IODP Expedition 352: Izu-Bonin-Mariana Forearc
Site U1441 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 recovered during dredging and submersible sampling of the IBM Forearc. Drilling at Site U1440 also intersected this rock type.

The initial reconstruction of the IBM volcanic stratigraphy based on the diving and dredging provided evidence that FAB is overlain by the initial products of arc volcanism, specifically: lavas with compositions that are transitional between FAB and boninite, followed by boninite lavas themselves, and finally, by members of the tholeiitic and calc-alkaline series typical of "normal" island arcs. This stratigraphy was considered speculative, however, because it was pieced together from samples collected at sites that were a considerable distance apart. Coring at Sites U1439 and U1440 ended in doleritic dike rocks with compositions resembling the overlying lavas, suggesting an alternative crustal architecture, which is that boninites erupted to the west of FAB crust.

Site U1441 was chosen for drilling because it was the most promising location of the remaining approved sites for further refining the sequence from FAB to boninite, as well as for providing further understanding of the pattern of eruption of these lava types. This site also was chosen 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. If lavas with transitional compositions were to be found at Site U1441, then this site also would provide the opportunity to determine the relative ages of these lavas compared to boninite and FAB. This would enhance our understanding of the forearc crustal architecture and the timescale of its construction. Ultimately, the data from all sites will allow us to better constrain the dynamics of subduction and concomitant mantle flow that led to the development of the Izu-Bonin-Mariana arc.

The specific Site U1441 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 U1441 was targeted to provide lavas with compositions and ages between FAB and boninite.

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 and U1440 allow for these lavas to be offset more horizontally than vertically. Clearly, the nature of the transitions from one magma type to the next needs to be better understood to enable us to more fully document how mantle and subducted sources and processes changed with time as subduction progressed. Site U1441 was targeted at lavas with compositions and stratigraphic positions between boninite and FAB. This site was therefore chosen to better define how the lava compositions changed in time and space, and investigate 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 will address this objective. FAB compositions indicate that adiabatic decompression is the most important process at the very beginning of subduction initiation, and boninites indicate that flux melting of more depleted mantle was important shortly thereafter. Information obtained from the Site U1441 cores may allow construction of 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 U1441 was targeted to provide a crucial middle section of 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 6.2 nmi transit from Site U1439 in dynamic positioning mode while the drill string was being lowered to the seafloor. The vessel arrived at Site U1441 (proposed Site BON-6A) at 1512 h on 11 September (all times reported are ship local time, which is UTC + 9 h), and a seafloor positioning beacon was deployed.

Site U1441 consists of one hole. A rotary core barrel (RCB) bottom-hole assembly was assembled with a C-4 bit. Hole U1440A was spudded at 2245 h on 11 September 2014. The RCB coring system with non-magnetic core barrels was deployed 22 times (Cores U1441A-1R to 22R) and the hole was advanced to 205.7 mbsf. Cores U1441A-11R and 12R had no recovery as a result of a plugged bit. Hole U1441A was terminated as a result of poor core recovery and the rubbly nature of the formation and high risk of getting stuck. The RCB cores recovered 50.7 m over the 205.7 m interval cored (25%). The total time spent on Hole U1441A was 75.75 h. The seafloor positioning beacon was recovered at 0914 h on 14 September, and the vessel started the slow transit to Site U1442 while continuing to pull the drill string to the surface.

Principal Results

Sedimentology

Pelagic and volcaniclastic sediments were recovered from the seafloor to 83.00 mbsf, beneath which igneous rocks were recovered. The sedimentary succession is divided into five lithologically distinct units. Unit I is further divided into two subunits. The volcanic rocks beneath are interpreted as the forearc basement. 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, 16 ash or tuff layers were

observed. The bedding planes are generally oriented sub-horizontally, with dip angles <10º.

Unit I (0–15.02 mbsf) is subdivided into two subunits. Subunit IA (0–0.17 mbsf) is recognized by the occurrence of brownish mud with medium to coarse sand. Subunit IB (0.17–15.02 mbsf) is a relatively nannofossil-rich interval of silty calcareous ooze with nannofossils and sparse planktic foraminifers.

