic crust, and drilling into the deeper layers of the oceanic crust. Thus despite the successful establishment of the first "zero-age", "bare-rock" drill hole in the Mid-Atlantic Ridge rift valley on Leg 106, subsequent drilling at this site on Leg 109 was unable to extend this hole significantly into Layer 2. However, not much progress has been made in achieving even the more technically feasible lithospheric drilling objectives noted above. This is primarily attributable to the fact that through the first 29 legs of ODP (~5 yrs) the equivalent of only about 4 legs of drilling have been devoted to the highest priority lithospheric objectives outlined in the COSOD I report.

Some progress, however, has been made. The most notable technical achievement of ODP has been the development of the hard-rock guide base, and associated drilling hardware, which has proven to be an effective means of spudding a drill hole on bare rock with only minimal support for the bottom hole assembly. This has long been a goal of the lithospheric drilling community and overcomes a major engineering obstacle to the establishment of the "natural laboratories" at ridge crests envisioned in the COSOD I Report. Over the past year substantial progress has also been made in adapting small-kerf, diamond-bit mine coring systems for use in ODP. These systems offer considerable promise for significantly improving the penetration and recovery rates for crustal drilling. Communication between the ODP Engineering Development Group and the JOIDES advisory panels has also been substantially improved during the past three years, resulting in much better co-ordination of development efforts with long-term program planning.

From the perspective of the lithospheric drilling community, there have been three main scientific accomplishments of ODP to date: (1) characterization of the *in situ* physical properties of oceanic Layer 2, (2) exploration of the deeper structure of the oceanic crust, and (3) new constraints on hot spot evolution and true polar wander.

In situ Physical Properties of Layer 2 - An important accomplishment of the first two years of ODP was the completion on ODP Legs 102, 109 and 111 of logging programs at the three deepest crustal holes drilled in the Deep Sea Drilling Project (Holes 504B, 395A and 418A). The extensive suite of state-of-the-art logging tools and borehole experiments carried out in these holes have provided unique data on the physical properties of both young and old oceanic crust. For example, at 504B it was found, somewhat unexpectedly, that the lower 1000 m of the hole, comprising the partially-sealed pillow lavas and sheeted dikes of Layer 2, has uniformly low permeability (5-20 x 10^{-18} m^2). Thus the only highly permeable section of the crust in this hole is the upper 100-200 m of pillow basalts. These results are extremely important for modeling hydrothermal processes at mid-ocean ridges and understanding the alteration history of the oceanic crust.

Exploration of the Lower Oceanic Crust - Drilling results from ODP Legs 109 and 118 on the Mid-Atlantic and Southwest Indian Ridges have provided important new constraints on the structure and composition of the oceanic crust and upper mantle along slowly accreting plate boundaries. On Leg 109 serpentinites and partially serpentinized harzburgites were recovered at Site 670 in the Mid-Atlantic Ridge rift valley only a few kilometers from the accretionary axis. The presence of these rocks, thought to be typical of the lower crust or upper mantle, at very shallow crustal levels away from any major fracture zone, indicates that slow spreading ridges must be characterized by periods of very low magma supply and/or extensive tectonic thinning. The peridotites themselves have been extremely useful in studies of the compositional variability and melting history of the upper mantle beneath a slow spreading ridge.

The most exciting, and unexpected, lithospheric drilling result to date is unquestionably the 500 m of gabbro drilled at Hole 735B during Leg 118 on the Southwest Indian Ridge. Technically, this hole was a major triumph for the new bare-rock drilling techniques developed by ODP, as well as setting new records for both penetration (60 m/day) and recovery rates (95% over over the bottom 400 m; 87% overall) in a crustal drill hole. The gabbros obtained at this site represent the first coherent section of *in situ* Layer 3-type material ever recovered from the ocean basins. Studies of the geochemical and petrologic variations in this section will allow the magmatic evolution of a fossil oceanic magma chamber to be investigated in its true stratigraphic context. The logging and borehole experiments carried out in Hole 735B have also provided the first *in situ* information on the physical properties (porosity, permeability, seismic velocity, magnetism) of Layer 3.

Hot Spot Evolution and True Polar Wander - The floor of the central Indian Ocean is dominated by two prominent hot spot lineaments, the Ninetyeast Ridge and the Chagos-Laccadive Ridge. Drilling on Leg 115 investigated the poorly known Chagos-Laccadive Ridge and clearly established that the age of the volcanoes comprising this feature increase from south to north as would be predicted for a model in which the hot spot remains fixed in the mantle. Surprisingly, however, this hot spot, which is now located under Reunion Island, appears to have gradually moved northward relative to the earth's magnetic pole over the past 55 million years. This corresponds with a proposed southward motion of the Hawaiian hot spot, suggesting that the paleomagnetic reference frames for the Pacific and Indian Ocean mantle have moved in opposite directions over the same time period. These intriguing new results have lead to a revival of the old theory of "true polar wander" in which the whole outer shell of the Earth rotates with respect to the spin access, and caused renewed debate among geophysicists about the interaction between hot spots, the lithosphere and convection in the mantle.

B. *Practical spin-offs*

The hard-rock guide base, and associated drilling hardware, developed by ODP for ridge crest drilling also have potential applications in the exploitation of economically valuable, massive sulfide deposits in the ocean basins. The adaptation of high-speed, small-kerf, diamond-bit mine coring systems by ODP for ocean drilling is at the forefront of offshore technology, and is of considerable interest to both the petroleum and minerals industries. The oil industry is giving serious consideration to utilizing mining technology for drilling small diameter, low cost exploratory oil and gas wells both onshore and offshore. By drilling smaller diameter holes, there is potential for considerable savings in downhole equipment and operating costs. At the present time, several companies are field testing these same mining techniques for drilling ultradeep exploratory holes on land. In South Africa, for example, a mining company is currently drilling deep (>4000 m) exploration wells for the purpose of sampling specific ore bodies. There has also been limited deployment of mine coring systems from floating vessels for doing shallow soil studies and geological work.

