LEG 185

CRUSTAL FLUXES AND MASS BALANCES AT THE MARIANA-IZU CONVERGENT MARGIN

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ABSTRACT

During Leg 185 two deep-water sites will be drilled, one seaward of the Mariana Trench (Ocean Drilling Program Hole 801C) and one seaward of the Izu-Bonin Trench (Site BON-8A). The primary objectives are to investigate sediment subduction along this arc-trench system and to characterize the chemical fluxes during alteration of the oceanic crust. Despite the simple setting and shared subducting plate, there are still clear geochemical differences between the Marianas and Izu volcanic arc systems. Drilling the crustal inputs (sediments and basalts) can help test whether geochemical contrasts in the volcanics derive from contrasts in the crustal inputs to the two trenches. Previous drilling has already provided sections through the sedimentary layer approaching the Mariana Trench. Drilling during Leg 185 will provide samples of the remaining input fluxes to the subduction zones: the upper 300-500 m of altered basaltic crust at Hole 801C, and the sediments (500-600 m) and upper 300-400 m of basaltic crust at Site BON-8A. With Hole 801C, the science party will also provide the first reference site for the structure and composition of old Pacific (Jurassic), fast-spreading oceanic crust to compare with other crustal end-members (e.g., young-slow, young-fast, and old-slow). One outcome of Leg 185 will be the best existing mass balance of input and output fluxes for several key tracers (H_2O, CO_2, U, and Pb) cycled through the subduction factory.

INTRODUCTION

The State of Crust-Mantle Recycling Science

Subduction zones are the modern sites of continental crust formation and destruction. Continental growth occurs today by accretion of island arcs and magmatic additions to the crust at arcs. Crustal destruction occurs by subduction of crustal material (seawater components, marine sediments, and basaltic crust) at oceanic trenches. Thus, the geochemical and physical evolution of the Earth's crust and mantle depends in large part on the fate of subducted material at convergent margins (Armstrong, 1968; Karig and Kay, 1981). The crustal material on the downgoing plate is recycled to various levels in the subduction zone. Some of it returns to the shallow crust during forearc accretion and dewatering, some returns to the arc crust via volcanism, some is mixed back into the deep mantle, and some may even re-emerge in mantle plumes. Despite strong evidence for these different types of crustal recycling (from seismic imaging, drilling, and isotopic tracers), and despite the important ramifications for mantle evolution, continent formation, and geochemical cycles, few studies have focused on quantifying crustal fluxes through subduction zones.

Von Huene and Scholl (1991) calculated a large global flux of subducted sediment—as high as modern crustal growth rates. Their calculations, however, represent an upper limit on sediment fluxes into the mantle because some material is cycled back to the upper plate. It is a common misconception that the sediment contribution to the volcanic arc is trivial (around 1%), based on isotopic mixing arguments, which constrain only the proportion of sediment to mantle and not the proportion of the total subducting budget that contributes to the arc. To calculate the latter, estimates of input fluxes (sediment) and output fluxes (volcanic) are required. Earlier flux balances by Karig and Kay (1981) for the Marianas suggested that 10% of the sedimentary section contributes elements to the arc, whereas more recent calculations (Plank and Langmuir, 1993; Zheng et al., 1994) give values of 30%-50% globally.

These estimates, however, have large uncertainties because none of them take into account all of the crustal outputs. Plank and Langmuir (1993) do not consider underplating or erosion at the forearc; von Huene and Scholl (1991) do not consider recycling to the arc, and neither study considers the mobile components dissolved in fluids that are lost to the forearc. It is entirely possible that the 50%-70% recycling efficiency to the deep mantle suggested by Plank and Langmuir (1993) could be reduced to 0% for many important element tracers, given the other shallower outputs that have yet to be taken into account. Clearly, the difference between 70% and 0% recycling would lead to vastly different outcomes for mantle evolution and structure.

The Role of Drilling

The recycling equation involves many variables—aging of the oceanic lithosphere, flow of material through accretionary prisms, and fluid circulation at active margins—that are linked across a convergent margin and can be explored in combination through a drilling transect (Fig. 1; Scholl et al., 1996). The incoming section of sediment and altered oceanic crust can be drilled near trenches. The extent of sediment accretion, underplating, erosion and subduction can be determined by combining forearc drilling with seismic reflection images and material balance considerations. The fluids lost from the downgoing plate can be sampled by drilling into fault zones and serpentine seamounts. Output to the arc can be determined from the chemical composition of the volcanics and from arc growth rates. The flux of crustal material that is eventually recycled to the mantle is then the input minus the output. Because the bulk sediment is not conserved through the entire subduction process, chemical tracers must be used to track the sediment and deduce the recycling processes. Thus, the problem is impossible to solve by remote means and is completely dependent on drilling to recover material for chemical analysis.

Determination of crustal fluxes into the mantle is not yet possible. This is largely because the current approach is a piecemeal one, with various parts of the problem investigated at different margins. Although this is a good way to understand individual processes, it is not a good way to determine the behavior of the entire system. The approach that we emphasize here is to try to solve the recycling equation at a few margins where significant progress can be made on most fronts by a focused drilling effort.

BACKGROUND

Crustal Recycling at the Izu-Mariana Margin

There are several reasons why the Marianas-Izu margin is ideal for studying subduction recycling (Fig. 2). Significant progress has already been made on many parts of the flux equation. Forearc sites of fluid outflow (serpentine seamounts) have already been drilled (Leg 125; Fryer, 1992), as have most of the sedimentary components being subducted at the Mariana trench (Leg 129; Lancelot and Larson, 1990). The volcanic arcs and backarcs are among the best characterized of intraoceanic convergent margins, both in space and time (Legs 125 and 126; Gill et al., 1994; Arculus et al., 1995; Elliott, et al., 1997; Ikeda and Yuasa, 1989; Stern et al., 1990; Tatsumi et al., 1992; Woodhead and Fraser, 1985). And here the problem is simplified because the upper crust is oceanic, so upper crustal contamination is minimized. Sediment accretion in the forearc is nonexistent (Taylor, 1992), so sediment subduction is complete. Despite the simple oceanic setting and the shared plate margin, there are still clear geochemical differences between the Mariana and Izu arcs (e.g., in Pb isotopes and in elemental enrichments; Figs. 3a and 3b). The divergence of compositions between the volcanics of these two oceanic arcs provides the simplest test for how the composition of the subducting crust affects them. The key missing information is the composition of the incoming crustal sections, particularly the (altered) basement sections.

