THEMATIC OBJECTIVES IN THE WESTERN PACIFIC
JOIDES Tectonics Panel
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At our February 1986 meeting, we recommended that drilling in the western Pacific be focused on three tectonic problems: the origin and evolution of island arcs; the nature of active collisions; and the development of back-arc basins. Of the myriad attractive tectonic problems that could be studied in this region, we selected these three because they meet the following criteria. First, they are clearly issues of global thematic importance. Second, we feel that the western Pacific is the best place in the world to address these particular issues. Finally, we feel that drilling alone can answer specific questions related to these tectonic problems.

The following remarks, presented from our global perspective as a thematic panel, summarize our reasons for advocating these objectives.

I. The Rationale for Island Arc Drilling in the Western Pacific

The origin and evolution of magma within the earth stand squarely at the heart of deciphering the evolution of Earth itself. Of all magmatic provinces, island arcs offer the best possible natural laboratory within which to decipher the physical and chemical evolution of magma. Unlike all other areas, the greatest depth of magma formation is limited to be at or above the subducting plate. Moreover, the source material is either normal mantle peridotite or subducted oceanic crust or mixtures thereof, and the thermal regime of the entire region is reflected in the heat transfer of magmatism itself. In addition, the timing of the events of subduction, incipient volcanism, volcanic-center migration, and magmatic flux provides truly fundamental constraints on the mechanics of separation and ascension of magma. Purely geochemical studies in the way of phase equilibria, bulk chemical composition, and isotopic signatures can only be understood when properly viewed through the context of the mechanics of magmatism. Island arcs offer our only hope of clearly understanding large scale magmatic processes. The arcs that are best suited to unravel such problems and that are accessible to drilling are in the western Pacific.

A detailed accounting through time of the mass and composition of all materials associated with arc evolution (magmatic flux, volatile flux, hydrothermal fluids in the forearc, and flux of downgoing oceanic crust and sediment) and also of the isostatic response of arcs on a regional basis provides the fundamental boundary conditions governing all arc processes. The most critical element of such a menu is time. Although old arcs span much time, their heavy blanket of sediments, pyroclastics, and lavas greatly obscures sampling this history. Arcs must be studied early in their evolution to answer most all of the important themes at issue.

Arcs of the critical age for analysis are Izu-Bonin, Mariana, Scotia, and Tonga-Kermadec. Accessibility and operating conditions essentially preclude Scotia, especially when considered in light of land-based follow-up studies. The overall Mariana-Bonin arc system is ideally suited to tackle nearly all of the essential problems, and Tonga covers what is left. Possibly only in studying the correlation between arc magma composition and downgoing plate composition does another arc, the Aleutians, offer a better perspective. What follows is a list of the principal thematic issues with a few words highlighting, where necessary, their importance and position within more global issues.

Themes in arcs and forearc regions

1) Arc evolution (structural, volcanic), beginning, timing, periodicity, magma transport
   - Allows entire problem of magma production, mechanics of ascension, and wall rock chemical interaction to be assessed, and allows quantitative evolution of intimate coupling of downgoing plate and arc plate (i.e. segmentation, fracture zones, etc.).

2) Nature of arc igneous/metamorphic basement
   - Are granodioritic plutons also characteristic of incipient volcanic fronts? Is the broad submarine arc ridge or welt of MORB type material produced during the initial breakoff and plumage of the lithosphere, or is it arc magma? What thermal regime is reflected in the metamorphic grade of these rocks?

3) Thermal regimes (isostatic response)

   - The very major question of the deep thermal regime of subduction and magmatism can be largely answered by knowing the thermal regime of the forearc, and this couples with the visco-mechanical isostatic regime which further constrains the nature of the arc lithosphere.

4) Fluids, their budget and chemistry

   - Do fluids from dehydration of the downgoing plate travel back up the oceanic crust and erupt in the forearc, carrying base metals stripped from the oceanic crust at high pressure? Are these the fluids that form forearc ore deposits?

5) Intra-arc structure (rotations, etc.)

