Fryer, P., Pearce, J. A., Stokking, L. B., et al., 1990
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1. INTRODUCTION[1]

Shipboard Scientific Party[2]

OVERVIEW

The Izu-Bonin-Mariana region is made up of a complex series of arcs and basins that formed since the start of westward subduction of Pacific lithosphere in the Eocene. The principal objective of Leg 125 was to study two important and poorly understood aspects of this system, namely:

1. The origin and evolution of the forearc terranes, to be investigated by drilling a series of holes through the sediments and into the basement of the Mariana and Izu-Bonin forearc basins (Sites 782, 785, and 786) and into and adjacent to serpentinite seamounts from the Mariana mid-forearc region (Sites 778 through 781) and the Izu-Bonin lower-slope terrace (Sites 783 and 784).
2. Dewatering of the subducted lithosphere, to be investigated indirectly from the composition of forearc basin crust and directly from the analyses of fluids, chemical precipitates, and metamorphic rocks from the serpentinite seamounts.

TECTONIC SETTING AND EVOLUTION OF THE IZU-BONIN-MARIANA FOREARC

The present-day tectonic configuration of the Izu-Bonin-Mariana region (Fig. 1) comprises (from east to west): the trench; the forearc terrane; the active Izu-Bonin and Mariana island arcs; the actively spreading Mariana backarc basin or, in the case of the Izu-Bonin region, the incipient rift basins of the Izu-Bonin backarc; the West Mariana Ridge, a remnant arc; the Parece Vela and Shikoku marginal basins; and the Palau-Kyushu Ridge, the westernmost remnant arc. Subduction of Pacific oceanic lithosphere is currently taking place at absolute velocities between 8 and 10 cm/yr to the northwest; the subduction angle is about 12° at shallow depths, steepening in some parts of the Mariana system to nearly vertical below about 100 km.

The evolution of these arc-basin systems is thought to have begun in the early-middle Eocene, when westward subduction of Pacific lithosphere began beneath the Philippine Sea Plate (Uyeda and Ben-Avraham, 1972; Karig, 1975). Development of the system continued through the early Oligocene, forming an intraoceanic volcanic arc on top of a forearc that may have been as much as 200 km wide. In the Mariana area, this arc formed on or near the edge of the West Philippine Basin, whereas in the Izu-Bonin area, it formed on the edge of the Amami-Oki Daito province, a series of island arcs and intervening basins of Santonian to Paleocene age (Karig, 1975).

Middle Oligocene rifting split the arc, and late Oligocene to early Miocene backarc spreading in the Parece Vela and Shikoku basins isolated a remnant arc (the Palau-Kyushu Ridge) from an active Izu-Bonin-Mariana arc (Kobayashi and Nakada, 1979). The initiation of this backarc spreading event was not synchronous along the length of the Oligocene arc. Spreading began at about 31 Ma in what became the central Parece Vela Basin and propagated both north and south, giving the basin its bowed-out shape. A second spreading episode began by 25 Ma in what became the northernmost Shikoku Basin and propagated south (Kobayashi and Nakada, 1979). By 23 Ma the two systems had joined at what is now approximately 25°N, and both basins shared a common spreading axis until spreading ceased at 17 to 15 Ma.

A repetition of this cycle of events began in the late Miocene, when the southern part of the arc split again. Subsequently, 6 to 8 m.y. of spreading in the Mariana backarc basin isolated the active Mariana arc from the West Mariana Ridge remnant arc (Karig et al., 1978; Hussong and Uyeda, 1981). The extent of spreading has been greatest in the center of this backarc basin, causing the active arc to have a marked eastward convexity. Spreading in the Mariana backarc basin may now be propagating to the north, either "unzipping" the Mariana arc from the West Mariana Ridge (Stern et al., 1984) or pivoting about a point north of the volcanic islands (Beal, 1986). The Izu-Bonin arc is still in the early rifting stage of backarc formation, undergoing extension along most of its length (Honza and Tamaki, 1985).

The forearc terrane is made up of an inner trench wall, an outer-arc high, a forearc basin, and a frontal-arc high. In the Izu-Bonin system, the inner trench wall has a 50-km-wide along-strike terrace or ridge. In the Mariana system, the inner trench wall has several reentrants, some of which are adjacent to positions of subducting seamounts and horst blocks associated with partially subducted seamounts. These differences among the forearcs may be attributed in part to differences in arc-basin evolution between the Mariana and Izu-Bonin systems, and in part because seamount chains and aseismic ridges on the subducting plate have collided with only the Mariana forearc and the southernmost Izu-Bonin arc.

In contrast to the Mariana forearc, the Izu-Bonin forearc has experienced only minor deformation since the Eocene, when subduction began (Honza and Tamaki, 1985). This forearc constitutes a broad forearc basin filled with volcaniclastic and hemipelagic sediments that developed behind an outer-arc high, west of the break in slope between the inner trench wall and the forearc basin (Fig. 2A). In the southern part of the Izu-Bonin forearc, this outer-arc high is the Ogasawara Ridge and includes the islands of the Izu-Bonin group (the Ogasawara Islands). Biostratigraphic dating of the strata that lap onto this outer-arc high, both on its subaerial expression on the Ogasawara Islands (Hanzawa, 1947) and offshore, suggests that this high has been a positive topographic feature since its uplift in the early Eocene. North of about 30°N, the outer-arc high is more subdued and is situated at a distance of from 50 to about 100 km from the Izu-Bonin Trench (Fig. 2B). Where imaged by seismic-reflection profiles, the arc has separated from the forearc basin by normal faults with apparent throws of less than 500 km, down-dropped to the west (Horine et al., this volume). Several mature, dendritic submarine canyon systems have developed across the

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[2] Shipboard Scientific Party is as given in the list of participants preceding the contents.