Exisiting Crustal Inventory at the Izu-Mariana Margin

Of the eight holes drilled in the seafloor immediately east of the Izu-Bonin Trench (not including the Shatsky Rise sites), only one penetrated basement, Site 197 (Fig. 2). No sediments, however, and only 1 m of basalt were recovered. Recovery was poor at most of the other sites: less than 25 m of sediment was recovered at all sites drilled during Leg 20 (Sites 194-198); the recovered material being dominantly pelagic clays above resistant cherts. Although more was recovered at Sites 52 (45 m) and 578 (165 m), drilling again was stopped by the cherts, leaving hundreds of meters of unsampled sediment below. Prior drilling has provided us with many samples of the upper 50- to 150-m pelagic clay and ash unit, but almost nothing of the units below, including the oceanic crust.

- *The main goal of Izu-Bonin drilling is to sample all sedimentary units and the upper alteration zone (~ 300 m) of the oceanic crust below.*

The success rate in coring sediments and basement to the south, seaward of the Marianas, was just about as poor as that experienced to the north, until Leg 129, when three complete sections (Ocean Drilling Program [ODP] Sites 800-802) were sampled through the cherts to "basement." Sedimentary units were well sampled during Leg 129, but normal oceanic crust was sampled at only one site, Hole 801C. At the other two sites, off-axis Cretaceous sills and flows were encountered as "basement." The crustal inventory at the Marianas Trench includes (from top to bottom): pelagic clay, chert, and radiolarite (± chalk), Cretaceous volcaniclastic turbidites, radiolarite, off-axis Cretaceous intrusives and extrusives, and Jurassic oceanic crust. Based on Leg 129 drilling and prior Deep Sea Drilling Project (DSDP) efforts, we have adequate samples of the sedimentary units being subducted at the Mariana Trench (providing estimates of chemical fluxes with better than 30% precision for most elements [Plank and Langmuir, in press]). However, our only sample of Jurassic oceanic crust, which must comprise the largest mass of crustal material being subducted at the Mariana Trench, comes from the lowest 63 m at Hole 801C (of the ~135 m total penetration into basement at Holes 801B and C, only the lower 63 m of drilling recovered 43 m of normal, Jurassic tholeiitic oceanic crust).

- *Thus the main goal of Mariana drilling is to provide a more complete sampling of the upper alteration zones in the Jurassic seafloor, which constitutes a significant part of the budget for many geochemical tracers of the subduction process.*

Exisiting Crustal Mass Balance for the Marianas

With information in hand, it is possible to calculate many of the input and output fluxes for a few chemical components through the Marianas subduction zone. We consider here a preliminary flux balance for H_2O (Fig. 4). The sediment input is fairly well constrained by previous drilling during Leg 129 (Sites 800-802), and by the extensive chemical analyses of the recovered material (Karl et al., 1992; Karpoff, 1992; Lees et al., 1992; France-Lanord et al., 1992) as well as the geochemical logs for the different holes (Pratson et al., 1992; Fisher et al., 1992). As a result, H_2O flux estimates for sediments from Sites 800 and 801 are quite consistent with one another (within 15%). The other crustal input flux is the subducting oceanic crust, which is very poorly constrained because of a lack of significant penetration into the mid-ocean ridge (MOR) basement in this area (63 m at Hole 801C). The geochemical budget of elements in the oceanic crust has two sources: primary igneous and secondary alteration. The primary igneous composition is fairly well constrained, based on extensive sampling of modern mid-ocean ridge basalt (MORB) and on the relatively unaltered samples recovered from Hole 801C. The secondary alteration fluxes are virtually unknown, however, and can only be estimated from various other regions, compilations, and assumptions: the average global H_2O flux in Peacock (1990), alteration studies of DSDP Hole 504B (Alt et al., 1986) and DSDP Sites 417/418 (Staudigel et al., 1995), and assuming 10% interpillow material at Hole 801C (Castillo et al., 1992b). These estimates show that the alteration fluxes may be large, but are poorly known. The applicability of existing data (obtained for slow-spreading old crust at Sites 417 and 418 and medium-spreading young crust at Hole 504B) to the crust seaward of the Marianas Trench (old-fast spreading) remains to be seen and is, in fact, a major goal of Leg 185.

Unique to the seafloor seaward of the Marianas Trench is an overprint of Cretaceous basement flows and sills. There are two sources of uncertainty in estimating this flux: the thickness of the Cretaceous "basement" layer and its chemical composition. Calculations based on sonobuoy velocities, reflection data, and drilling results from Leg 129 indicate a 100- to 400-m-thick layer of massive Cretaceous basalt, and possibly some interbedded sediments, overlying Jurassic oceanic crust (Abrams et al., 1993). Although this is not the case for water, the total flux of many elements depends critically on whether this Cretaceous basalt is alkalic (as for Site 800 basalts and various seamounts of the Pigafetta Basin [PB]) or tholeiitic (as for Site 802 basalts of the East Mariana Basin [EMB]). Although plate trajectories (Fig. 2) indicate that the seafloor subducting beneath the Marianas is largely the tholeiitic EMB, we consider both EMB (tholeiitic) and PB (alkalic) type basalts in estimating the water flux into the subduction zone (Fig. 4). Both estimates yield small water input fluxes relative to the sediment and altered Jurassic MORB.

The first measurable outputs from the subduction zone are the forearc fluids, which have shown to be freshened and from a subducted source (Mottl, 1992). It is currently difficult to estimate rates based on the fluid flow itself, and we therefore use a model based on the total (maximum) water generated during clay mineral breakdown in the subducted sediments (Plank et al., 1994). This calculation is model dependent, but further study of the nature of these fluids will help to identify the actual dehydration reactions that are occurring with depth during subduction. Figure 4 shows that the water outputs to the forearc may be a significant fraction of the sediment input. Magmatic outputs to the volcanic arc and backarc are determined from the chemical composition of arc and backarc basalts (assuming 5.7 and 1.25 wt% H_2O above MORB background, respectively; Stolper and Newman, 1994) and from magmatic addition rates. The magmatic arc water flux is the largest of the crustal outputs from the subduction zone.

These preliminary calculations provide some initial insights into the flux balance in subduction zones and reveal where the major uncertainties lie. If we ignore the igneous MORB and Cretaceous basalt contributions as no net gain from the mantle perspective, then the continental water inputs and outputs appear to be remarkably closely balanced across the subduction zone. The balance hinges critically, however, on the magnitude of the basement alteration fluxes. Current estimates are poor, and the actual flux balance could still go either way. Drilling through the upper oceanic crust subducting beneath the Marianas, however, can dramatically improve one key flux in the mass balance equation—the alteration flux.