Unit II (15.02–24.50 mbsf) is recognized on the basis of a downward change to more clastic-rich sediments composed of muddy volcanic breccia-conglomerate and volcaniclastic sand layers.

Unit III (24.50–58.64 mbsf) is characterized by a return to finer grained silty mud with relatively abundant radiolarians.

Unit IV (58.64–70.38 mbsf) is distinguished by a distinct downward change to greener colored, relatively fine-grained sediments, which are dominated by greenish gray silty clay.

Unit V (70.38–83.00 mbsf) is a much coarser mud-supported conglomerate with sandy and silty clay and also clay.

Biostratigraphy

Calcareous nannofossils were present in three of 10 core catcher samples. Samples U1441A-1R-CC and 2R-CC are nannofossil oozes, whereas siliceous fossils dominate Sample 5R-CC. Preservation was “moderate” to “good” in each sample. Samples U1441A-1R-CC and 2R-CC yield an approximately Late Pleistocene age, whereas Sample 5R-CC yields an approximately late Miocene age (5.59–8.12 Ma). The widespread presence of radiolarians in the lower part of the sediments will help us improve the biostratigraphy postcruise.

Fluid Geochemistry

Ten samples were collected from Hole U1441A for headspace hydrocarbon gas analysis as part of the standard shipboard safety monitoring procedure. Methane concentrations range from 1.08 to 1.29 ppmv, and neither ethane nor propane were detected.

Petrology

All of the igneous rocks at Site U1441 are forearc basalts (FAB) similar to those drilled at Site U1440. These basalts are very similar texturally and chemically to FAB recovered in diving expeditions in the region. They are dominated by modal plagioclase and clinopyroxene in the groundmass, and most are aphyric. Four units were identified based on hand specimen and thin section description and XRF data. Microphenocrysts of plagioclase are rare, but Unit 3 contains 2%–3% clinopyroxene phenocrysts. Not surprisingly, Unit 3 is also the unit with the highest CaO content. Three chemical varieties of basalt were found. The upper basalts (Units 1 and 2) are depleted in TiO_2 and Zr, and have low Cr concentrations. The lowest basalts, which comprise Unit 4, are normal FAB very close in composition to those at Site U1440. In contrast, basalts that lie stratigraphically between these types are among the most depleted basalts found along the IBM Forearc, with very low TiO_2 and Zr concentrations and high Ti/Zr ratios. With the exception of Unit 3, TiO_2, Zr, and Cr all show subtle increases steadily downhole.

Rock Geochemistry

Seven igneous rocks from Cores U1441A-10R to 22R were analyzed by ICP-AES for major and trace elements and by CHNS for CO_2 and H_2O contents. The igneous rocks recovered have LOI of 2.0–4.6 wt%. They have higher H_2O contents in the upper part of the basement (Unit 1) and relatively uniform H_2O contents of 2.0–2.5 wt% in the lower units.

The igneous rocks recovered from Hole U1441A are all basalts, with SiO_2 concentrations of 49–51 wt% and total alkali contents of 2–4 wt%. Overall, the major element composition of Site U1441 basalts is relatively homogeneous with MgO of 6.4–8.4 wt%, CaO of 10.7–11.6 wt%, and Fe_2O_3 of 10.8–12 wt%. Site U1441 basalts mainly plot in the compositional field of MORBs and are very similar in composition with the IBM forearc basalts previously recovered by drilling at Site U1440 and by diving. The single sample analyzed from Unit 3 has a high Mg#, low TiO2, high Cr, and low Zr and Y. This sample plots as a magnesian end-member composition on trace element variation diagrams but, despite its lower Ti contents, is both geochemically and petrographically distinct from Site U1439 boninites.

Structural Geology

In the igneous units, viscous-plastic fabrics related to magmatic flow are rare and limited to millimeter- to centimeter-wide domains, defined primarily at the microscale. These domains are relatively common in the lower parts of Hole U1441A (e.g., in Sections U1441A-19R-1 and 22R-1). The magmatic foliation is mainly defined by the shape-preferred orientation of acicular feldspar crystals embedded within a glassy or microcrystalline matrix.

