IODP Expedition 352: Izu-Bonin-Mariana Forearc

Site U1442 Summary

Background and Objectives

The Izu-Bonin-Mariana (IBM) forearc is believed to have formed during the period of seafloor spreading that accompanied the rapid rollback and sinking of the newly subducting Pacific plate immediately following subduction initiation at 51–52 Ma. The deepest and oldest volcanic rocks appear to be forearc basalts (FAB), a distinctive type of volcanic rock akin to mid-ocean ridge basalts that has been recovered during dredging and submersible sampling of the IBM Forearc, as well as by drilling at Sites U1440 and U1441. More strongly subduction-affected magnesian lavas called boninites also erupted in the IBM nascent arc. These lavas are named after the type section on the island of Chichijima in the Bonin Islands, and were also drilled at Site U1439.

End-member hypotheses about the nature of the IBM volcanic stratigraphy before drilling started at Site U1442 were (1) that FAB is overlain by the initial products of arc volcanism; namely lavas with compositions that are transitional between FAB and boninite, boninite lavas themselves, and then by more typical island arc lavas; and (2) that this stratigraphy was offset at progressive distances westward from the trench, such that each lava type was underlain solely by its own plutonic equivalents. Hypothesis (1) has the implication that melting sources evolved through time beneath specific forearc locations, whereas hypothesis (2) implies that the strongly subduction-affected, and younger, boninites erupted to the west of FAB crust, which itself was produced shortly after subduction initiation and nearer to the nascent subduction zone.

Site U1442 (proposed Site BON-5A) was chosen for the final drilling location because it was significantly more likely to provide lavas with compositions between those of FAB and boninite than the other remaining approved site (BON-3A). The specific drilling location was selected to be as far to the east of Site U1439 (~1.35 km) as we could drill while remaining within the approved limits of Site BON-5A. This eastward offset allowed us to target a location to the east of a west-dipping normal fault identified along multichannel seismic Line 1Br11 that had the potential of placing us deeper into the volcanic stratigraphy than at Site U1439. Having a site this close to Site U1439 also provided the opportunity to determine how the thicknesses of the igneous units changed from east to west, which would allow better constraints on vent migration through time and on compositional variations between vents. As with Site U1441, Site U1442 was also intended to determine whether the compositions of IBM forearc lavas are entirely gradational between FAB and boninite, or whether a compositional gap exists between these two end-members. Thus, this was our final site for enhancing our understanding of the forearc crustal architecture, as well as the dynamics of subduction and concomitant mantle flow that led to the development of the Izu-Bonin-Mariana arc.

The specific Site U1442 objectives fit into the four overall expedition objectives as follows.

1. Obtain a high-fidelity record of magmatic evolution during subduction initiation by coring volcanic rocks down to underlying intrusive rocks, including radiometric and biostratigraphic ages.

Coring of the volcanic succession at Site U1442 was targeted to provide lavas with compositions and ages between FAB and boninite, as well as to better understand the areal distribution of boninites.

2. Use the results of Objective 1 to test the hypothesis that forearc basalt lies beneath boninites and to understand chemical gradients within these units and across their transitions.

We expected FAB to be present at the base of the Bonin forearc volcanic succession, and a sequence of boninitic and arc-like lavas to be present at the top, but results at Sites U1439, U1440, and U1441 suggest that these lavas might be offset more horizontally than vertically. Site U1442 was targeted at lavas that are deeper than those encountered at Site U1439 and with compositions and stratigraphic positions between boninite and FAB. The goal was to better document the nature of the transitions in magma types with space and time, and thus how mantle and subducted sources and processes changed with time as subduction progressed. We also expected this site to allow us to investigate more thoroughly the interplay between decompression melting of the mantle above the subducting slab, and the timing, scope, and location of the first fluid fluxes involved in magma genesis.

3. Use drilling results to understand how mantle melting processes evolve during and after subduction initiation.

Determining how lava compositions and their locations of eruption change with time after subduction initiation in the IBM system addresses this objective. FAB compositions indicate that adiabatic decompression is the most important process at the beginning of subduction initiation, and boninites indicate that flux melting of more depleted mantle was important shortly thereafter. Information obtained from the Site U1442 cores will be used to construct more realistic models of when and where this change in mantle melting processes occurred.

4. Test the hypothesis that the forearc lithosphere created during subduction initiation is the birthplace of supra-subduction zone ophiolites.