Exisiting Crustal Mass Balance for Izu-Bonin

Because we have yet to sample either the sediments or altered oceanic crust seaward of the Izu Trench to any significant extent, we are much more limited in our ability to determine the mass balance. However, we can make some predictions about the crustal inputs to the Izu Trench based on the Izu volcanic output. Izu basalts record almost half the K or Ba enrichment of Marianas basalts (Fig. 3b), whereas sediment mass fluxes into the two trenches are roughly comparable, or even greater, at Izu (600 m of sediment into Izu vs. 400 m into the Marianas Trench). Thus, Izu sediments should be much poorer in K and Ba than Marianas sediments. One way to explain this would be to replace the volcaniclastic sections in the Marianas sediment columns with cherts, which are barren of K and may be very poor in Ba (Karl et al., 1992). This makes some sense given what we know about the history of sedimentation in this part of the ocean—the Cretaceous overprint east of the Marianas may be absent to the north, east of Izu (Fig. 2), where the seafloor spent a longer time on average beneath equatorial zones of high biologic productivity (Fig. 5), possibly leading to greater sections of chert and/or carbonates. Drilling the seafloor east of Izu can directly test these predictions. Sediment layers are fairly uniform throughout the region, reflecting fairly uniform pelagic sedimentation. Thus, a single hole should give us a fairly representative sampling of sediments being subducted at the Izu trench. If the extra thickness of sediments off Izu is not dominantly barren cherts, this means that much of this sediment does not contribute to arc magmas, either because it is underplated (we can see that it is not accreted), or because it fails to dewater or melt beneath the arc. Thus, by drilling and sampling the crustal inputs, we can learn more about the process of sediment subduction and recycling.

The geochemical differences between the Mariana and Izu arc volcanics could also be related to the chemical composition of the altered oceanic crust. K or water contents in the altered basaltic sections may vary regionally, possibly explaining regional variations in K and the extent of melting reflected in Marianas and Izu lavas. This can be tested by drilling the upper oxidative alteration zone, which contains most of the alkali budget in the oceanic crust, in both regions.

Finally, some of the differences between the Izu and Marianas lavas may have nothing to do with subducted input and may be explained by more enriched mantle beneath the Marianas. Evidence for enriched mantle in the region comes from enriched shoshonites of the adjacent Volcano arc (Bloomer et al., 1989; Lin et al., 1989). Although drilling cannot test whether enriched mantle exists beneath the Marianas, it can make invoking it unnecessary.

SCIENTIFIC OBJECTIVES

Previous drilling has already provided us with many parts of the crustal flux equation at the Izu and Marianas margins and provides a strong rationale for continuing the effort to detemine the mass balance fluxes across the subduction zones. The missing part of the flux equation is largely the input: (1) both the incoming sediment and basaltic sections approaching the Izu-Bonin Trench and (2) the altered oceanic crust seaward of the Mariana Trench. To provide this critical information on the crustal inputs to the subduction zone, drilling is planned at two sites: one seaward of the Izu Trench (Site BON-8A) and one seaward of the Marianas Trench (ODP Hole 801C).

Site BON-8A

The primary motivation for Site BON-8A, a site ~60 km seaward of the Izu Trench (Fig. 2), is to provide the first complete section of sediment and altered oceanic crust entering this subduction zone. Previous drilling failed to penetrate successfully through resistant cherts, so most of the sediment column is unsampled. Only 1 m of basalt has been recovered from basement in this vast area. We propose to drill and core the entire sedimentary sequence (~600 m) at Site BON-8A, as well as the upper oxidative alteration zone of the basaltic basement (~300 m). The scientific objectives are to

1. provide estimates of the sediment inputs and altered basalt inputs (geochemical fluxes) into the Izu subduction zone;
2. contrast crustal budgets here with those for the Marianas, to test whether along-strike differences in the volcanics can be explained by along-strike variations in the crustal inputs;
3. compare basement alteration characteristics with those at Hole 801C (also in old Pacific crust);
4. provide constraints on the Early Cretaceous paleomagnetic time scale; and
5. provide constraints on mid-Cretaceous carbonate compensation depth (CCD) and equatorial circulation fluctuations.

In addition to serving as an important reference site for crustal inputs to the Izu-Bonin Trench, Site BON-8A can also address additional paleomagnetic and paleoceanographic problems. Because the subduction cycling objectives have already been discussed in some detail above ("Background" section), we elaborate more below on the paleomagnetic and paleoceanographic objectives.

Site BON-8A is approximately on magnetic Anomaly M12 (Nakanishi et al., 1988). Its basement age should be about 135 Ma and should correspond to the Valanginian Stage of the Early Cretaceous according to recent time scale calibrations (Harland et al., 1990; Gradstein et al., 1994; Channell et al., 1995). However, those age estimates are poorly known and can be tested by drilling at Site BON-8A. Specifically, a reasonably precise date on M12 at Site BON-8A could test the proposed new time scale of Channell et al. (1995).

Based on its theoretical Cretaceous paleolatitude history, Site BON-8A may have formed at about 5°S, drifted south to 10°S in its early history, and then gradually drifted north, crossing the paleoequator as the Pacific Plate accelerated its northward motion about 85-90 Ma (Fig. 5). A site such as Site BON-8A with an Early Cretaceous basement age (~135 Ma), an equatorial paleolatitude history during the mid-Cretaceous, and a predictable subsidence history for the Cretaceous is ideal for testing proposed CCD variations (Theirstein, 1979; Arthur et al., 1985). In addition, Erba (1992), following Roth (1981), has shown that certain species of nannoplankton can be characterized as "high fertility indices" and used as approximate indicators of the paleoequatorial upwelling zone. Using these nannoflora, potential fluctuations in the mid-Cretaceous equatorial circulation system could be studied at Site BON-8A when it was nearly stationary near the paleoequator (especially from 115 to 95 Ma).

Site 801

The primary motivation for returning to ODP Hole 801C, seaward of the Marianas Trench (Fig. 2), is to sample the upper oxidative zone of alteration, and possibly the entire extrusive layer (layer 2b), of this oldest in situ oceanic crust. Previous drilling during Leg 129 only penetrated 63 m into "normal" Jurassic basement. Based on Hole 504B and other basement sites with sufficient penetration, the upper oxidative zone of alteration, which contains the lion's share of some element budgets (e.g., K, B, etc.), lies in the upper 200-300 m of the basaltic crust. The transition from volcanics to dikes may not lie much deeper (500-600 m at Hole 504B; only a few 100 m at Hess Deep). We propose to drill at least 350 m farther into basement at Hole 801C to accomplish the following scientific objectives:

1. Characterize the geochemical fluxes and geophysical aging attending the upper oxidative alteration of the oceanic crust at Hole 801C;
2. Compare igneous compositions, structure, and alteration with other drilled sections of in situ oceanic crust (in particular Hole 504B, contrasting a young site in Pacific crust with the oldest site in Pacific crust);
3. Help constrain general models for seafloor alteration that depend on spreading rate and age (Hole 801C is the world's oldest oceanic crust and was formed at a fast-spreading ridge, so it embodies several end-member characteristics); and
4. Test models for the Jurassic Magnetic "Quiet" Zone.