III. Future Scientific Opportunities and Objectives

A. *Scientific Objectives defined by COSOD I and II*

In 1987 the accomplishments and future scientific objectives of ODP were discussed at the Second Conference on Scientific Ocean Drilling (COSOD II). The recommendations discussed at COSOD II, together with those included in the earlier COSOD I Report, can be used to construct the following set of major lithospheric drilling objectives for ODP (*not prioritized*):

- Determining the structure and composition of the oceanic crust, and its variation with age, tectonic setting and spreading history
- Investigating the magmatic and hydrothermal processes at mid-ocean ridges
- Characterizing the magmatic processes associated with the onset of the earliest phase of seafloor spreading
- Characterizing intraplate volcanism, especially that associated with seamount formation and the origin of oceanic plateaus
- Understanding the geochemical fluxes and magmatic processes at convergent margins
- Determining the state of stress, and thermal and mechanical evolution of the oceanic lithosphere

- Characterizing the dynamics, composition and geochemical evolution of the upper mantle

B. *Scientific Objectives Not Addressed by the COSOD Conferences*

One lithospheric drilling objective that was not specifically addressed in either COSOD Report, but that has been consistently ranked high by the Lithosphere Panel is the magmatic evolution of young hot spot volcanoes. The discovery of an early, alkalic phase of hot spot volcanism at Loihi was a milestone in the development of our understanding of mid-plate volcanism. It has had important implications for models of mantle plumes and their interaction with the lithosphere. However, the role of this juvenile alkalic stage in the formation of Loihi, and hot spot volcanism in general, remains controversial. Drilling a young hot spot volcano like Loihi or Mehetia could provide valuable, stratigraphically-controlled samples of this critical, early stage of hot spot volcanism. This type of drilling should be included in future plans for lithospheric drilling.

C. *Technical/Logistical Requirements*

Achieving the major scientific objectives of the lithospheric drilling community will require significant improvements in crustal drilling technology and borehole instrumentation. These requirements include:

- Penetration and sampling of young, highly fractured, extrusive basalts comprising the uppermost part of Layer 2
- Developing the capability of *routinely* drilling deep crustal sections (>3 km total penetration)
- Improved recovery rates for more representative sampling of the crustal section
- Drilling and logging equipment, and borehole instrumentation, capable of operating under sustained high-temperature conditions (up to 400°C)
- Improved methods of borehole and *in situ* fluid sampling
- Methods for long-term instrumentation and data recovery from boreholes

D. *Status of Scientific Objectives at the End of Phase I of ODP (1992)*

It is unlikely that any of the major lithospheric drilling objectives outlined above will achieved by the end of the first phase of ODP in 1992. However, depending upon the amount of time devoted to drilling in the Pacific during the next four years, and the success of ongoing engineering development efforts, substantial progress is possible in addressing several long-term lithospheric drilling goals.

LITHP has proposed that an additional 1 1/2 legs of drilling be spent at Hole 504B in the 1990-1992 time frame in order to deepen this hole into seismic Layer 3. Sampling of the Layer 2/3 boundary at this site, already the deepest crustal hole in the ocean basins, would be a major scientific achievement. However, even with this success we would still be far from reaching our long-term objective of drilling a hole through the entire thickness of the oceanic crust. The COSOD II Report proposed that a realistic goal for ODP by 1992 is *routine* drilling, with a minimum of 75% recovery, to depths of 1000 m below the basement/sediment interface.

The East Pacific Rise Working Group has proposed that four legs be devoted to drilling ridge crests in the eastern Pacific prior to 1992; two legs on the fast spreading East Pacific Rise and two legs on the sedimented ridge crests of the northeast Pacific. If this drilling is successful, a major step will have been taken toward the establishment of the "natural laboratories" envisioned in the COSOD I Report. However, this would only be the first phase in a much longer-term effort. At least an additional 2-4 legs of drilling would be required after 1992 to complete the East Pacific Rise program, and a minimum of 4-6 legs would be needed to establish a comparable suite of holes at one site along a slow spreading ridge.

There are other important lithospheric drilling objectives that could be addressed in the next four years, if the necessary drilling time is made available. For example, drilling in the western Pacific near the Bonin and Mariana arcs could provide the first constraints on geochemical fluxes at convergent margins, while a drill hole on Loihi could be used to investigate the recently discovered juvenile, alkalic stage of hot spot volcanism discussed above. However, in both cases these programs would represent only one part in a longer-term, global effort to understand the geochemical evolution of the oceanic crust and the underlying mantle. The concept of global geochemical mapping to investigate the composition and dynamics of the mantle as outlined at COSOD II entails a large number of drill holes on a variety of targets (seamounts, plateaus, hot spots, old crust etc.) that will require a decade-long program of drilling on a global scale.

Attaining the major scientific objectives of lithospheric drilling will require a two-fold commitment on the part of ODP: a long-term (5-10 yr) engineering development effort to improve crustal drilling technology, and the allocation of significant amounts of drilling time, including multiple legs to a single site. Without this two-fold commitment it is unlikely that any of the major scientific objectives of lithospheric drilling will be achieved in the foreseeable future.