Drilling at Site U1442 was targeted to provide more information about the volcanic chemostratigraphy of the Bonin forearc, enhancing our ability to compare the IBM forearc with supra-subduction zone ophiolites, such as Pindos in Greece, Mirdita in Albania, Semail in Oman, and Troodos in Cyprus.

Operations

The *JOIDES Resolution* completed the 5.5 nmi transit from Site U1441 in dynamic positioning mode while the drill string was being raised from the seafloor. The vessel arrived at Site U1442 (proposed Site BON-5A) at 1630 h on 14 September 2014 (all times reported are ship local time, which is UTC + 9 h), and a seafloor positioning beacon was deployed. The vessel then offset 500 m at an azimuth of 81°.

A rotary core barrel (RCB) bottom-hole assembly was assembled with a C-4 bit and then lowered to the seafloor. Hole U1442A was spudded at 2320 h on 14 September 2014 (28°24.5784′N, 142°37.3368′E, 3162 m water depth). The RCB coring system with non-magnetic core barrels was deployed 57 times (Cores U1442A-1R to 57R), with 529.8 m cored and 100.7 m recovered (19%). The basement contact was at ~82 mbsf. A free-fall funnel was deployed on 19 September so that the RCB bit could be changed upon reaching 46.1 h of coring time. Hole U1442A was terminated when the time available for coring expired. The hole was then logged with the triple combo–magnetic susceptibility sonde (MSS) tool string (to 379 mbsf on the first pass and 305 mbsf on the second pass) and the Formation MicroScanner (FMS)–sonic (to 287 mbsf on both passes) tool string.

The total time spent on Hole U1442A was 235.75 h. The seafloor positioning beacon was recovered at 0940 h on 24 September. After the thrusters were raised at 1030 h on 24 September, the vessel started the transit to Keelung, Taiwan.

Principal Results

Sedimentology

Pelagic and volcaniclastic sediments were recovered from the seafloor to 83.1 mbsf, beneath which igneous rocks were drilled. The sediments represent part of the Late Oligocene to Recent deep-sea sedimentary cover of the Izu-Bonin fore-arc, which is stratigraphically condensed owing to its position on a basement high.

The recovered sedimentary succession is divided into four lithologically distinct units. Unit III subdivided into two subunits. The main criterion for the recognition of the lithologic units and subunits is a combination of primary lithology, grain size, color and diagenesis. Within the overall succession, 21 ash or tuff layers were observed.

Unit I (0–2.59 mbsf) is mostly silty to sandy nannofossil mud and nannofossil ooze, with additional dark gray “blotches” rich in volcanic glass that probably represent the remains of thin ash-rich layers.

Unit II (2.59–33.00 mbsf) is dominantly silty nannofossil ooze with slight color banding (off-white to pale brown), reflecting the presence of muddy and silty/sandy layers. The silty and sandy material is volcaniclastic in origin and is accompanied by several thin, discrete, ash layers, which are dispersed over tens of centimeter-thick intervals within the background sediment.

Unit III (33.00–62.40 mbsf) is subdivided into two subunits. Subunit IIIA (33.0–52.60 mbsf) is recognized by the presence of brownish mud and nannofossil-rich mud. Subunit IIIB (52.60–62.40 mbsf) is relatively pure clay with some manganese-stained horizons and also nannofossil ooze intervals.

Unit IV (62.40–83.12 mbsf) is distinguished by nannofossil-rich sediments, which become more lithified downwards and transition to nannofossil chalk. These sediments contain variable amounts of clay, volcaniclastic silt/siltstone, and volcaniclastic fine sand/sandstone. The most clastic-rich sediment can be classified as nannofossil-bearing fine sand/sandstone. The sedimentary succession is terminated downwards by a thin manganese layer, followed by a profound change to brownish red, non-calcareous volcanogenic sandy and silty clay, interspersed with clasts of mafic extrusive igneous rocks.

Biostratigraphy

Calcareous nannofossils were examined in core catcher Samples U1442A-1R-CC to 9R-CC. An additional sample was taken from Section U1442A-10R-2, 22–23 cm, just above the layer containing igneous rocks. Preservation was “moderate” to “good” in each sample. A fairly continuous condensed section was recovered comprising sediments from the Eocene/Oligocene boundary up to as recent as the Late Pleistocene.

Fluid Geochemistry

Ten samples were collected from sediments at Hole U1442A for headspace hydrocarbon gas analysis as part of the standard shipboard safety monitoring procedure. Only minor methane was detected (1.08–1.29 ppmv), and the relatively low and uniform methane concentrations imply negligible concentrations of organic matter. No ethane or propane was detected.