In addition to serving as an important reference site for crustal inputs to the Mariana trench, Hole 801C can also address additional paleomagnetic problems. Because the subduction cycling objectives have already been discussed in some detail above ("Background" section), we elaborate more below on the paleomagnetic objective.

Site 801C is located in an area of very low-amplitude magnetic anomalies, usually called the Jurassic Magnetic "Quiet" Zone (JQZ). The JQZ has been suggested to result from (1) oceanic crust of a single polarity with small anomalies from intensity fluctuations, (2) oceanic crust with magnetic reversals so numerous as to "cancel each other out" when measured at the sea surface, or (3) oceanic crust with a more normal frequency of magnetic reversals acquired when the dipole field intensity was anomalously low. Deepening Hole 801C will allow testing of the above hypotheses—particularly the third hypothesis of magnetic reversals during a period of anomalously low field intensity— if fresh, unaltered volcanic glass can be obtained. Such material can yield reliable paleointensity information (Pick and Tauxe, 1993) on the very fine, single-domain grains of the titanium-free magnetite within the volcanic glass.

DRILLING STRATEGY

Site BON-8A

The site objectives for Site BON-8A are to continuously core the sedimentary section (600 m) and the upper pillow alteration zone in the basement section (300 m of basement). Drilling and hole stability in the sediment section are predicted to be good at this site, but recovery will be moderate to poor in the anticipated cherty sediments. It is recommended that the uppermost 150 m clay and volcanic ash section be cased off in the reentry hole with an extra-long conductor casing to avoid possible swelling clays that may threaten the subsequent basement drilling and downhole measurements programs. Recovery within chert sequences, especially of soft, chalky sediments, was still a problem during Leg 129 because of the need to pump heavily during chert penetration to keep the hole clean. The recent, dramatically increased recovery of hydrothermal sediments in the TAG area during Leg 158 with the newly designed, motor-driven core barrel (MDCB) in place of rotary core barrel (RCB) coring raises the encouraging possibility of similar enhanced recovery in chert/chalk sequences. We envision deploying the MDCB in a second hole at Site BON-8A to sample at least the upper part of the chert/chalk sequence, if recovery was unacceptably poor in the first hole and geochemical logging did not successfully bridge the sampling gap.

Site 801

The site objective is to penetrate through the upper, oxidative alteration zone in basaltic basement, deepening Hole 801C at least another 350 m (to ~940 meters below seafloor [mbsf] or ~480 m sub-basement, with a total drill string length of 6630 m. If drilling problems are encountered, several other sites in the Pigafetta Basin near Site 801 show the Jurassic basement reflector on seismic records and have at least 50 m of pelagic clay overlying the shallowest cherts to laterally support the drill string during initial chert penetration.

LOGGING PLAN

Recording downhole geochemical and physical properties data during Leg 185 is essential to filling recovery gaps in both sediment and basement sections, as well as enabling site-to-site comparisons of the chemical signatures of the drilled sequences.

Downhole Measurements at Site BON-8A

The oceanic crust subducted in the Izu-Bonin Trench has never been sampled nor logged. To compare the sedimentary sequence and the upper oceanic crust at Site BON-8A with the those at Hole 801C, the geochemical and geophysical tools as well as the formation microscanner (FMS) will be used. Moreover, to satisfy the time-scale objective (i.e., to determine the age of the basement), the magnetic susceptibility and total magnetic field measurements could provide a paleomagnetic reversal sequence of the overlying sediment. The azimuthal resistivity tool (ARI) will also be used in the basement section to measure resistivity. Because determining the geochemical budgets in sediment and basement columns is central to the objectives of Leg 185, geochemical logging (GLT) will be extremely valuable. Leg 129 geochemical logging served as an excellent proxy for actual recovery of sediments similar to those expected at Site BON-8A (Fisher et al., 1992).

Downhole Measurements in Hole 801C

Downhole measurements were conducted in the upper 100 m of basement in Hole 801C during Leg 144 to begin the characterization of typical old oceanic crust generated at a fast-spreading rate (Larson et al., 1993). The most surprising result from the Leg 144 downhole measurements was the extremely high permeability measured below 501 mbsf in a hydrothermal alteration zone. This zone appears to act as an aquifer, an argument supported with the apparent bulk porosity profile. Below the hydrothermal zone and within the tholeiitic basalts, the logs begin to approximate more expected values for old oceanic crust. Additional permeability experiments will be carried out deeper in the hole to characterize the hydrologic properties of this end-member oceanic crust, away from the perturbations of off-axis lavas. To further characterize the petrology, hydrogeology, structure, and physical properties of this old oceanic crust, the hole will be logged using the triple combo, geochemical, and the FMS tool strings. The ARI tool will also be used to measure resistivity in basement sections.

PROPOSED SITES

Site BON-8A

Site BON-8A is approximately 60 km east of the Izu-Bonin Trench, where the plate surface is broken by normal faults as it bends into the subduction zone. Avoiding some of this complexity, Site BON-8A is located on the top of a fault block in flat-lying sediments. Coring the complete sedimentary section as well as the upper oxidative zone of the oceanic crust at Site BON-8A will sample the main crustal components that enter the Bonin Trench. Based on our assessment of regional variations in subducting sediments elsewhere (Plank and Langmuir, in press), we feel confident that a single reference site will provide adequate constraints on the crustal inputs to the Izu-Bonin Trench. Even though the sedimentary stratigraphy will vary regionally, changes in unit thickness can be mapped more efficiently seismically than with multiple drill holes. Site BON-8A should provide us with samples of the largely pelagic sediments from the region. Of the approximately 600 m of sediment, we anticipate 150 m of pelagic clay and volcanic arc ash above 450 m of mid- to Early Cretaceous cherty porcellanites and chalks. The basement should be Early Cretaceous MORB, with the upper 300 m of extrusives containing the oxidative alteration zone. Specific site objectives are discussed in the "Scientific Objectives" section.