IV Prioritization and Implementation of Objectives

A. *Scientific Prioritization*

The overall thematic objective of lithospheric drilling is to understand the origin and evolution of the oceanic crust, lithosphere and underlying mantle. Over the years, there has been a remarkable consensus within the lithospheric community on its drilling priorities. The two highest priorities have consistently been: (1) determining the structure, composition and alteration history of the crust, and (2) characterizing the processes of magma generation, crustal construction and hydrothermal circulation involved in the formation of oceanic crust. Drilling can also provide important insights into the magmatic processes associated with the onset of sea floor spreading, mid-plate volcanism, convergent margin processes, the physical properties of oceanic lithosphere, and the composition and dynamics of the underlying mantle. We have not attempted a prioritization of these secondary objectives, since it was recognized that they are all components of a global system, and thus are all equally important. In this section we briefly abstract from the LITHP White Paper and the COSOD I and II Reports the goals, drilling strategies and technical requirements needed to achieve each of these drilling objectives.

Primary Objectives

The structure and composition of the oceanic crust

Goals We still have no direct knowledge of the structure, composition and physical properties of over two-thirds of the oceanic crustal section. Deep crustal drilling is essential for determining the bulk composition and physical properties of the oceanic crust, interpreting the geological significance of seismically-defined crustal layering, and understanding the alteration history of the oceanic crust. Deep crustal drilling can provide definitive answers to major outstanding questions such as: How do ophiolites compare with "normal" oceanic crust?, What are the compositions of primary mantle-derived melts and how are they modified by magma chamber processes?, and What is the depth and nature of hydrothermal interaction in the crust? Drilling deep crustal sections would produce a quantum leap in our understanding of oceanic crustal processes, and has been ranked a top priority by COSOD I, by WG-2 at COSOD II and by the JOIDES Lithosphere Panel.

Drilling strategy In terms of cost, required engineering development and long-term planning, deep crustal drilling is on an entirely different scale from the kind of drilling ODP has attempted in the past. The long-term objective is nothing less than a complete crustal section from the top of Layer 2 to Moho, although in the shorter term much can be learned from intermediate-depth holes (1-3 km deep) on crust of different ages in a variety of tectonic environments. At a minimum, holes should be drilled on crust at a slow and fast spreading ridge, since a comparison of the crustal structure for these two end members would resolve many outstanding questions concerning the significance of spreading rate on the crustal formation process. Two general drilling strategies have been discussed. The first involves drilling through layer 2 into the lower crust at sites considered "typical" of normal oceanic crust. This approach has the advantage of providing a complete crustal section at a single site, but it will be both time consuming and technically difficult. An alternative drilling strategy for reaching the lowermost crust and upper mantle is to locate holes in areas (e.g. proximal to fracture zones) where the plutonic foundations of the crust are exposed. Ideally, these holes should be located near sites which sample the upper crust so that the entire crustal section can be reconstructed.

Technical/logistical requirements Some progress can be made in achieving these objectives using existing drilling systems by locating holes in older crust off-axis where layer 2 is weathered and sealed, or by drilling in areas where massive layer 3-type rocks are exposed. However, our longer-term goal of complete crustal penetration will require new drilling systems capable of drilling 5-6 km into the crust in water depths of 5000-6000 m. Development of these systems will require a long-term (~10 yr) phased development effort, ship time for testing, substantial financial resources and close collaboration between scientists and engineers. Also needed will be new high-temperature, small-diameter logging tools and borehole instrumentation. Most importantly, successful deep crustal drilling will require patience, and a willingness to commit the drillship to a single site for a year or more of drilling (although this drilling would not have to be done as consecutive legs). Overall, we estimate the need for at least three holes 2000-3000 m below basement, with the hope of extending one of them to Moho by the year 2000. One of the shallower holes should be located on thin crust.

Crustal Accretion Processes

Goals Sixty percent of the earth's surface is created at oceanic spreading centers, as magmas generated in the underlying mantle are transformed into crust. In the most general terms, the goal of crustal drilling at ridge crests is to understand the complex and interrelated magmatic, tectonic and hydrothermal processes involved in the formation of the ocean crust. An example of one important focus for ridge crest drilling is the dynamic boundary between magma and cooled, fractured rock at the margins of a magma chamber. The physical and chemical interactions between rock and water at this boundary are almost completely unknown, yet it is at this boundary that the solid crust is formed. Other important objectives of ridge crest drilling include investigating temporal and spatial variations in magmatic activity, providing ground truth for geophysical horizons such as the pillow/dike or dike/gabbro boundary, and providing sites that can be used for a variety of down-hole experiments and long-term geophysical monitoring. Ridge crest drilling was the highest crustal drilling objective identified at COSOD I, and was highly ranked by WG-2, 3 and 4 at COSOD II, as well as by the JOIDES Lithosphere Panel.

Drilling strategy The East Pacific Rise Working Group has outlined a potential drilling strategy for fast spreading, unsedimented ridge crests involving a suite of eight holes. The highest priority site is a single deep (>1 km) hole near the ridge axis, outside the central zone of fissuring, that penetrates as close as possible to the top of the magma chamber. The second priority is a ~500 m deep hole in the axial fissure zone that penetrates far enough into the underlying dikes to characterize the temperature gradients and permeability structure of the shallow crust. A transect of three, relatively shallow holes (~300 m deep) across the rise axis and, and three holes along the rise axis toward the boundary of a spreading cell segment, were also proposed to investigate temporal and spatial variations in magmatic and hydrothermal activity. A somewhat different strategy might be appropriate at a slow spreading ridge or a sedimented ridge crest. For example, a shallow hole, or suite of holes, in an axial hydrothermal discharge zone is considered to be a very high priority, but was not recommended for the East Pacific Rise because the known vent sites are too small and immature.