   - What are the timing and mechanics of major structural readjustments with the arc itself? Are these driven by regional or local forces?

6) Forearc dynamics, seamount offscraping, "cold volcanoes" (i.e. diapirs)

   - Are cold forearc volcanoes a principal means of transporting and redistributing debris from the top side of the downgoing plate? What is the thermal-rheological regime associated with these features; what are the deformation rates; is the process selective of material type?

7) Boninites, relationship to ophiolites

   - Are ophiolites sections shaved off in forearcs? Are boninites continually produced in the forearc region, or only early in arc development? Is there a progression from boninites to more typical arc magmas?

8) Relations of arc chemistry to plate chemistry

- Are regional variations in downgoing plate (oceanic crust ± sediment) chemical composition reflected in the composition of the lavas of the volcanic front?

9) Isostatic response of lithosphere to loading at different stages of arc/backarc evolution

- How thick is the arc lithosphere? Does it thin or thicken with time? Can the rates of isostatic adjustments of volcanic centers and arc crustal blocks be measured through sedimentation history and then be inverted to learn of lithosphere evolution?

II. The Rationale for Drilling along Collisional Plate Margins in the Western Pacific

A growing body of geologic data indicates that mountain systems along continental margins are composed of discrete fault-bounded, crustal fragments, commonly referred to as tectonostratigraphic terranes. These terranes may represent dislodged and repositioned pieces of the local continental margin, or they may be truly exotic fragments such as volcanic arcs, seamounts, and even slivers of distant continental margins. The accreted terranes are commonly surrounded by and immersed in a sedimentary melange, but deeper crustal exposures demonstrate discrete tectonic contacts between the crystalline bodies. Several lines of evidence can be interpreted to show that continents are growing at a rate of ca. 1 km^3/yr while continental accretion on a global scale is expanding continental margins at a rate of ca. 2.5 km^3/yr. The 1 km^3/yr of new growth represents the addition of first-cycle volcanic island arcs and seamounts while the remaining 1.5 km^3/yr constitutes the accretion of recycled continental debris (graywacke) and pelagic carbonate and chert.

The best area to study the processes of collision is in the western Pacific where young arcs with thin sediment carapaces are now colliding with a diverse array of oceanic features. Nowhere else are collision processes so clearly shown and so unobstructed by complicated tectonic relations or thick sediment cover. For geologists to understand continental growth and the dynamics within tectonic collages such as the Cordillera, Caledonides, and the collapsed Tethyan margin (to name but a few), it is critical to investigate a variety of accretionary settings in the western Pacific.

A complicated array of collision styles is exemplified in the western Pacific: (1) Ocean crust colliding with volcanic arcs (thin sediment cover as in Tonga, thick sediment cover as in New Zealand and Japan, and even active ridges as part of the ocean crust as in the Woodlark ridge/Solomon arc system); (2) Continent or continental fragments colliding with volcanic arcs (Palawan with Philippine archipelago, Australia with Timor); and (3) Ocean crust colliding with ocean crust (intraplate shortening as inferred for the Mussau and Zenisu ridges).

Attendant with these varying collision styles are a number of boundary conditions that are equally variable; (1) The angle of collision (perpendicular, oblique to almost parallel, e.g., on the southside of the Aleutians, the angle of collision covers the whole spectrum along strike, whereas, the

New Hebrides arc shows principally orthogonal collisions, and the Tonga arc is affected largely by oblique subduction/collision); (2) The oceanic crust involved in the collision may be either old or young. (Off of Japan, Kuriles, and Tonga, the crust is old while along the south side of the Solomon arc, the crust is young.); (3) The shape of the so-called indentor may vary from linear (Louisville ridge) to broad and equant (Ontong Java) to a single seamount (Erimo); and (4) The crustal thickness of the indentor may be thin or thick (Loyalty ridge contrasted with Ontong Java). And finally, the stages of collision vary from incipient obduction such as Okushiri ridge to the opposite extreme where dispersion and crustal fragmentation prevail such as in the Banda Sea.