Hole 801C

Although located almost 1000 km from the Mariana Trench, Hole 801C is the most promising site for penetrating Jurassic MORB in the region. Throughout much of the Pigafetta and East Mariana Basins (Fig. 2), "basement" consists of Cretaceous flows and sills that overlie the "normal" Jurassic crust. Because these Cretaceous units have already been sampled during Leg 129 drilling, the remaining goal is the MORB section. Hole 801C is the only location where Jurassic-aged material has been reached in a reasonable amount of drilling time, and that material should be essentially the same as what is now being subducted beneath the Marianas. It is necessary to penetrate several hundred meters into the upper oxidative layer of Jurassic basement to constrain that part of the crustal input equation, and that section is now available directly beneath the bottom of Hole 801C. Hole 801C was left clean with a reentry cone that is cased and cemented into basement, and it is ready for more extensive basement drilling. Further background on Hole 801C can be found in Lancelot and Larson, et al. (1990). Specific site objectives for Leg 185 are listed in the "Scientific Objectives" section.

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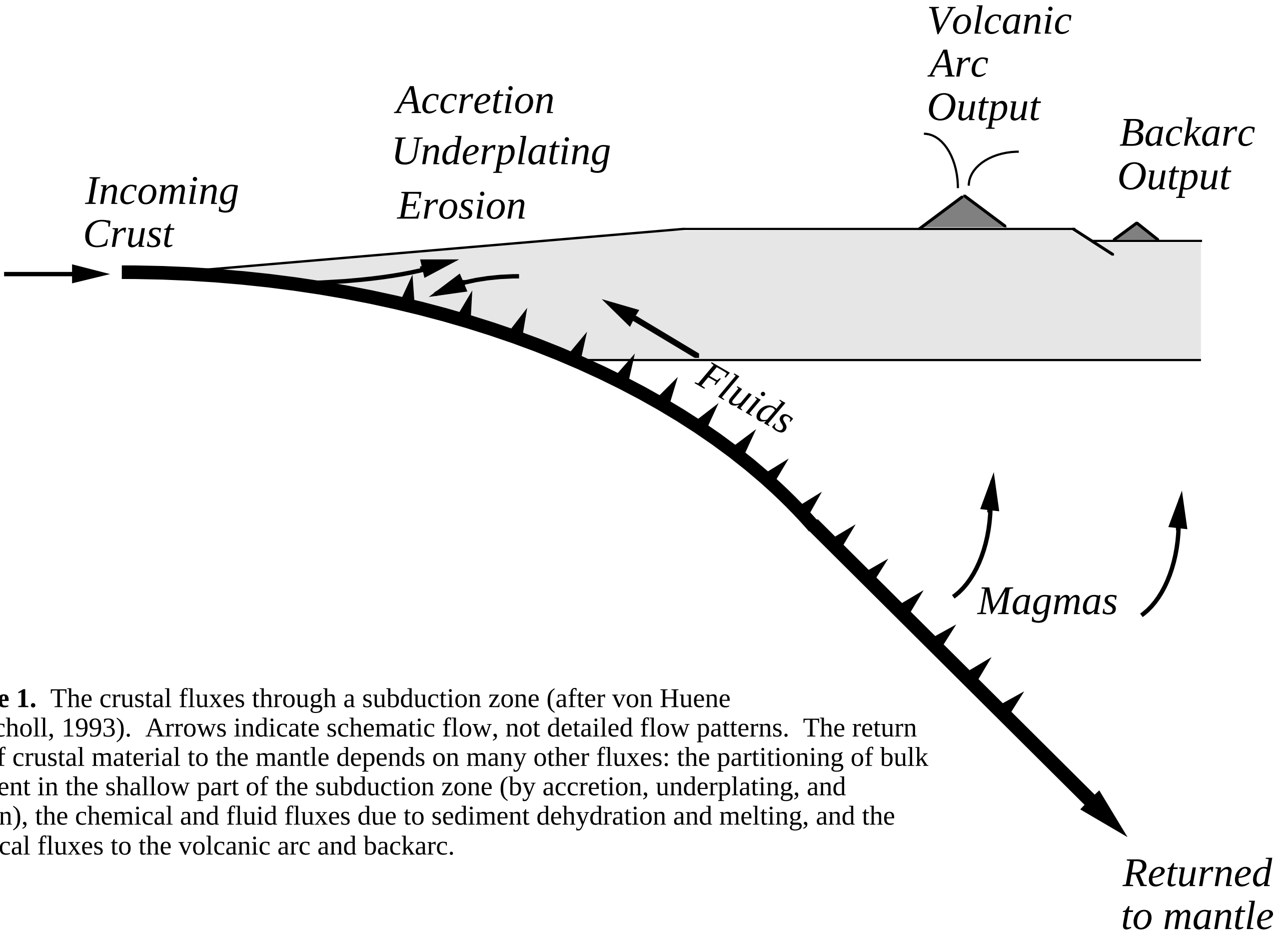

Crustal Fluxes at Subduction Zones

Figure 1. The crustal fluxes through a subduction zone (after von Huene and Scholl, 1993). Arrows indicate schematic flow, not detailed flow patterns. The return flux of crustal material to the mantle depends on many other fluxes: the partitioning of bulk sediment in the shallow part of the subduction zone (by accretion, underplating, and erosion), the chemical and fluid fluxes due to sediment dehydration and melting, and the chemical fluxes to the volcanic arc and backarc.