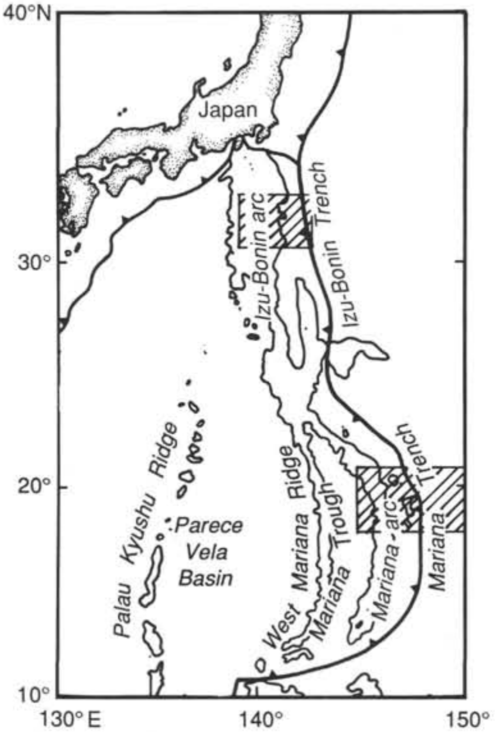

Figure 1. Active plate boundaries in the Philippine Sea region. Barbed lines locate subduction zones. Basins and ridges are outlined by the 4-km bathymetric contour, except for the Izu-Bonin, West Mariana and Mariana arcs, which are outlined by the 3-km contour. Boxes show locations of Figures 2 and 3.

Izu-Bonin forearc basin and the outer-arc high by mass wasting and headward erosion. These canyons have incised as much as 1 km into the 1.5- to 4-km-thick sedimentary section (Taylor and Smoot, 1984). Another feature of the outer forearc appears north of about 30°N. Between the outer-arc high and the Izu-Bonin Trench are a number of serpentinite seamounts, ranging from less than 10 to more than 20 km in diameter and from several hundred to more than 1400 m high (Ishii, 1985). These seamounts are spaced at intervals of 15 to 60 km along a terrace, which is situated less than 50 km from the trench axis on the inner wall of the trench (Fig. 2B).

The Mariana forearc (Fig. 3) has a broadly similar structure, but lacks the lower-slope terrace. This forearc has undergone extensive uplift and subsidence that resulted from both seamount collision and the tensional and rotational fracturing that is associated with adjustments to plate subduction, changes in the configuration of the arc, and variations in the angle of convergence. A broad zone of serpentinite seamounts (up to 2500 m high and 30 km in diameter), 50 to 120 km from the trench axis, has been identified west of the break in slope at the top of the inner trench wall (Fryer et al., 1985a; Fryer and Fryer, 1987). Some of the seamounts in the Mariana forearc appear to be horst blocks. Others have formed by the "diapiric" rise and extrusion of serpentinite. These serpentinite seamounts, and the fault zones with which many of them are associated, may represent pathways whereby fluids that have migrated upward from the subduction zone reach the surface. These fluid pathways contrast with pathways in accretionary forearcs: only very minor, and probably ephemeral, accretionary complexes have been found at the bases of the inner walls of the Izu-Bonin and Mariana trenches.

Scientists of Leg 125 focused on two seamounts: Conical Seamount in the Mariana forearc and Torishima Forearc Seamount in the Izu-Bonin forearc. Conical Seamount, drilled at Sites 778 and 779 (the flank sites) and Site 780 (the summit site) (Fig. 4), lies in the broad zone of forearc seamounts along the Mariana outer-arc high. It is a nearly perfectly circular seamount, 20 km in diameter, that rises 1500 m above the seafloor, a distance of about 80 km from the trench axis. A side-scanning sonar and bathymetry survey showed that flows mantle the surface of the seamount (Hussong and Fryer, 1985). The constitution of these flows was subsequently identified as unconsolidated sedimentary serpentine by submersible exploration, which also discovered evidence for fluid emanations at its summit (Fryer et al., 1987). An additional site (Site 781) was drilled into the forearc just off the flank of the seamount.

The Torishima Forearc Seamount, drilled at Sites 783 and 784 on the outermost part of the Izu-Bonin forearc (Fig. 5), also has yielded serpentinite in dredges (Ishii et al., 1981; Ishii, 1985; Ishii et al., 1985). Several dredges and one core from seamounts along this ridge have yielded serpentinized harzburgite, metamorphosed gabbro, diabase, and basalt, and their sedimentary derivatives (serpentinite breccia, sandstone, and mudstone). Side-scanning sonar and bathymetry surveys of the three seamounts south of 32°N indicate sedimented western slopes, and seismic-reflection profiles along and across the seamounts reveal an acoustically complex basement with thin or no sediment cover (see Horine et al., this volume). Most of the inner trench wall, both above and below the terrace, has been stripped of sediment, presumably by slumping or faulting. However, sediments showing complex unconformities, including turbidite deposits and pelagic sequences, are ponded behind the seamounts, drape their lower flanks, and fill the lows between them (Taylor, 1984). Site 783 is situated on the north flank of a seamount at 31°N, and Site 784 is at its western base.

COMPOSITION OF THE FOREARC BASEMENT

Our knowledge of the basement of the Izu-Bonin and Mariana forearcs comes from three main sources: (1) on-land exposures on Guam, Saipan, and Ogasawara islands; (2) dredges from inner trench walls, seamounts, and large fault scarps; and (3) Sites 458 through 461 of Leg 60 of the Deep Sea Drilling Project (DSDP).

The islands of Guam and Saipan in the Mariana forearc contain exposures of pillow lavas, breccias, and volcanic sediments of middle-late Eocene age known as the Facpi Formation (Tracey et al., 1964; Meijer, 1979; Reagan and Meijer, 1984). This formation is overlain by the late Eocene to Oligocene Alutom Formation, which includes volcanic breccias, clastic and carbonate sediments, and subordinate pillow lavas and is intruded by sills of Oligocene (32 Ma) age, coincident with the rifting of the Palau-Kyushu Ridge. The Alutom Formation is unconformably overlain by the Umatac Formation, comprising middle Miocene limestones, volcanic breccias, and pillow lavas. The magma types present in the lavas range from boninite and island-arc tholeiite series in the Facpi Formation, island-arc tholeiite to calc-alkaline series in the Alutom Formation, and high-potassium, calc-alkaline series in the Umatac Formation (Reagan and Meijer, 1984; Hickey and Frey, 1982; Shiraki et al., 1980).