Understanding the kinematics and dynamics of these collisional processes will require a wide range of disciplines and research strategies. Nonetheless, ODP drilling is an appropriate tool to investigate a number of critical aspects of the collision process. Drilling:

1. Establishes whether or not parts of the colliding mass are accreted
2. Provides constraints on the timing of collision event(s)
3. Opens windows to appraise changes in physical properties and amounts of strain associated with a collision event
4. May reveal large-scale deformational features such as thrust faults
5. Makes it possible to observe varying stages of diagenesis or metamorphism related to collisions
6. Permits an opportunity to relate vertical tectonic responses to a collision event

From the multitude of possibilities to study collision phenomena in the western Pacific, we have selected four sites where we believe the prospects of good holes are combined with a range of targets covering many of the styles and boundary conditions discussed above. Our recommendations are:

1. D'ENTRECASTREAUX COLLIDING HEAD-ON WITH THE NEW HEBRIDES ARC
2. LOUISVILLE RIDGE SLIDING ALONG AND IMPINGING ON THE TONGA ARC
3. THE EFFECTS OF ONTONG JAVA AMALGAMATING WITH SOLOMON ARC
4. OKUSHIRI RIDGE OBDUCTING ONTO JAPAN

III. The Rationale for Drilling in Western Pacific Back-arc Basins

The global thematic issue that might profitably be addressed by drilling in back arc basins is lithospheric extension. Like continental rift zones and passive continental margins, back-arc basins originate through lithospheric extensional processes. An immediately obvious question is whether the extension of island arc lithosphere (ultimately to form a back-arc basin) differs significantly from extension of continental lithosphere (which may lead ultimately to normal seafloor spreading). ODP has drilled, or will drill, holes at a number of passive continental margins (New Jersey, Galicia, Norway, Exmouth Plateau) to focus on lithospheric extension problems, so it seems that extension of arc lithosphere is a novel problem that can be addressed by drilling in back-arc basins of the Western Pacific.

The whole issue of lithospheric extension has been revitalized recently, with the recognition by Wernicke and other structural geologists that large scale extension in the Basin-and-Range province is mainly accommodated by normal slip on low-angle detachment surfaces rather than by wholesale stretching and thinning of the lithosphere, a concept popularized by McKenzie. We now have two schools of thought with their proponents: Lithospheric extension via a simple shear (detachment) mechanism, and extension via pure shear (stretching and thinning). The most important difference between the two concepts is that the location of maximum thinning of the mantle is laterally offset from the location of maximum crustal thinning in the detachment model. A likely result is the development of asymmetric patterns of structure, sedimentation, heat flow, and gravity anomalies over the extended lithosphere that would be difficult to explain using a stretching and thinning model unless special conditions are assumed.

The Western Pacific provides a wealth of opportunity for studying extension of arc lithosphere with ODP drilling. Drilling establishes boundary conditions (timing, kinematics, temperatures) that are essential for developing or testing models of extension. Best results are likely in the simplest tectonic situations. For this reason we advocate drilling extensional domains in demonstrably intra-oceanic arcs. We are therefore limited to the following locations:

1) Bonin arc
2) Coriolis trough
} active island arc rift zones

3) Lau basin
4) Mariana trough
} Rifted arc fragments with active back-arc spreading

To be properly effective, ODP drilling must be preceded, or accompanied by thorough deeply-penetrating MCS surveys in order to examine whether master detachment surfaces are present in these extensional domains. Gravity, heatflow, and SeaBeam/Seamarc surveys may also be required to properly locate drill sites.

The detachment model also predicts surface, or near surface exposure of deep-seated rocks, which is consistent with the recovery of metavolcanic rocks and gabbros in the Mariana trough, and upper amphibolite grade mafic mylonite from the Sorol Trough (east of Yap Island). Thus if extension of arc lithosphere occurs by slip on detachment surfaces, a window into the plutonic foundation of island arcs may be available for drilling without requiring large amounts of penetration.