Technical/logistical requirements None of the drilling described above can be attempted with present drilling technology. Especially critical is the development of a reliable technique for penetrating and stabilizing the upper 200-300 m of highly fractured extrusives present at ridge crests. High temperatures (>400^{o}C) will be encountered at depth in many of the holes, and the mechanical and chemical consequences must be considered for drilling, fluid and rock sampling, and logging. A suite of holes, like that proposed for the East Pacific Rise, could require 8-12 months of drilling time. Individual legs should ideally be separated by 9-12 months to allow the engineers time to react to unanticipated problems. Drilling should, of course, be only part of a carefully co-ordinated and integrated program of multidisciplinary geological, geophysical, geochemical and biological investigations at each ridge crest "natural laboratory" as envisioned in the RIDGE Report. A major goal of ODP should be establishing three ridge crest "natural laboratories" by the year 2000: at both fast (EPR) and slow (MAR) spreading ridges, and at a sedimented ridge crest (Juan de Fuca/Gorda Ridge; Gulf of California).

Secondary Objectives

Magmatic processes associated with the initiation of sea floor spreading

Goal The transition from a continental to oceanic rift, and the initiation of sea floor spreading, is a fundamental geotectonic problem that is still very poorly understood. Variations in the response of the lithosphere to the rifting process provides an opportunity to examine the relative importance of brittle and ductile deformation, magmatism, and metamorphism on lithospheric evolution. Of particular interest is the nature and origin of the volcanism that accompanies early rifting, and the mechanisms that control the volume of rift-related volcanism. A better understanding of this magmatism is important to models of global crust-mantle interactions. At most margins the volcanic products of early rifting are buried under thick accumulations of post-rift sediments and drilling offers the only way of sampling this crust. Rift-related processes were identified as important secondary drilling objectives by both COSOD I and WG-4 at COSOD II.

Drilling strategy There are two different ways drilling can be used to address these problems. The first is to drill in young, active rifts like the Red Sea or Gulf of California. Both areas were drilled during the Deep Sea Drilling Project with considerable success, and further drilling in these areas is clearly warranted. A second approach is to drill relict rifts preserved in passive margins such as those bordering the Atlantic. In many cases, the thick accumulations of post-rift sediments along these margins make this approach impractical.

But in other, sediment-starved areas it is feasible to drill into rift-related volcanics as was successfully demonstrated on Leg 104.

Technical/logistical requirements Many of the drilling objectives outlined above are feasible using present drilling technology. WG-4 at COSOD II emphasized the need for deeper holes (3-4 km) into thicker sedimentary, igneous and metamorphic sections on conjugate margin pairs. On "volcanic" margins hard-rock penetration of 2-4 km is expected which will necessitate improved crustal drilling technology.

Intraplate volcanism

Goals Intraplate volcanism is the second most common type of volcanic activity occurring in the ocean basins. It takes many forms including small, near-axis seamounts, linear volcanic chains, aseismic ridges, oceanic plateaus and massive off-axis flood basalts or intrusive complexes. Studies of the products of mid-plate volcanism can provide important constraints on the composition and chemical evolution of the upper mantle. Four problems related to mid-plate volcanism are of particular interest: (1) the character and origin of compositional variability in the mantle, (2) the early magmatic evolution of hot spot volcanos, (3) the formation of near-axis seamounts and oceanic plateaus, and (4) determining the internal stucture of seamounts.

Drilling strategy The range of products of mid-plate volcanism (seamounts, plateaus, flood basalts, etc.) require different drilling strategies and technical capabilities. One of our highest priorities is a characterization of the magmatic evolution of young hot spot volcanoes. Loihi is a particularly attractive drilling target; it is already extremely well-mapped and studied, it is located in relatively shallow water (~1500 m), and it is logistically convienent to Hawaii for permanent instrumentation. A single, relatively deep hole (>500 m) near the summit of this volcano could provide valuable, stratigraphically controlled samples of the juvenile alkalic phase of Hawaiian volcanism and its transition to the main theoleiitic shield-building stage. It could also serve as a permanently instrumented "natural laboratory" on an active, submarine volcano. Similarly, drilling a small near-axis seamount is necessary for an understanding of the internal structure and composition of these features, the most abundant volcanoes on earth. Drilling is the only method of unambiguously determining the age and composition of oceanic plateaus, and of sampling the mid-Cretaceous flood basalts and intrusive complexes found in the western Pacific. For this type of drilling, modest basement penetration (100-500 m) is adequate at a few carefully chosen sites

Technical/logistical requirements Drilling young hot spot volcanoes or near-axis seamounts will be technically difficult and will require both a bare-rock drilling capability and improved techniques for drilling in young, fractured basaltic rocks. However, drilling of older seamounts may be feasible with present technology. Multiple legs may be necessary at a single site, although one logistical advantage of seamount drilling is the relatively shallow water depths of some of these targets. Drilling oceanic plateaus and mid-

Cretaceous flood basalts and intrusive complexes is technically feasible with present drilling technology, although penetration of overlying cherts may be a problem in some areas.

Geochemical fluxes and magmatic processes at convergent margins

Goals It has long been clear that the subduction of the lithosphere is intimately connected to volcanism at convergent margins. What remains unclear is to what extent subducted crust, and the overlying sediments, contribute to the source of these volcanics. Some workers have suggested almost no input from the downgoing plate, others maintain the downgoing plate is *the* major source of arc magmas, and still others have argued that the subducting plate contributes material primarily through metasomatic transport caused by dewatering of hydrous phases. A quantitative evaluation of the geochemical fluxes at convergent margins is critical to an understanding of crust-mantle interactions on a global scale. The main goals of this work are thus twofold: (1) characterizing the geochemical input (sediments and crust) from the downgoing plate, and (2) estimating the crustal output in the form of arc and back-arc volcanism on the overriding plate. Neither of these first order fluxes are well-known and both require drilling as one means of study. This program was ranked highly by WG-2 at COSOD II and has been endorsed by both the JOIDES Lithosphere and Tectonics panels.