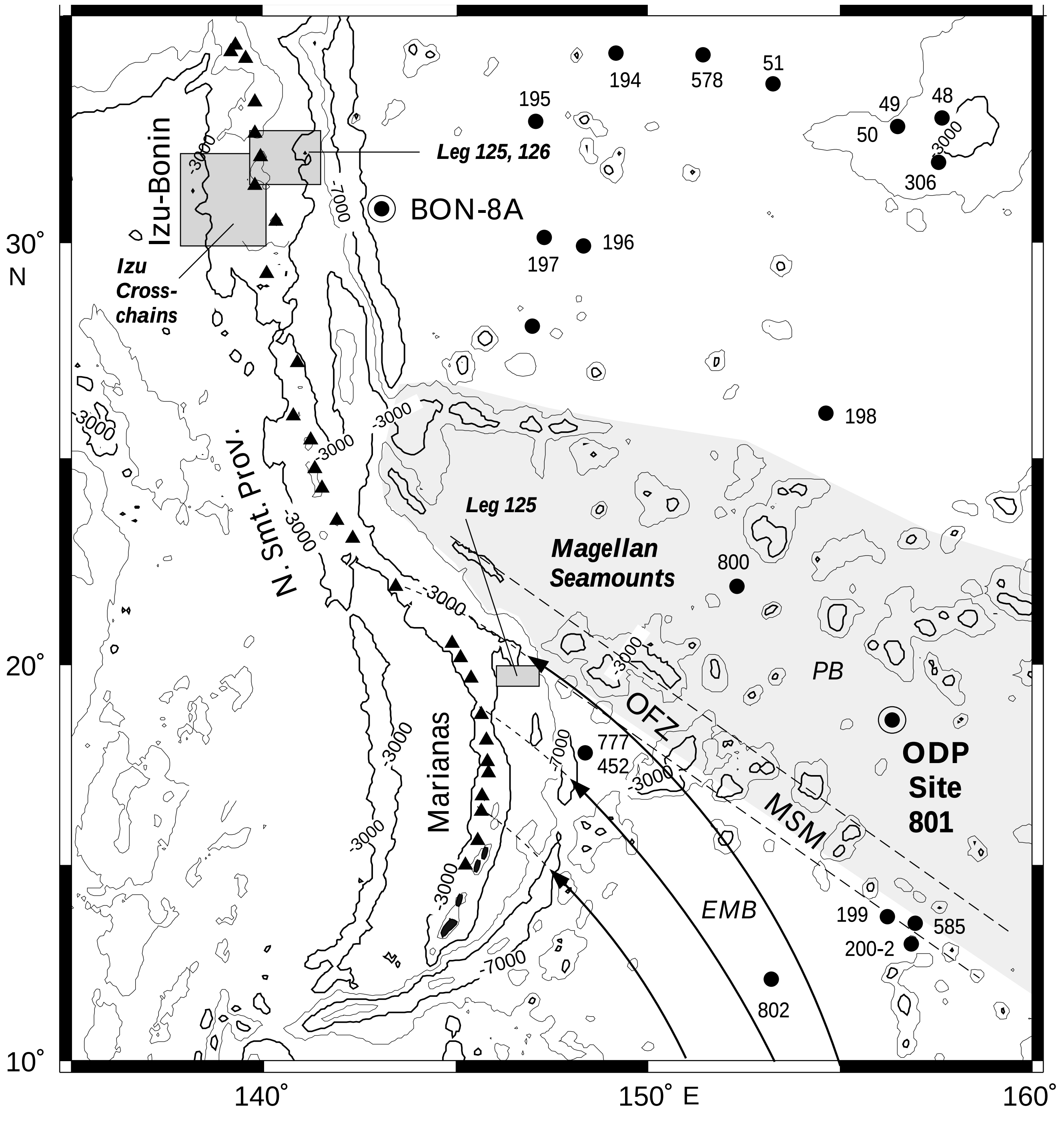

Figure 2. Map of the Western Pacific and Mariana, Izu-Bonin, and Northern Mariana Seamount Province volcanic arcs. Solid circles = existing drill holes; most drilling prior to Sites 800-802 failed to penetrate the complete sedimentary section and/or had poor recovery (see Table 1). Shaded seafloor includes Pigafetta Basin (PB) and Magellan Seamount, where alkalic Cretaceous overprint predominates. Solid triangles = active volcanoes. Site BON-8A and Hole 801C are proposed drill sites. Ogasawara Fracture Zone-Magellan Seamount Flexural Moat (OFZ-MSM) after Abrams et al., 1992 (their Fig. 2). Curves = instantaneous trajectories for the Pacific Plate relative to the Philippine Plate, after Seno et al., (1993). Dashed curves = continuation of trajectories beneath the arc.

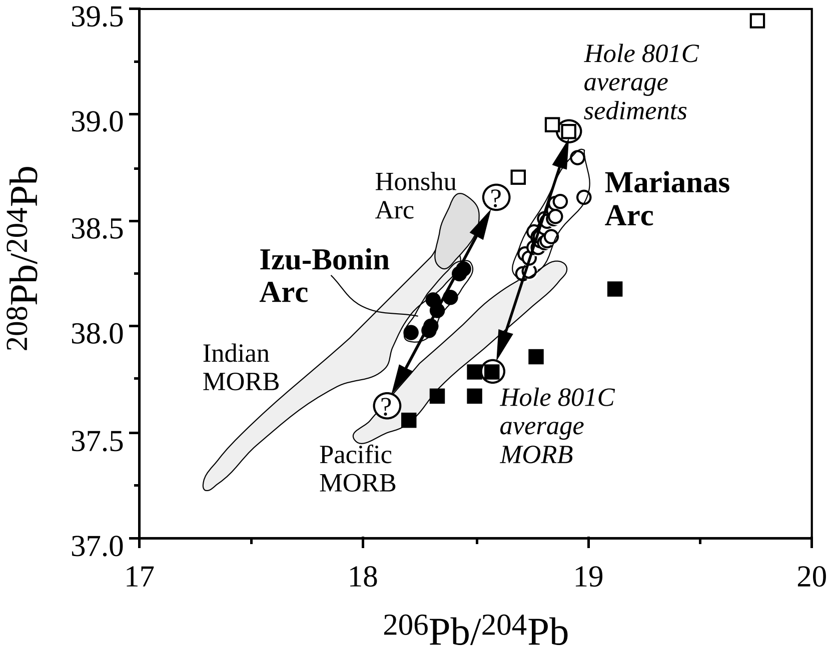

Figure 3a. Contrasting Pb isotopic composition of Marianas (open circle) and Izu-Bonin (solid circle) arc volcanics. Marianas volcanics form a mixing trend (arrow), almost perfectly coincident with mixtures of ODP Hole 801C sediment (open boxes) and basalt (solid boxes) averages. Drilling at Site BON-8A will test whether Izu-Bonin arc trend (arrow) is consistent with different subducted material than for the Marianas. Modern Indian MORB, Pacific MORB, and Honshu arc are shown for reference. Data sources: Elliott, et al., 1997; Gill, et al., 1994; Plank and Langmuir, in press; Castillo, et al., 1992a; Gust et al., 1997.