The Ogasawara Islands are made up of a dominantly Eocene volcanic basement that is overlain by interbedded tuffs and limestones of Eocene-Oligocene age (Kuroda et al., 1988). The volcanic basement is made up mainly of pillow lavas, breccias, hyaloclastites, and dikes belonging to the boninite and island-arc tholeiite series and includes the type locality for boninites on the island of Chichijima.

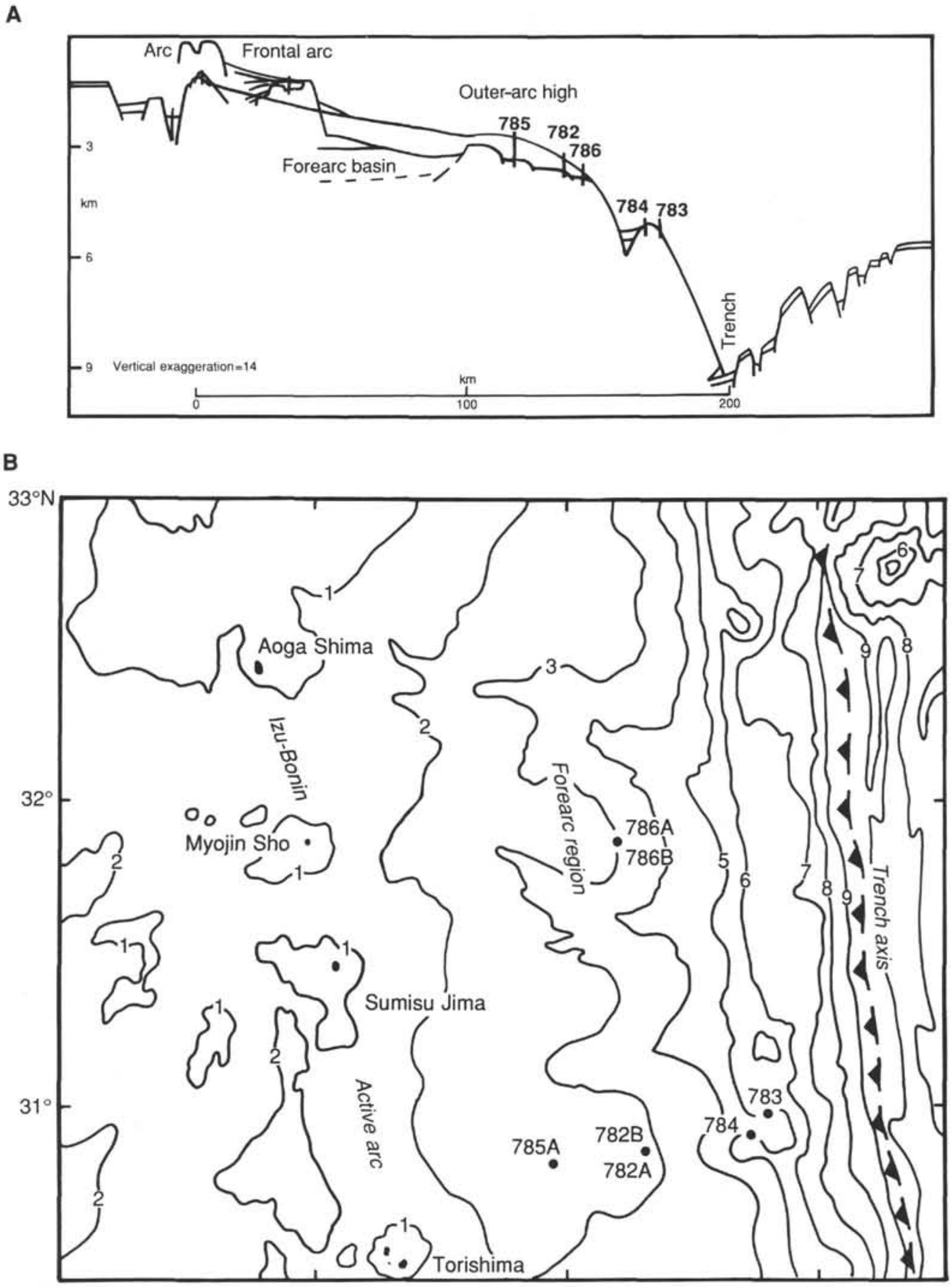

Figure 2. Locations of Sites 782 through 786 in the Izu-Bonin forearc, as seen in (**A**) schematic cross section and (**B**) plan. Bathymetry in kilometers.

Dredges from the inner trench walls have recovered a wide variety of rock types. In the Mariana forearc, Sharaskin et al. (1980), Beccaluva et al. (1980), Dietrich et al. (1978), Bloomer (1983), and Bloomer and Hawkins (1983) described serpentinized ultramafic rocks from nearly all structural levels of the inner trench wall of the Mariana Trench from depths of 1200 to 8000 m. They also described cumulate and isotropic gabbros, and a range of altered to fresh volcanic rocks that included boninites, subalkaline basalts to dacites, and rare alkali basalts and sedimentary rocks. More detailed dredging and submersible sampling of Conical Seamount showed that serpentinized ultramafic rocks are the dominant rock type on this seamount (Saboda and Fryer, 1987). Dredge hauls from a fault scarp bounding a deep graben adjacent to Conical Seamount (Sites 778–780) yielded boninites and a variety of basalts of island-arc, mid-ocean ridge basalt (MORB), and alkalic ocean-island affinities (Johnson and Fryer, 1988). The recovery of both MORB and ocean-island basalts from the forearc suggests that relict fragments of pre-Eocene crust (possibly Philippine Sea Plate) and/or accreted fragments of Pacific Plate may also contribute to the forearc crust (Ogawa and Naka, 1984; Bloomer, 1983; Johnson and Fryer, 1988). In the