Drilling strategy In order to evaluate the geochemical fluxes at convergent margins, drilling will be required on the downgoing plate, and in the forearc and backarc environments. Quantifying the input fluxes will require sampling of the three major components being subducted: (1) a normal, marine pelagic sequence, (2) oceanic crust, and (3) ocean-island lavas and volcanogenic sediments (in some areas off-axis flood basalts and intrusive complexes may also be important). Multiple holes will thus be required at any given arc. They should be located on older crust, comparable in age to the crust presently being subducted, adjacent to well-studied island arcs. Since a significant portion of the input from the downgoing slab may come from the uppermost crust, only moderate basement penetration (~300 m) will be necessary. There are two ways of obtaining a more complete and representative record of arc output through drilling. One approach is to drill directly into basement on the arc or in back-arc basins. An alternative strategy is to drill in the clastic aprons adjacent to the arc which should record a history of the arc's evolution. Ideally, the clastic apron drilling would be co-ordinated with deeper basement drilling on the arc itself. A transect of comparatively shallow basement holes across an arc-back-arc transition, carefully sited near one or two deep holes on the arc itself, would provide good constraints on the output flux. In the longer term, arcs in a variety of geologic and tectonic settings with different geochemical signatures should be investigated.

Technical/logistical requirements Most of the drilling described above can be accomplished using the conventional technology now employed by ODP. Basement drilling in the arc and outboard of the trench would benefit from better crustal drilling techniques and improved capabilities for drilling through chert and in volcaniclastic sediments. Basement re-entry holes will be necessary in some cases, but many of the sites can be single-bit holes. Logistical considerations (weather, proximity to good ports and other drilling targets) will be important in choosing candidate arcs since the feasibility of multiple legs over a period of several years is desirable.

Physical state and evolution of the oceanic lithosphere

Goals A knowledge of the thermal and mechanical evolution of the oceanic lithosphere, and the stresses acting on the plates, is important for an understanding of a number of fundamental problems including the subsidence history of oceanic crust, the kinematic evolution of plate boundaries (spreading centers, transforms, convergent margins), and the coupling between lithospheric and asthenospheric processes. While these problems can be approached with a variety of different techniques (satellite geoid and gravity studies, high-resolution sea floor mapping, earthquake seismicity studies, seismic reflection and refraction investigations, heat flow measurements, etc.), drilling represents a potentially valuable, and often neglected, tool. A drilling program addressing these problems could have several different components. One high priority focus for this work should be to determine the stress and deformation history of the lithosphere in the critical tectonic regimes that characterize mid-ocean ridges. A program of this type could be closely integrated with the ridge crest drilling described above, and would complement the activities of RIDGE. It was ranked a top priority by WG-4 at COSOD II.

Drilling strategy. Reliable *in situ* stress measurements can now be made in ODP boreholes using stress-induced wellbore breakouts and acoustical imaging logging tools. Determining the stress regime at a mid-ocean would involve drilling a series of holes that penetrate 100-200 m into basement located in a number of relatively closely-spaced (<1 km to tens of km) arrays or transects along and across the ridge crest.. Spreading ridge segments with contrasting opening rates (2-16 cm/yr), ridge-transform intersections, and transforms with variable slip rates and strike-slip geometries should be studied. The *in situ* stress measurements should be augmented with detailed physical property and borehole studies which would help define the kinematics of brittle crustal deformation and the physical properties of the crust. Beyond this immediate goal, other lithospheric properties can be investigated as well. One drilling objective that is technically feasible, and addresses a scientifically mature problem, is flexural moat drilling. The volcanoclastic sediments filling flexural moats adjacent to mid-plate volcanoes potentially contain a valuable record of the mechanical response of the lithosphere to volcanic loading. This information will better constrain models for the mechanics of flexure, not only for oceanic volcanoes, but in other tectonic settings such as the sedimentary basins that form along passive continental margins and in front of orogenic fold/thrust belts.

Technical/logistical requirements A program of systematic mapping of *in situ* stress in crustal boreholes can begin immediately. In many cases, the same holes drilled for studies of paleoclimate change, extinction events or crustal geochemical variability can be used for *in situ* stress measurements, provided the hole is deepened 100-200 m into basement. The ridge axis stress studies will require improvements in drilling capabilities in young crust, but they can be closely co-ordinated with other ridge crest drilling.

Mantle chemistry and dynamics

Goals Long-standing questions of mantle composition, heterogeneity and dynamics are of fundamental importance to our understanding of the differentiation of the mantle, plate driving forces, and the evolution of the ocean basins and continents through geologic time. The geochemical and isotopic composition of lavas erupted along ocean ridges, at seamounts and hot spots, and on oceanic plateaus contain unique information on the chemistry and dynamics of the mantle. Radiogenic isotope ratios and related information on parent/daughter element ratios are particularly useful for identifying different mantle reservoirs, mixing of reservoirs, and the importance of crustal recycling. Major element variations in crustal and ultramafic rocks may also be useful for inferring mantle temperatures, and, with less certainty, the major element composition of the mantle source itself.

A complementary perspective on mantle dynamics has come from recent three-dimensional seismic imaging of the mantle. These "tomographic" images of the earth's mantle are showing large regional variations in the seismic velocity of the upper and lower mantle that can be related to patterns of mantle convection. Integrating these geophysical observations with a global program of geochemical mapping holds great promise for revolutionizing our understanding of the earth's mantle over the next decade.

ODP can make two unique contributions to these studies: (1) expansion of the Global Seismic Network to include ocean-bottom seismic stations located in drill holes to substantially improve the spatial resolution of mantle tomographic studies, and (2) systematic sampling of older, sedimented crust, seamounts, oceanic plateaus and hot spot volcanoes to improve constraints on the global geochemical variability of the mantle over time scales of 10^6-10^8 yrs.