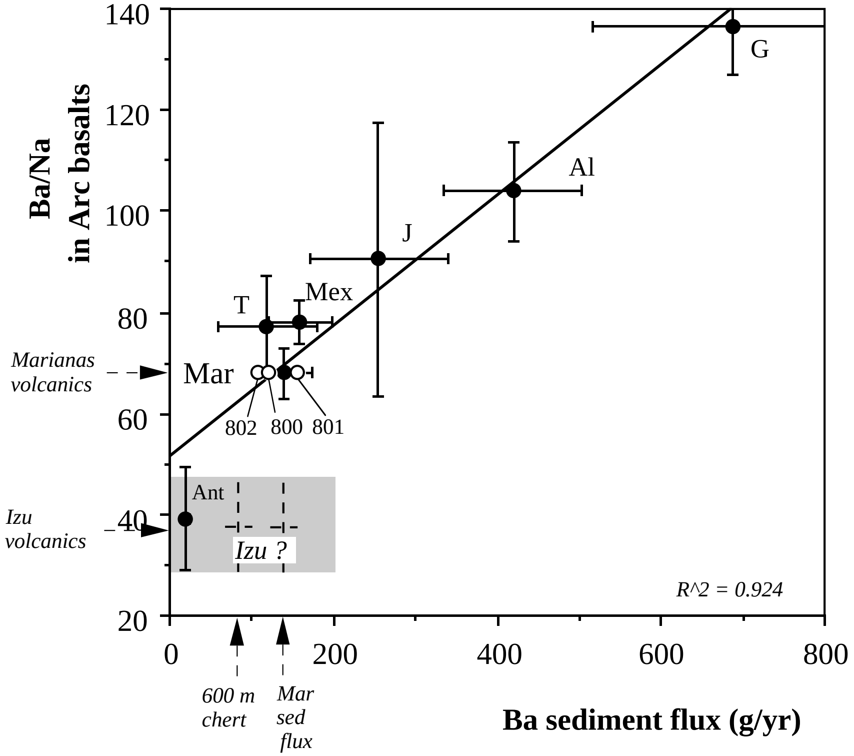

Figure 3b. Correlation between Ba flux in subducted sediment and Ba enrichment of arc basalts for various arcs around the world (after Plank and Langmuir, 1993). Open circles = three different sediment flux estimates for the Marianas, based on the three ODP Sites drilled during Leg 129 (800-802) (Plank and Langmuir, in press). Although there are variations from site to site, the average sediment input to the Marianas is fairly well constrained (+/- 20%). Note Izu volcanics are lower in Ba/Na than Marianas volcanics by a factor of two. Drilling at Site BON-8A will help to test if the low Ba/Na of the Izu volcanics is related to a lower Ba sediment flux. Shown for reference are the average Mariana Ba sediment flux and the flux for a 600-m section of chert (with 125 ppm Ba, similar to the upper radiolarites at 801C; Karl, et al., 1992).

Existing Water Mass Balance Across the Mariana Margin

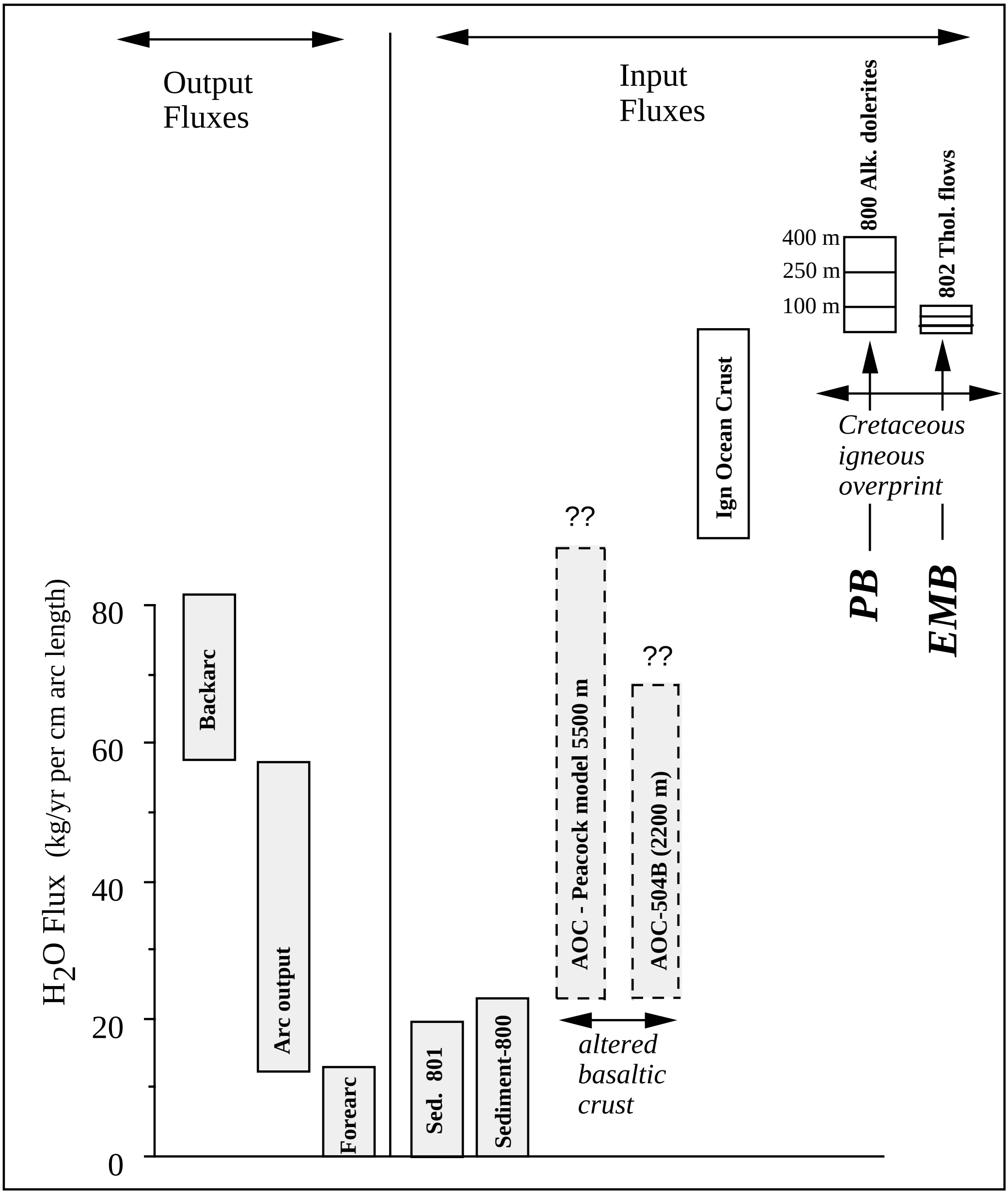

Figure 4. Estimates H_2O input and output fluxes for the Marianas subduction zone. Height of bar gives the flux for each parameter (scale on the left); bars are placed side-by-side to show competing estimates (as for Site 801 vs. Site 800 sediment) and are stacked to show cumulative input (on the right) and output (on the left). Shaded bars represent "continental" fluxes; unshaded bars are pristine igneous fluxes. Note that continental inputs and outputs may be very closely balanced; however, the balance depends critically on the real alteration fluxes for Hole 801C, which can only be constrained by further drilling. Cretaceous overprint given for both the East Mariana Basin (EMB) and Pigafetta Basins (PB); lines show fluxes resulting from different layer thickness (100, 250, 400 m).