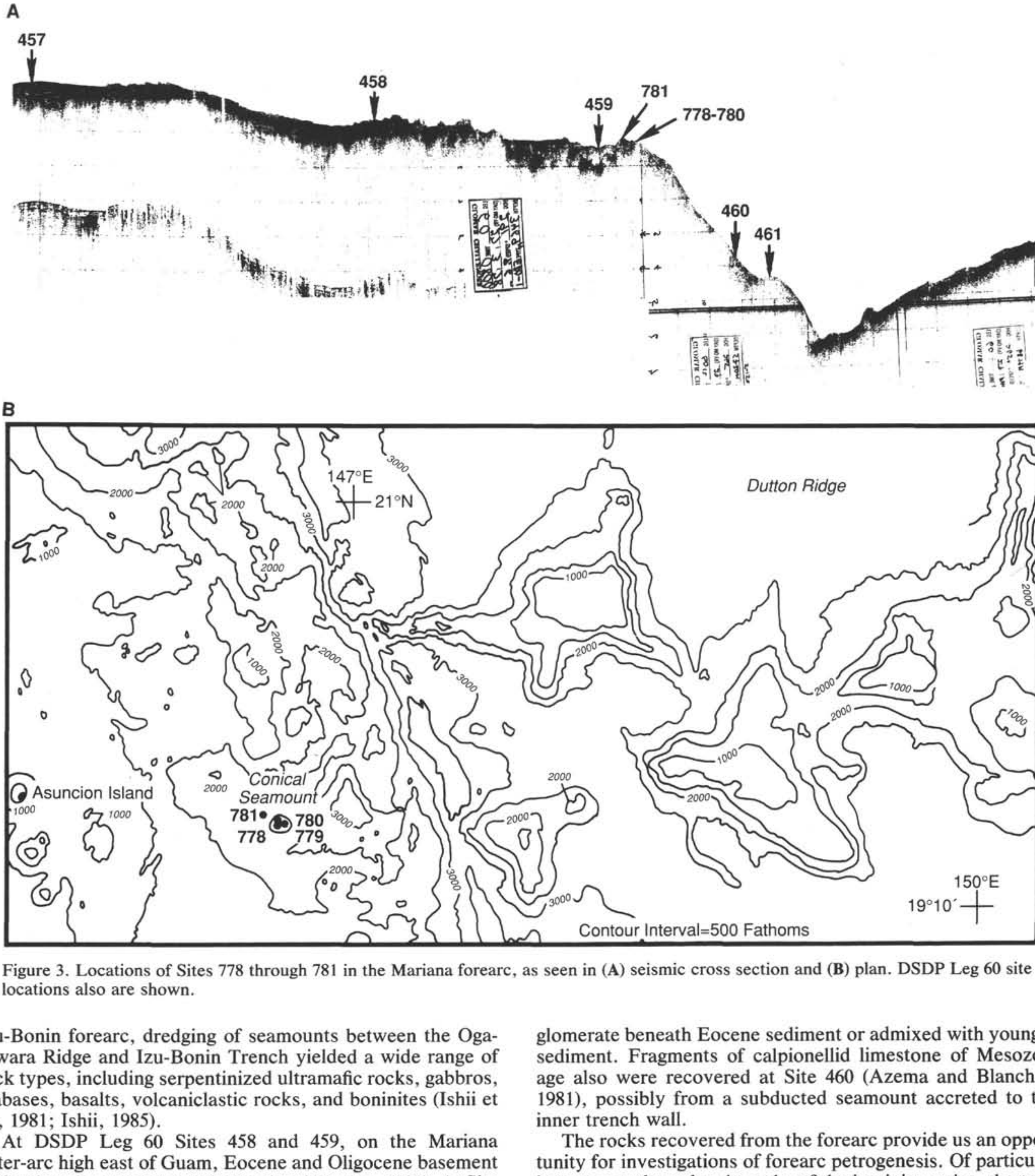

Figure 3. Locations of Sites 778 through 781 in the Mariana forearc, as seen in (A) seismic cross section and (B) plan. DSDP Leg 60 site locations also are shown.

Izu-Bonin forearc, dredging of seamounts between the Ogasawara Ridge and Izu-Bonin Trench yielded a wide range of rock types, including serpentinized ultramafic rocks, gabbros, diabases, basalts, volcaniclastic rocks, and boninites (Ishii et al., 1981; Ishii, 1985).

At DSDP Leg 60 Sites 458 and 459, on the Mariana outer-arc high east of Guam, Eocene and Oligocene basement rocks also were recovered (Natland and Tarney, 1981). At Site 458, interbedded pillow lavas and massive flows are overlain by lower Oligocene vitric tuffs. The lavas constituted two rock types: high-MgO bronzite andesites of the boninite series and basalts of the island-arc tholeiite series. At Site 459, a series of pillow lavas, massive flows, and possible sills are overlain by middle Eocene claystones. The rock types are basalts and andesites transitional between the boninite and island-arc tholeiite series. Igneous rocks were also recovered at Sites 460 and 461, on the deep inner trench wall of the Mariana Trough, as cobbles of basalts, metabasalts, and metagabbros in conglomerate beneath Eocene sediment or admixed with younger sediment. Fragments of calpionellid limestone of Mesozoic age also were recovered at Site 460 (Azema and Blanchet, 1981), possibly from a subducted seamount accreted to the inner trench wall.