Drilling strategy To accomplish the objective of improving mantle tomographic imaging, we endorse the goal of establishing 15-20 sea floor seismic stations by the year 2000. These stations should be located in crustal holes 100-200 m deep (placing the instruments in boreholes significantly reduces noise levels), and should include both short-period and long-period, broad-band seismometers. The stations should be located in all the major ocean basins in such a fashion so as to complement the land-based stations of the Global Seismic Network. Auxiliary studies, including seismic investigations, tilt and strain measurements and electromagnetic measurements may be desirable at many of these sites.

Grid-like geochemical mapping on a global scale, as envisioned in the COSOD II document, is probably not feasible given present platform limitations (i.e. one drilling ship) and is probably not defensible scientifically. An alternative, more practical approach may be to carry out selected regional investigations, such as the sampling carried out around the Azores on DSDP 82. Another strategy is to drill transects of shallow holes, with 50-100 m of basement penetration, along a spreading flow line. Sampling of basement at seamounts, aseismic ridges, and oceanic plateaus is another approach.

Technical/logistical requirements Long-term, sea floor geophysical stations are not now technically feasible and will require advances on several fronts including: (1) a better understanding of the sources, propagation mechanisms and environmental controls on ocean floor noise in the 3 mHz- 50 Hz band, (2) determining the dependence of noise spectra on the depth of burial of the sensor below the sea floor, (3) comparing signal and noise data from sea floor stations with nearby island stations, (4) proving the operational reliability of sensors, data recording and/or telemetry schemes, power sources and timing systems for long-term (>1 year) deployments, (5) a routine wireline re-entry capability.

B. Implementation Plan

1. Needed Technological Development

Perhaps more than any other group in ODP, success in achieving the major scientific objectives of lithospheric drilling will require major new technological developments in drilling systems, logging equipment and borehole instrumentation.

Drilling In terms of drilling systems, three major problems must be overcome: (1) penetration and sampling of young, highly fractured, extrusive basalts comprising the uppermost part of Layer 2, (2) low penetration rates, short bit life, hole instability and incomplete flushing of cuttings in deeper crustal holes, and (3) low recovery rates. Solving these major engineering problems will require a commitment on the part of ODP to:

- Develop a long-term plan for improving crustal drilling technology
- Assign a senior ODP engineer (and staff) permanently to this project.
- Give this group an adequate development budget that is independent of leg-to-leg operating expenses.
- Devote ship time exclusively to testing new drilling equipment on a regular basis.
- Maintain close liaison between ODP engineers and scientists within the JOIDES panel advisory structure.

While it is impossible to predict with any confidence the pace at which this engineering development effort can proceed, we recommend that the following goals be established for the program:

By 1992: Routine drilling, with a minimum of 75% recovery, to depths of 1000 m below the basement-sediment interface

By 1996: Drilling to 2000-3000 m, well within Layer 3
By 2000: The capability of drilling through the entire crustal section to Moho

Logging and borehole instruments Improvements in logging equipment and borehole instrumentation will also be required for a successful long-tern lithospheric drilling program. Both ridge crest drilling and deep crustal boreholes are likely to encounter high temperatures, up to and possibly exceeding 400°C. These high temperatures will necessitate special temperature-resistant logging tools and borehole instruments. A collection of slim-line logging tools may also be needed since the experimental mine coring systems will probably drill a hole with a maximum diameter of only about 4". A second major need is for improved borehole sampling techniques. A reliable side-wall coring technique could significantly improve the representativeness of the material recovered from crustal holes and reduce the need for very high recovery rates when drilling. New methods of borehole fluid sampling are critical for many hydrothermal and pore-water geochemistry studies. Techniques need to be developed for sealing boreholes after drilling and logging operations are completed, with some method of access for later work, Finally, ODP needs to improve the utilization of drill holes for a variety of possible hole-to-hole experiments, sea floor experiments and long-term measurements and sampling. Of particular importance is developing methods for remote data storage and retrieval from borehole emplaced, long-term instrumentation.

Ship facilities Our highest priority objectives of deep crustal and ridge crest drilling require a vessel with at least the capabilities of the present *JOIDES Resolution*. Logistically, these objectives will involve drilling a few (~ 30 total) technically difficult, time-consuming holes in a few carefully selected and intensely studied areas. However, some of our secondary objectives (e.g. geochemical mapping, global stress measurements) involve shallow basement holes, widely distributed throughout the ocean basins that could potentially be drilled with a vessel with much more modest capabilities. Such a vessel could also re-enter holes previously drilled by *JOIDES Resolution* for logging, downhole experiments and deployment or recovery of downhole instruments.

2. Drilling Areas and Required Pre-Drilling Data

The site survey requirements and selection criteria for deep crustal drilling and ridge crest drilling have been discussed in the COSOD II and East Pacific Rise Working Group Reports. For both kinds of drilling, sites should only be selected after exhaustive site surveys. Regional bathymetric, side scan, magnetic and gravity surveys will be required to unambiguously define the tectonic setting of candidate sites. The crustal structure near drill sites should be determined using multichannel seismic reflection techniques (CDP and expanding spread profiles), OBS seismic tomography studies and medium-scale electromagnetic sounding experiments. Near ridge crests this work should be accompanied by detailed-surficial mapping and sampling to characterize the petrologic and geochemical diversity of the area, and water column geochemistry studies to define the distribution of hydrothermal vents and constrain the advective heat output from the ridge. This site survey work should begin as soon as possible to develop the necessary databases for at least 6 candidate sites for deep crustal drilling and 4 sites for ridge crest observatories so that site selection can proceed in a timely fashion. In addition, pilot experiments should be carried out at selected boreholes (e.g. near Hawaii), to begin to address the technical issues related to the establishment of sea floor seismic observatories and global stress mapping.