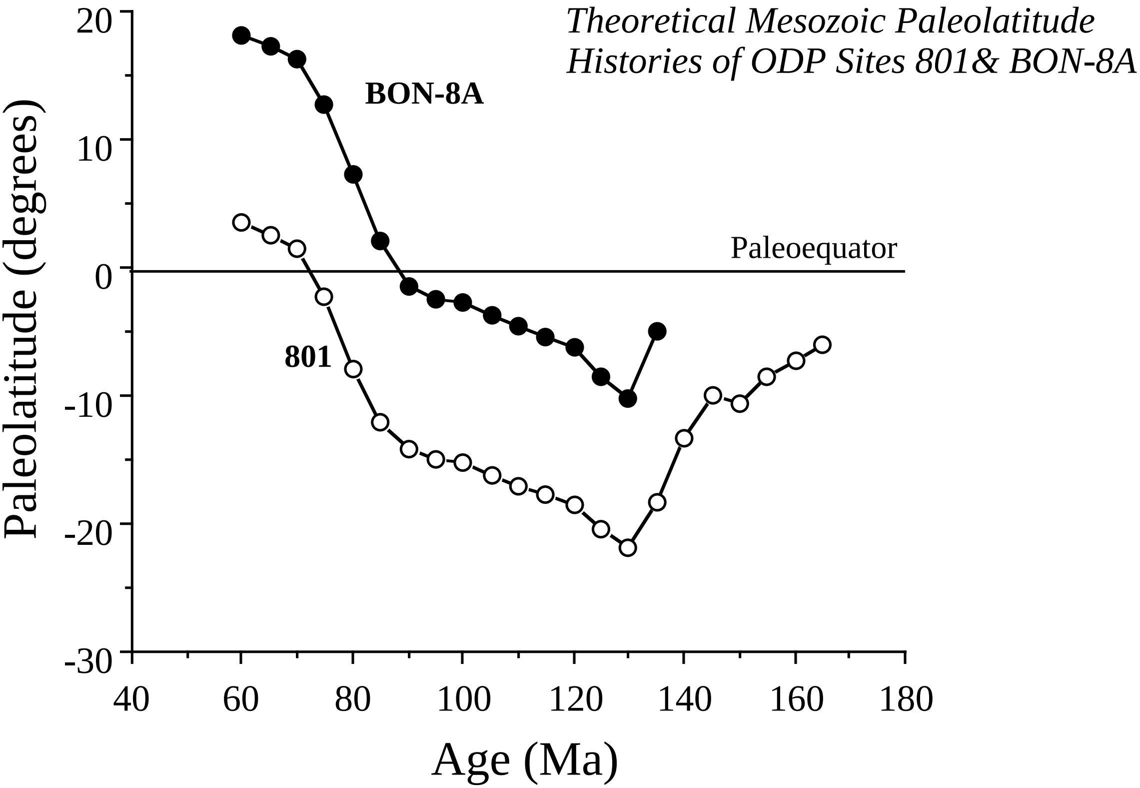

Figure 5. Theoretical Mesozoic paleolatitude histories of ODP Sites 801 and BON-8A based on the combined polar wander paths for the Pacific plate of Sager and Pringle (1988) for 60-100 Ma and Larson and Sager (1992) for 100-155 Ma. Great circle distances are measured at 5-Ma intervals on the combined polar wander path to the present-day site locations and then converted to paleolatitudes to construct these histories. The paleolatitudes of 155-165 Ma for ODP Site 801 are based on measured remanent inclinations in Jurassic core samples from that site.

TABLE 1

PROPOSED SITE INFORMATION AND DRILLING STRATEGY

SITE: BON-8A **PRIORITY**: 1 **POSITION**: 31°18.5´N, 142°57.5´E
WATER DEPTH: 6000 m **SEDIMENT THICKNESS**: 600 m **TOTAL PENETRATION**: 900 m
SEISMIC COVERAGE: Conrad 2005, Line 39, shotpoint #2936 at 1613Z on 10/13/76

Objectives: (1) Provide estimates of the sediment inputs and altered basalt inputs (geochemical fluxes) into the Izu-Bonin subduction zone. (2) Contrast crustal budgets here with those for the Marianas to test whether along-strike differences in the volcanics can be explained by along-strike variations in the crustal inputs. (3) Compare basement alteration characteristics with those at Hole 801C (also in old Pacific crust). (4) Provide constaints on the Early Cretaceous paleomagnetic time scale. (5) Provide constraints on mid-Cretaceous CCD and equatorial circulation fluctuations.

Drilling Program: APC, XCB, MDCB, RCB

Logging and Downhole Operations: Triple combo, GLT, FMS/Sonic, GHMT, ARI, Permeability

Nature of Rock Anticipated: Pelagic clay with volcanic arc ash (150 m); cherty porcellanites and chalks (450 m); basaltic pillows, flows, breccia, and possibly dikes (>300 m)

SITE: BON-9 (alternate to 8A) **PRIORITY**: 2 **POSITION**: 31°18.5´N, 143°2.5´E
WATER DEPTH: 5875 m **SEDIMENT THICKNESS**: 600 m **TOTAL PENETRATION**: 900 m
SEISMIC COVERAGE:

Objectives: Same objectives as BON-8A.

SITE: 801C **PRIORITY**: 1 **POSITION**: 18.642°N, 156.36°E
WATER DEPTH: 5674 m **SEDIMENT THICKNESS**: 460 m **TOTAL PENETRATION**: 950 m
SEISMIC COVERAGE: MESOPAC II, Line 10 at 0600, 8/26/89

Objectives: (1) Characterize the geochemical fluxes and geophysical aging attending the upper oxidative alteration of the oceanic crust at Hole 801C. (2) Compare igneous compositions, structure, and alteration with other drilled sections of in situ oceanic crust (in particular Hole 504B, contrasting a young site in Pacific crust with the oldest site in Pacific crust). (3) Help constrain models for seafloor alteration that depend on spreading rate and age (Hole 801C is the world's oldest oceanic crust and was formed at a fast-spreading ridge, so it embodies several end-member characteristics). (4) Test models for the Jurassic Magnetic "Quiet" Zone.

Drilling Program: RCB

Logging and Downhole Operations: Triple Combo, GLT, FMS/Sonic, ARI, Permeability

Nature of Rock Anticipated: Basaltic pillows, flows, breccia, and possibly dikes (>350 m)

SITE: PIG-3B (alternate to 801C) **PRIORITY**: 2 **POSITION**: 18.663°N, 157.095°E
WATER DEPTH: 5674 m **SEDIMENT THICKNESS**: 460 m **TOTAL PENETRATION**: 950 m
SEISMIC COVERAGE:

Objectives: Same objectives as Hole 801C.