The rocks recovered from the forearc provide us an opportunity for investigations of forearc petrogenesis. Of particular interest are the volcanic rocks of the boninite series, the type locality of which is in the Izu-Bonin Islands, which are predominantly, perhaps uniquely, associated with oceanic terranes and ophiolite complexes that were thought to have formed above subduction zones (e.g., Cameron et al., 1979). Boninite is described petrographically by a phenocryst assemblage dominated by orthopyroxene and/or clinoenstatite, commonly accompanied by olivine; plagioclase is characteristically absent, except in highly fractionated members of the series (e.g., Shiraki et al., 1980). The formation of boninite series rocks appears to require variable degrees of hydrous

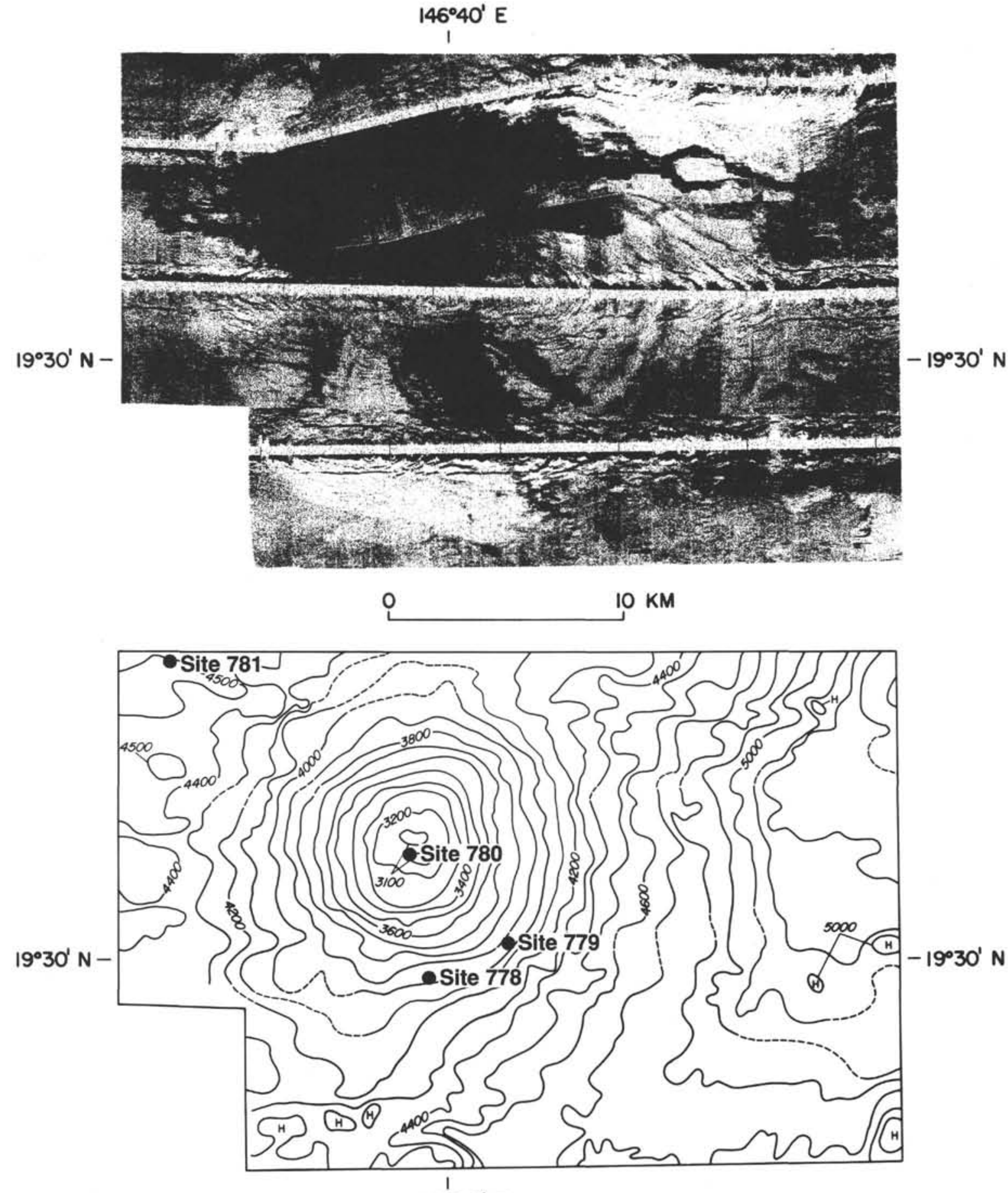

Figure 4. Bathymetric sketch of Conical Seamount in the Mariana forearc showing the locations of Sites 778 through 781 and the apparent distribution of surface flows from side-scanning sonar imagery. Bathymetry in meters.

partial melting of a refractory peridotite source under conditions of low pressure and geothermal gradients similar to those at mid-ocean ridges (van der Laan, 1987). These unusual conditions may occur only during initial subduction or arc rifting, although the eruptive style and exact tectonic setting of boninite volcanism in the Western Pacific, as elsewhere, is unclear.

The ultramafic rocks recovered from the inner trench walls and some seamounts in forearc terranes also provide important information about the nature and composition of the mantle wedge and its melting history. Most of these rocks proved to be harzburgites, which contain very small proportions of clinopyroxene, low contents of alumina, and high chromium numbers (Cr/[Cr + Al]) in their spinels, all indicating a highly depleted mantle rock that represents the residue from a high degree of partial melting or more than one melting event (Dick and Bullen, 1984; Dick et al., 1984). These compositions are in marked contrast to the compositions of ultramafic rocks from other tectonic environments (fracture zones, attenuated continental margins) that have significantly

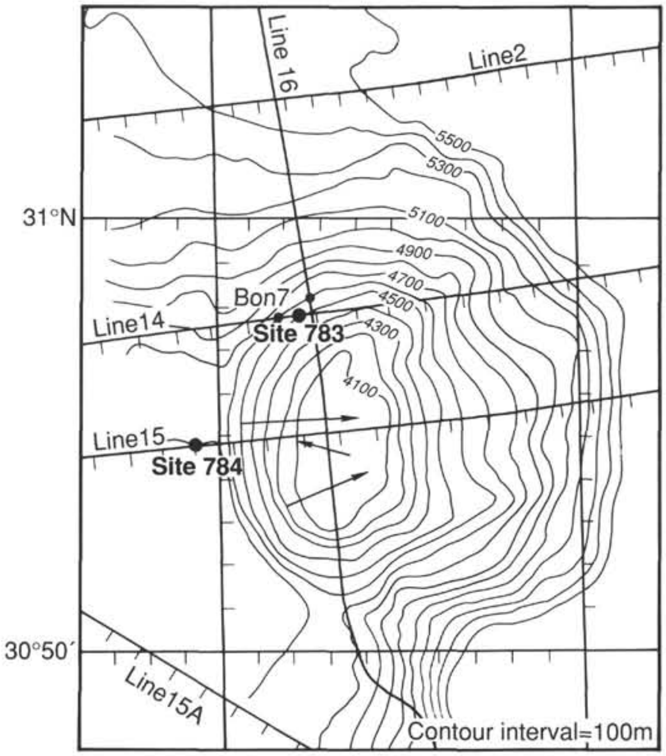

Figure 5. Bathymetric sketch of the Torishima Forearc Seamount drilled at Sites 783 and 784.

more clinopyroxene, more alumina, and more aluminous spinels (Bonatti and Michael, 1989).