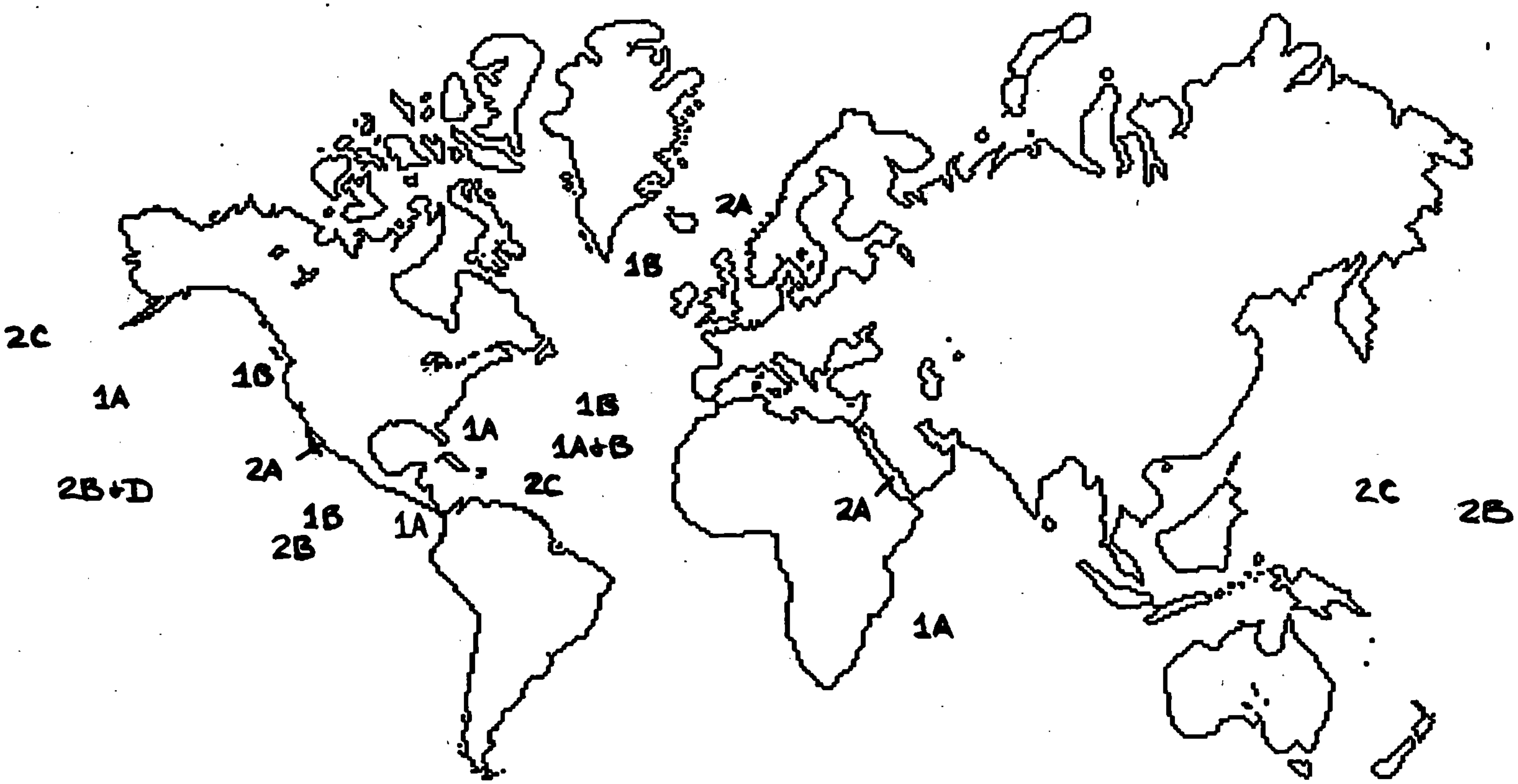
The accompanying map indicates the regions that are likely targets for future lithospheric drilling. As noted above, there is an obvious division between those objectives that require drilling a few technically difficult, time-consuming holes at a few carefully selected sites, and others that involve a relatively large number of shallow holes spaced widely across most of the major ocean basins. The most likely areas for drilling deep crustal holes, given the criteria discussed above, are in the central and western North Atlantic, in the eastern Pacific (Hole 504B), or in the north-central Pacific. Potential sites for a deep crustal hole proximal to a large-offset fracture zone include the Atlantis II fracture zone on the Southwest Indian Ridge, the Oceanographer or Kane fracture zones in the central North Atlantic, or one of the large equatorial Atlantic fracture zones. Likely locations for the ridge crest "natural laboratories" include the East Pacific Rise between 9°N and 13°N, the Juan de Fuca/Gorda Ridge system, the MARK/TAG area in the central North Atlantic, and possibly the Reykjanes and Southwest Indian Ridges, or the Guaymas Basin in the Gulf of California.. Other second priority lithospheric drilling targets exist in all the major ocean basins, although most are concentrated in the Atlantic and Pacific Oceans. None are located at high latitudes.

Finally, it is important to note that all of the highest priority lithospheric drilling requires multiple legs at individual sites or in the same area. Thus it is **critical** that the drillship be scheduled so that it can reoccupy drill sites at intervals of 9-12 months. All of these considerations suggest that the circumnavigation philosophy that has driven the first eight years of ODP planning is **not** the optimal strategy for lithospheric drilling. Instead, we would favor a plan in which ship scheduling is driven not by regional political interests, but by the longer-term thematic drilling objectives outlined above.