Petrology

Igneous rocks were recovered in Hole U1442A, which penetrated over 440 m of igneous basement. The top of the igneous basement is defined by a Mn-rich sediment layer. The uppermost part of the section comprises breccias that may represent seafloor colluvium. These are underlain by boninitic lavas and hyaloclastites. Hole U1442A contains multiple zones of faulting.

Hole U1442A recovered similar igneous units to those in Hole U1439C, which lies ~1.3 km away. Nevertheless, there are notable differences between the two holes. Hole U1442A recovered low- and high-silica boninites together with evolved low-silica boninites. However no basaltic boninites were recovered and no dikes were encountered. Given the proximity of the two sites and the wealth of pXRF data we correlated like units between the sites. However, faults were encountered in Holes U1439C and U1442A, most indicating normal slip and some with evidence for reverse and oblique strike-slip motion. These faults raise the possibility that their stratigraphic records were disturbed and that the two sites were originally further apart. However, with the exception of the Unit 1–2 boundary discussed below, units continued across fault surfaces at both holes suggesting that the stratigraphic record disturbance was minimal. We have no evidence for significant strike-slip motion between the sites, but such motion cannot be ruled out based on present knowledge.

Unit 1 (83–250 mbsf) consists mostly of hyaloclastites and lava flows of high-Si boninitic affinity. Unit 1 at Hole U1439C compositionally correlates with this unit, but contains significantly less hyaloclastite. The most distinctive chemical feature of the upper section of Hole U1442A is the variable Cr content, which reaches values in excess of 1000 ppm. Below a fault zone at 240–270 mbsf, which separates Subunit 1e from Subunit 2a, Cr contents drop significantly and, with a few exceptions, remain below 500 ppm. Units 2, 3, and 4 contain what appear to be mingled magmas of evolved boninite intruded by less evolved boninite. The subtle petrographic and chemical differences seen below Unit 1 were used to define subunits.

Finally, a striking feature of Hole U1442A is its excellent preservation in comparison to Site U1439, which is located only ~1.3 km away. Fresh glass is pervasive throughout the entire igneous interval in Hole U1442A, making it an invaluable resource for postcruise research requiring primary material.

Rock Geochemistry

Seven sediment samples were analyzed from Hole U1442A (one per core from Cores U1442A-1R to 4R, 7R, 8R, and 10R) for carbonate contents. Carbonate contents range from 50 to 78 wt%, except for one sample (7R-5, 49–50 cm) with ~0.6 wt% carbonate.

We selected 21 representative igneous rock samples from Sections U1442A-11R-1 through 43R-1 to be analyzed for major and trace element concentrations by ICP-AES. In addition, H_2O and CO_2 concentrations were determined for any samples with LOI > 2%. The rock surfaces of 167 archive-half pieces were analyzed pXRF instrument for chemostratigraphic purposes.

The igneous rocks analyzed from Hole U1442A are primarily boninites and their andesitic to dacitic differentiates. The samples have SiO_2 contents of 52.5–63.4 wt%, total alkali ($Na_2O + K_2O$) contents of 1.44–4.74 wt%, and MgO contents of 2.6–17.0 wt%. Primitive magmas from Sites U1439 and U1442 have wide ranging major and trace element compositions allowing boninite series with different genetic histories to be distinguished. We adopted the nomenclature of basaltic boninite, low-Si, boninite and high-Si boninite for these series, and were able to track the differentiates for each series based on mineral abundances and variations in the concentrations of SiO_2, MgO, and TiO_2. Site U1442 extend to less high alkali abundances compared to Site U1439, reflecting the greater degree of alteration in the latter.

Structural Geology

Bedding planes are subhorizontal in the sedimentary units above 75 mbsf, with dips generally <10°. Between 75 and 155 mbsf, the bedding planes dip ~ 35° on average. This change in dip angle defines an angular discordance at ~27–32 Ma based on biostratigraphic ages. In the igneous units, magmatic structures include contacts between distinct rock types, laminations, flow banding structures, alignments of elongated vesicles, and magmatic breccias. In general, magmatic minerals exhibit relatively weak to moderate alignment. Tectonic structures in the basement include shear fractures, cataclastic shear bands, cataclastic shear zones, veins, slickensides, and breccias. Three main fault zones occur at 238.2–267.5 mbsf, 432.8–444.8 mbsf, and 490.9–502.2 mbsf. The uppermost fault zone comprises fault gouge rich in talc and zeolites, including phillipsite. Slickensides dominantly indicate reverse dip-slip motion, although normal and oblique sense of shear is also observed.