Many authors now ascribe a majority of ophiolites to subduction-related settings because of their chemistry and associated sediments. Pearce et al. (1984) proposed the use of the term "supra-subduction zone (SSZ) ophiolites" to describe ophiolites having the geochemical characteristics of island arcs, but the structure of oceanic crust. They proposed that many SSZ ophiolites (including the Troodos Massif of Cyprus and the Semail Nappe of Oman) may have formed by seafloor spreading during the initial stages of subduction prior to the development of any major volcanic arc. The association between ophiolite formation and forearcs has also been noted by marine geologists and petrologists studying the rocks recovered from the inner trench wall, and several authors have used the term "ophiolitic" to describe forearc basement (e.g., Ogawa and Naka, 1984; Bloomer and Hawkins, 1983). The absence of any extant examples, however, has meant that the exact setting, or settings, of formation of SSZ ophiolite complexes are still the subject of debate. Thus, the more comprehensive understanding of forearc basement is needed to establish the precise relationship between ophiolite complexes and forearc terranes.

From the available data, it therefore appears that the present 150- to 220-km-wide Izu-Bonin and Mariana forearcs formed in large part by volcanism during the initial stages of arc development in the Eocene and early Oligocene. Prior to this leg, there has been no evidence for any subsequent volcanic activity within these forearcs. However, basement beneath the thickly sedimented forearc basin between the active volcanic arc and the break in slope of the inner wall of the trench has never been sampled. One of the main objectives of Leg 125 (Sites 782, 785, and 786) was to penetrate basement in the Izu-Bonin forearc basin. The existing evidence also suggests that mobilization of the forearc mantle wedge by serpentinization and diapiric intrusion is an important phenomenon in the region between the outer-arc high and the trench. The study of this process was another major objective of Leg 125 (Sites 778 through 781, 783, and 784).

FOREARC EVOLUTION

Three main alternative hypotheses can be postulated for the origin and evolution of this forearc terrane: (1) the volcanic arc and outer-arc high may have originally been continuous and subsequently separated by forearc spreading; (2) the volcanic arc and outer-arc high may have been built separately, but nearly synchronously, on former Philippine Sea Plate crust; or (3) the terrane may form part of a continuous Eocene arc volcanic province, possibly with overprints of later forearc volcanism.

Each scenario for the development of forearc basement implies a different crustal structure for the forearcs. Multichannel seismic (MCS) surveys of the Izu-Bonin forearc (B. Taylor, pers. comm., 1989) revealed a complicated basement that in many places is seismically stratified and cut by dipping reflectors. These reflection characteristics are unlike those of normal oceanic crustal sections and suggest that the Eocene volcanism may have been accompanied by tectonic activity and/or that it was superimposed on an older arc terrane, such as the Amami Plateau. The Izu-Bonin forearc basin drill sites (Sites 782, 785, and 786) were aimed at investigating the hitherto unstudied forearc basement to constrain some of these models of forearc evolution.

The presence of subduction-related igneous rocks near the trench, together with observations of normal faulting in the forearc and interpretations of outer-arc subsidence, have been cited as evidence for large-scale removal of Mariana forearc material by tectonic erosion since the late Eocene (Hussong and Uyeda, 1981). This analysis was subsequently questioned by Karig and Ranken (1983), who inferred that the Mariana forearc did not undergo significant tectonic subsidence or erosion. Likewise, in the Izu-Bonin forearc, the presence of shallow-water Eocene fossils on the Ogasawara Islands and of a well-developed submarine canyon system and lower-slope terrace elsewhere in the forearc suggest that fairly stable conditions have prevailed since the anomalous Eocene phase of arc-basin development. We hope that data from Leg 125 will enable us to test this hypothesis by providing the information needed to model the uplift-subsidence history across the forearc, using backstripping techniques for cored and logged holes and seismic stratigraphic analyses of interconnecting MCS profiles. Microstructures in the drill cores should also help us to determine the intensity of faulting in space and time across the forearc terrane.

Another fundamental question is whether the volcanic arc and outer-arc high developed by igneous construction or by differential uplift, or whether the upper-slope basin between them was caused by forearc spreading or differential subsidence, or whether flexural loading, either by arc volcanoes or by coupling with the subducting plate, is an important process. Determining the vertical displacement field of the forearc should provide some of the information about forearc flexure and basin development necessary for scientists to evaluate these hypotheses.

The forearc stratigraphy should also record a history of the variations in intensity and chemistry of arc volcanism. Currently, a number of conflicting models exist relating variations in arc volcanism to variations in tectonic processes. Karig (1975) proposed that periods of arc volcanic maxima correlated with periods of marginal basin formation and high subduction rate. Scott and Kroenke (1981) suggested rather that initial periods of backarc spreading are coincident with minimal arc volcanism. Contrary to both hypotheses, Hussong and Uyeda (1981) inferred that arc volcanism has probably been continuous since the Eocene, but that the initiation of backarc spreading by arc rifting produced drastic subsidence of the arc volcanoes, resulting in deep-water eruptions with limited lateral transport of volcanic material. Studies of the tephrachronology, and the frequency and geochemistry of ash and pyroclastic flow deposits in the forearc basin drill cores, will enable scientists to evaluate these various models. Such studies may also enable us to test whether boninitic (Beccaluva et al., 1980), alkalic (Stern et al., 1984), and/or rhyodacitic (Gill et al., 1984; Fryer et al., 1985a) volcanism characterizes periods of arc rifting.