3. Implementation plans at different levels of effort

Addressing the major lithospheric objectives outlined above during the coming decade will require a focussed, interdisciplinary drilling effort with the following major goals:

- By 1996 drill three holes 2000-3000 m into the oceanic crust, with the prospect of extending one of these holes to Moho by the year 2000. One of these holes should be located on thin crust (e.g. proximal to a fracture zone), the others on



Likely Targets for Future Lithospheric Drilling

1A - Deep crustal drilling; 1B - Ridge crest drilling; 2A - Young oceanic rifts;
2B - Intraplate volcanism; 2C - Convergent margins; 2D - Lithosphere stress/flexure;
Global distribution: sea floor seismic stations; mantle geochemical mapping

crust formed at fast and slow spreading ridges

- Drill arrays of shallow (~300 m) and intermediate (1-1.5 km) depth holes in several locations along the mid-ocean ridge system, including fast, slow and sedimented ridge crests. One of these areas should be permanently instrumented to establish a sea floor "volcano observatory" by the year 2000.

- Complete select lithospheric "case studies" (5 over a 10-year period) of well-documented, representative features addressing magmatic and dynamic processes associated with intraplate volcanism, plate convergence and mantle evolution and heterogeneity.

- Establish a global network of sea floor geophysical stations throughout the major ocean basins in 100-200 m deep crustal holes equipped with short and long-period, broad-band seismometers and other appropriate long-term geophysical instrumentation.

The following implementation plan gives a rough estimate of the activities and level of effort that might be required to achieve these lithospheric drilling objectives in coming decade:

Phase 1 (1989-1992)

- Establish detailed planning groups (DPGs) on "Drilling Deep Crust", "Ridge Crest Drilling", "Sea Floor Observatories", and others as appropriate
- Develop a long-term engineering development plan to improve crustal drilling technology, including cost estimates, manpower needs, and test-leg requirements
- Begin site survey work for at least 6 candidate sites for deep crustal drilling, 4 sites for ridge crest drilling, and 5-10 sea floor geophysical stations
- Complete 2 legs of deep crustal drilling at Hole 504B, or at another suitable deep crustal drill site
- Complete 4 legs of drilling on sedimented and unsedimented ridge crests of the eastern Pacific
- Complete one lithospheric "case study" on the nature of hot spot volcanism by drilling Loihi (one leg)
- Carry out recommended pilot experiments for the establishment of a sea floor seismic station, probably at a site near Hawaii

Phase 2 (1993-1996)

- Complete site survey work for deep crustal holes, ridge crest drilling and sea floor geophysical stations
- Complete three holes 2000-3000 m into the crust, including one hole in thin crust (1 leg/yr for four years)
- Begin first phase of Mid-Atlantic Ridge drilling; complete second phase of EPR

program (1 leg/yr for four years)
- Establish 5 sea floor geophysical stations and carry out two lithospheric "case studies" (e.g. drilling a near-axis seamount and a back-arc spreading center) (1 leg/yr for four years)

Phase 3 (1997-2000)
- Extend one crustal hole to Moho (6 legs/yr over four years)
- Complete second phase of MAR drilling (2 legs)
- Establish a sea floor volcano observatory (in conjunction with RIDGE) on a volcanically active part of the mid-ocean ridge system (1 leg/yr for four years)
- Complete global network of sea floor seismic stations; carry out two lithospheric "case studies" (e.g. a regional geochemical mapping program and an *in situ* stress experiment along an accretionary plate boundary) (1 leg/yr for four years)

In this scenario, approximately 3 legs of drilling would be required per year over the next decade to complete the four long-term drilling goals outlined above (the equivalent of about 1 leg/yr for deep crustal drilling; 1 leg/yr for ridge crest drilling; and 1 leg/yr for establishing sea floor geophysical stations and carrying out selected lithospheric "case studies"). However, LITHP's interest in sea floor seismic stations and *in situ* stress measurements clearly overlap that of TECP, and at least some other lithospheric drilling could be carried out in conjunction with the programs of other thematic panels. Thus the amount of <u>dedicated</u> LITHP drilling required to achieve these four goals is probably about 2 1/2 legs per year over ten years.

The optimal situation for carrying out this program would the case in which a second drilling platform is available to carry out drilling (e.g. hydraulic piston coring, shallow basement penetration) that does not require the advanced capabilities of the *JOIDES Resolution*. This would probably require a substantial (~50%) increase in the level of funding for ODP, but would make it possible to drill the technically difficult, time-consuming deep crustal holes that are the highest priority of the lithospheric community without compromising other drilling programs, including some with lithospheric objectives, that require a large number of shallow holes distributed throughout the major ocean basins.

With a 10% increase in funding for ODP, a second drilling platform would not be feasible and a compromise will have to struck in long-term planning between drilling that involves a few time-consuming holes and other programs that require more global coverage. If a substantial portion of the 10% budget increase is devoted to engineering development, then the deep crustal and ridge crest drilling programs should still be feasible.

With a steady-state effort, and only inflationary increases in the ODP budget, it might be difficult to mount the major engineering development effort needed to improve crustal drilling techniques. If this occurred, even the two highest priority lithospheric drilling objectives might not be achievable by the end of the next decade. However, even with level funding a more thematically-focussed, problem-oriented drilling program could make more progress in achieving long-term lithospheric drilling objectives than has been the case so far during the first phase of ODP.

V. Relationship between ODP and other Global Initiatives

The goals of the lithospheric drilling program outlined above are compatible with a number of international research initiatives that are in progress, or are planned. Our proposals for deep crustal drilling and ridge crest drilling are closely linked with RIDGE (Ridge InterDisciplinary Global Experiments), a major new global initiative which has the unifying goal of understanding the physical, chemical and geological processes involved in the formation of oceanic crust. Drilling is an important component of RIDGE plans for the establishment of one or more sea floor volcano observatories by the end of the next decade. Our proposal to establish 20 sea floor seismometer stations in boreholes would expand efforts already underway to establish a Global Digital Seismographic Network. The plans for global stress mapping would enhance an ongoing project to create a world stress map that is being compiled under the auspices of the Inter-Union Commission of the Lithosphere. Finally, our proposals to drill on seamounts and young hot spot volcanoes complement a proposal to DOSECC for a deep drill hole on Hawaii.