Physical Properties

In the sediments, *P*-wave velocity, magnetic susceptibility, and GRA density values increase across the boundary between Subunit IIIB and Unit IV at 62 mbsf. This depth corresponds to a strong reflector in the seismic profile across the site. Natural gamma ray (NGR) values decrease from the seafloor to the base of Unit IV, with the exception of higher values in Subunit IIIB (clay layer).

In the igneous basement, magnetic susceptibility values are low in Unit 1 (boninite hyaloclastite) and increase abruptly at 260 mbsf near the top of Unit 2 (evolved boninite lavas). NGR values decrease gradually from the top of Unit 1 (83 mbsf) to the base of Unit 4 (523 mbsf). *P*-wave velocities are high and porosities are low in discrete samples taken from 83–170 mbsf and 305–480 mbsf. Thermal conductivity values are relatively constant in Unit 1 and Subunit 2A, increase in Subunit 2B, and decrease in Units 3 and 4.

Paleomagnetism

Sediment cores U1442A-2R to 9R were measured with the pass-through cryogenic magnetometer. However a discontinuous record, poor recovery, and drilling-related deformation makes it impossible to interpret the magnetic stratigraphy reliably.

Paleomagnetic samples from the igneous units give paleoinclinations mostly near zero. Low negative inclinations predominate in the upper part of Hole U1442A above 400 mbsf, whereas low positive inclinations are seen below 440 mbsf. These shallow inclinations are consistent with the low paleolatitude of the Izu-Bonin arc at the time of its formation. Transitions between positive and negative inclinations above 400 mbsf are most likely the result of secular variation at low latitudes. The shift to positive inclinations in the lower part of the hole may indicate a magnetic reversal or simply eruption of igneous Units 3 and 4 in a short interval, during which there was little secular variation. Interestingly, the Hole U1439C igneous section shows mainly low positive magnetic inclinations, whereas that of Hole U1442A mostly shows low negative inclinations. This difference may represent a change in magnetic polarity.

Downhole Logging

Hole U1442A was logged with the triple combo-MSS and FMS-sonic tool strings. The borehole diameter was within the limits needed for the tools to function properly but the borehole conditions deteriorated during the first tool string deployment, with the hole filling in ~84 m by the time the second tool string was deployed. Weather conditions and sea state were excellent, with peak-to-peak heave <1 m. Natural gamma radiation, bulk density, resistivity, magnetic susceptibility, sonic velocity, and microresistivity images were acquired.

Overall, increases in density, resistivity, *P*-wave velocity, and magnetic susceptibility values are observed with depth, whereas gamma ray values decrease. Eight logging units are defined on the basis of distinguishing features and trends in the various logs. Logging Unit 1 (~95–120 mbsf) is characterized by decreasing gamma ray and velocity values, coupled with increasing resistivity and magnetic susceptibility values downhole. Logging Unit 2 (~120–188 mbsf) is differentiated from the overlying unit by elevated gamma ray and resistivity values and consistently low magnetic susceptibility values. There is increased borehole rugosity in Logging Unit 3 (~188–204 mbsf), which may account for the significant variability across the logging data sets, distinguishing it from the units above and below. Logging Unit 4 (~204–232 mbsf) has lower variability in the gamma ray and density logs and magnetic susceptibility values decrease with depth. Low magnetic susceptibility values, punctuated by three significant peaks, is the defining feature of Logging Unit 5 (~232–258 mbsf) in combination with high variability in gamma ray values. Logging Unit 6 (~258–282 mbsf) is characterized by decreasing downward trends in both resistivity and density values, which is counter to the overall trend in Hole U1442A. The character of the gamma ray, density, and resistivity logs is markedly different in Logging Unit 7 (~282–326 mbsf) compared to the overlying unit. Finally, Logging Unit 8 (>326 mbsf) does not have full data coverage but is differentiated from Logging Unit 7 by a relatively constant gamma ray profile and a less variable resistivity log. Oriented microresistivity borehole images indicate a range of textures and structural features, including veins, fractures, and vesicles.

The downhole logging data share similarities with the corresponding core physical properties and geochemical data. However, the logging unit boundaries that are defined on the basis of petrophysical properties do not correlate directly with the petrological boundaries. Postcruise core-log interpretation will focus on fully integrating the downhole and core data sets.