Interpretation of the evolution of the forearc terranes must also take into account post-Eocene terrane rotations. Paleomagnetic studies of the rocks recovered from DSDP Legs 31 and 60 in the Izu-Bonin and Mariana forearc suggested that 20° of northward translation has taken place since the Eocene, and paleomagnetic results from subaerial portions of the Izu-Bonin forearc indicate 90° of clockwise rotation since the Eocene (Keating et al., 1983). These data have been used to suggest that the Philippine Sea Plate has rotated like a ball bearing in response to motion between the Pacific and Eurasian plates. The rotation of the Philippine Sea Plate as a whole is further supported by paleomagnetic results from the Palau Islands (Haston et al., 1988), which point to 60° to 70° of clockwise rotation of the Philippine Sea Plate since the mid-Oligocene. Along the Mariana arc, paleomagnetic results from Guam (Larson et al., 1975; Fuller, unpubl. data) and Saipan (Fuller et al., 1980) also indicate clockwise rotations. McCabe and Uyeda (1983) proposed that the clockwise rotations of Guam and Saipan were associated with deformation of the Mariana arc in response to the collision of the Caroline Ridge. Paleomagnetic studies of the Izu-Bonin forearc will further test and refine these models.

ORIGIN AND INTERNAL STRUCTURE OF SERPENTINITE SEAMOUNTS

Drilling into serpentinite at the Mariana and Izu-Bonin forearc Sites 778 through 781 and 783 through 784 provided scientists with an opportunity to address the problems of the nature and origin of serpentinite in nonaccretionary, intraoceanic forearcs and hence provide information about the development of the outer forearc regions of intraoceanic island arcs. Conical Seamount is one of only two Mariana forearc seamounts (the other is a seamount at latitude 14°N) where active protrusion of sedimentary serpentinite is known to be taking place. Conical Seamount therefore provides an *in-situ* locality for studying the formation and emplacement of sedimentary serpentinite seamounts.

Side-scanning sonar and bathymetry surveys (Hussong and Fryer, 1985; Fryer et al., 1987) have not defined the internal structure of the edifice. Two potential "end-member" types of structure exist: a "mushroom" structure in which serpentinite rises up a narrow neck and spreads out near the surface; and a "dome" structure in which the serpentinite rises from a certain depth as a diapiric or tumescent protrusion that is widest at its base and narrows toward the surface. The final shape will then be modified by mass flowage on the surface.

Sedimentary serpentinite deposits of probable forearc origin have been identified in the Great Valley Sequence of California (Phipps, 1984a, 1984b; Lagabrielle, 1987), and around the Mediterranean and Caribbean (e.g., Lockwood, 1971). However, none of these areas has been known to exhibit development of serpentinite protrusion on the scale of that in the Mariana system. Serpentinite protrusion also makes an important contribution to ancient, ophiolitic sequences, although it is not always certain whether these formed during oceanic crustal accretion and/or ocean closure (Lagabrielle et al., 1986; Lagabrielle, 1987).

Serpentinites have been recovered from other present-day oceanic environments, notably transform faults, slow-spreading mid-ocean ridges, and along passive margins. Passive margin serpentinites, thought to have been associated with the tensional tectonics and crustal thinning in the earliest stages of ocean opening, have been identified in a number of localities, such as on Red Sea islands and on the eastern Atlantic margin (e.g., Lagabrielle and Auzende, 1982; Bonatti and Michael, 1989), and were drilled at Site 637 during ODP Leg 103 on the Galicia margin (Shipboard Scientific Party, 1986). Serpentinites have been dredged from a number of large fracture zones in the Atlantic and Indian oceans (e.g., Dick et al., 1984; Kimball et al., 1985) and were recovered as cobbles when drilling at Sites 732 and 734 during ODP Leg 118 on the Southwest Indian Ridge (Robinson et al., 1988). Many serpentinites have been recovered from dredge hauls on the rift valley and rift mountain regions of the slow-spreading Mid-Atlantic Ridge and Mid-Indian Ocean Ridge, not associated with transform faults (Bonatti and Hamlyn, 1981); these were drilled by DSDP during Legs 37 (Shipboard Scientific Party, 1977) and 45 (Shipboard Scientific Party, 1976) and by ODP at Site 670 during Leg 109, at 23.09°N on the mid-Atlantic Ridge (Juteau et al., 1990).

The intrusion of serpentinite in these settings differs in a number of ways from serpentinites that originated above subduction zones. For example, along the Galicia margin where the general shape of the serpentinized mantle resembles the "dome" model, the serpentinite is exposed on a basement ridge similar in some respects to the Izu-Bonin seamount occurrences, not on an isolated, conical-shaped seamount as in the Mariana forearc.

The physical properties of the serpentinite seamounts, and the mechanism, mode of emplacement, and rate of uplift of each, were studied at all of the seamount sites (Sites 778 through 780 and 783 through 784) during Leg 125. Serpentinite protrusions (such as those in the Mariana forearc) may be able to entrain deep-seated fluids during formation and ascent and to lose these fluids during seepage of the serpentine flows onto the surface. There is strong evidence that the flows settled soon after they were erupted, perhaps as a result of the escape of entrained fluids. Once the rising serpentinite has stopped extruding and/or stopped venting fluids, it is likely that the density of the serpentinite will increase. The physical properties of the serpentinite thus may change with depth as well as with age. Documenting such changes and studying the physical properties of the seamount material will allow us to interpret in greater detail the sedimentary serpentinite deposits studied in subaerial exposures.