Extensional fractures without mineral fillings are subvertical and are observed at 85.15 and 180.45 mbsf. Subvertical to inclined, whitish, crystalline, millimeter-thick veins are abundant at 122.22–141.43 mbsf and 190.2–190.6 mbsf. In the lower interval the veins form steeply inclined conjugate sets. The vein-filling material consists of (Mg-) calcite and/or zeolite and/or chlorite.

Slickensides are abundant at 84.00–88.25 mbsf and dip steeply to subvertically. The general sense of shear is left-lateral strike-slip to oblique reverse including a left-lateral component as well. One subhorizontal slickenside shows a normal sense of shear. In the lowermost sections of Hole U1441A (Section 20R-1, 15–27 cm), a semiductile to brittle, low-angle shear zone was observed within a highly altered domain. The shear zone was recovered as a single piece with an oblong shape, without a preserved contact with the wall rock. Its position within the lithostratigraphic sequence cannot be defined exactly because of the poor core recovery. The recovered basalt pieces below and above do not show any indication of comparable alteration or deformation. Within the shear zone, shear bands form subparallel sets, indicating top-down sense of shear.

Physical Properties

Many of the physical properties display similar downhole trends in the sedimentary section. *P*-wave velocities have peaks as high as 1580 m/s at 22–24 mbsf (Unit II) and 1540 m/s at 56–58 mbsf (Unit III). Magnetic susceptibility values also have peaks to 250–300 IU at the same depths. These peaks in *P*-wave velocities and magnetic susceptibility values correspond to tephra layers. Gamma ray attenuation (GRA) densities are 1.4–1.5 g/cm^3 and natural gamma ray (NGR) values are 10–20 cps from 0 to 69 mbsf. All of these parameters have a high peak at 70 mbsf at the bottom of Unit IV. Porosities are 65%–85% from 0 to 78 mbsf. Porosities are higher than 80% in Unit II and have the lowest value of 70% in Unit III.

Physical properties can be divided into two intervals in the basement section. In Units 1–4, magnetic susceptibility values start at >1000 IU at the top of the basement, at ~85 mbsf in Unit 1, and decrease to 500 IU in Units 2–4. GRA density values are 2–2.5 g/cm^3 with a peak of 2.7 g/cm^3 at 171 mbsf in Unit 3. NGR values increase from 9 to 20 cps in Unit 1 and decrease to 5 cps in Units 2–4. Although the values of reflectance parameter L* remain steady at 50–55 in Units 1–4, both a* and b* values are high (>10) in Unit 1 and low (<5) in Units 2–4. Bulk densities of the discrete samples are 2.4 g/cm^3 in Unit 1 and increase to ~2.8 g/cm^3 in Units 2–4. Porosities are ~30% in Unit 1 and decrease to 10% in Units 2–4. *P*-wave velocities of discrete samples are 3000–4000 m/s in Unit 1 and increase to 5500 m/s in Units 2–4.

Paleomagnetism

The remanent magnetization of archive-half sediment sections from sediment Cores U1441A-3R to 9R was measured with the cryogenic magnetometer. The magnetic inclinations of the sediments define normal and reversed polarity zones. The inclinations are steep, typically >60°, which is probably the result of sediment disturbance by rotary coring. However, there are significant gaps in core recovery that hinder interpretation. In addition, the reversal pattern shows a small number of polarity zones, whereas there should be several on the basis of the biostratigraphic ages and the geomagnetic polarity time scale. Thus, we are unable to interpret the polarity record of the sediments in Hole U1441A.

The remanent magnetization was measured on 14 igneous rock samples from Cores U1441A-10R to 22R. These samples have both normal and reversed polarities with two normal polarity zones at the top and bottom of the section bracketing a reversed polarity zone. The magnetic inclinations are close to that of the current field, implying that these rocks may have been remagnetized in the near geologic past. Most of the samples are from igneous Unit 1, which is thought to consist of talus, so the coherent inclinations are surprising. Therefore, remagnetization could explain the coherency of the jumbled pile of rocks.