CHEMICAL FLUXES IN FOREARC TERRANES

An understanding of chemical fluxes at subduction zones is an essential prerequisite for investigating global geochemical mass balances. Currently, however, such fluxes are poorly defined. A major source of information comes from the study of the geochemistry of island-arc basalts, which has provided evidence for cycling of some trace elements, particularly the large-ion-lithophile elements, radiogenic strontium and lead, ^{10}Be, and volatile elements, such as water and chlorine (see the review in Gill, 1981). However, island-arc magmas may not be the sole pathway by which elements are recycled above subduction zones: fluid pathways may also exist within the forearc. Studies of interstitial waters from accretionary convergent plate margins revealed the importance of element transfer by fluid flow in accretionary wedges. These studies include those during

DSDP Legs 66 and 67 (Harrison et al., 1982; Gieskes et al., 1985) and Leg 84 (Hesse et al., 1985) in the Middle America Trench, during ODP Leg 110 on the Barbados Ridge (Shipboard Scientific Party, 1988a), and during ODP Leg 112 at the Peru continental margin (Shipboard Scientific Party, 1988b). The principal characteristics of these forearc fluids are low chlorinities and the presence of hydrocarbons, especially methane, which form gas hydrates, given appropriate temperatures, pressures, and partial pressure of the hydrocarbons.

By contrast, the nature and magnitude of fluid flow within the forearc at nonaccretionary margins still are poorly understood. In the Izu-Bonin-Mariana region, hydration of the crust and upper mantle of the forearc wedge is probably facilitated by the escape of fluids from the subducting Pacific Plate. Large regions beneath the forearc lie within the chlorite, greenschist, and blueschist stability fields (e.g., Sugimura and Uyeda, 1973). Widespread metamorphism of the forearc wedge might explain the apparent capacity of forearc regions to accommodate the potentially large volumes of fluid driven off a descending slab over millions of years of subduction (Fryer and Fryer, 1987).

The Mariana serpentinite seamounts provide access to the products of alteration and metamorphism of a central forearc region that have formed by reaction with components derived from the subducting slab, and through which we can trace the changes in pressure-temperature regimes of the deep forearc. At Conical Seamount (Sites 778–780), fluids are known to be seeping from carbonate and silicate chimneys on the summit of the seamount and are precipitating cements within the uppermost portion of the sedimentary serpentinite flows (Fryer et al., 1987). Drilling at Sites 778 through 780 thus provided scientists an opportunity to sample the escaping fluids and metamorphosed xenoliths within the serpentine flows. At the Torishima Forearc Seamount (Sites 783 and 784), on the seaward part of the forearc, there is no evidence of active fluid exhalation, but study of the serpentine sediments and flows, along with entrained clasts at this locality, may provide an indirect record of the composition and metamorphism of the Izu-Bonin forearc and also provide a limited basis for comparison of the two forearc terranes.

Studies of the composition of fluids actively seeping from chimney structures on Conical Seamount revealed fluids of high pH and high alkalinity that are enriched in CH_4 and H_2S. The presence of these gases is particularly interesting. Because the Mariana forearc has only a small volume of sedimentary substrate (Hussong and Uyeda, 1981) with organic carbon contents typically less than 0.3% (Schorno, 1981), the methane and sulfide in the Mariana vent fluids are unlikely to have formed by the biogenic processes associated with accretionary complexes (Kulm et al., 1986), unless sedimentary underplating is more extensive than hitherto believed. It is probable, therefore, that they were generated during serpentinization reactions. The chemical analyses of these fluids imply that interaction with deep-seated, perhaps subducted, fluids; interaction of seawater with crustal rocks, and interactions of seawater with the surficial serpentinite may all contribute to the composition of these fluids.

Trace-element and stable-isotopic compositions of the carbonate chimney materials and serpentinized matrix from Conical Seamount are consistent with a source of these fluids that is not the same as that in serpentinite and associated carbonates from other environments (Haggerty, 1987; R. Sakai et al., pers. comm., 1989). Compared to fracture zone carbonates thought to have a dominantly seawater origin, for example, Mariana aragonite is depleted in strontium (Mariana samples = 7,000–9,400 ppm; fracture zone aragonite = 9,500–11,600 ppm), enriched in magnesium (Mariana = 750–6,300 ppm, fracture zone, ppm), and has a significantly lighter carbon isotopic signature (Mariana = −1.2 to −21.2 ‰, fracture zone = +0.03 to +1.12 ‰) and heavier oxygen isotopic signature (Mariana = +5.1 to +7.6 ‰, fracture zone = +3.16 to +4.87 ‰). These differences may indicate that serpentinite-related fluids in forearcs contain components from either the forearc mantle or the subducted slab or both (Haggerty, 1987; R. Sakai et al., pers. comm., 1989). By detailed sampling at depth within the serpentinite body and in the neighboring country rock, it should be possible to constrain either the nature of the shallow level reactions influencing the fluid composition or the possible sources of the fluids.

DRILLING OBJECTIVES

The Izu-Bonin and Mariana regions are two of the best-studied intraoceanic arc-trench systems. Yet fundamental questions remain unanswered about their evolution with regard to arc/forearc magmatism and structure, arc/forearc stratigraphy and vertical tectonics, and outer forearc serpentinite diapirism. To address these questions, the Leg 125 objectives were designed as follows:

Mariana Site 781 and Izu-Bonin Sites 782, 785, and 786 were to investigate the following:

1. The vertical tectonic history of the forearc to provide information about (1) forearc flexure and basin development and (2) the extent of tectonic erosion;
2. The stratigraphy of the forearc with its record of (1) sedimentation, depositional environment, and paleoceanography and (2) the variations in intensity and composition of arc volcanism over time;
3. The nature of the igneous basement of the volcanic arc, outermost forearc, and the intervening basin as a source of information for the initial stages of subduction-related volcanism, the origin of boninites, and the formation of the 200-km-wide arc-type forearc crust; and
4. The microstructural deformation and the large-scale rotation and translation of the forearc.

Mariana Sites 778 through 780 and Bonin Sites 783 and 784 were to investigate the following:

1. The timing and mechanism of emplacement of the serpentinite seamounts, including their internal fabric, fracture patterns, and flow structures;
2. The conditions at depth in the outer forearc from the igneous and metamorphic petrology of the lower crust and upper mantle rocks;
3. The chemistry, and hence source, of the associated fluids; and
4. The nature of regional fluid fluxes in forearc regimes and, by implication, the transfer of material from the descending slab into the mantle wedge.

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