International Ocean Discovery Program
Expedition 352 Scientific Prospectus

Izu-Bonin-Mariana Fore Arc

Testing subduction initiation and ophiolite models by drilling the outer Izu-Bonin-Mariana fore arc

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Abstract

During International Ocean Discovery Program Expedition 352, we intend to drill a section through the volcanic stratigraphy of the outer fore arc of the Izu-Bonin-Mariana system in order to trace the processes of magmatism, tectonics, and crustal accretion associated with subduction initiation. This study in turn has implications for understanding the origin of the many ophiolites that are now believed to form in this setting, and the expedition provides a good opportunity to test this supra-subduction zone ophiolite model. We intend two primary sites in the Bonin fore arc (Sites BON-1A and BON-2A), which form an offset-drilling pair that together should penetrate the full ~1.25 ± 0.25 km lava section. The sites have been surveyed and surface-sampled by several diving and dredging cruises. Studies of the recovered samples have established a stratigraphy in which peridotites, gabbros, and sheeted dikes are overlain by "fore-arc basalt" (FAB) and then in turn by boninites. Drilling Sites BON-1A and BON-2A will contribute to our understanding of intra-oceanic convergent plate margins by providing (1) a high-fidelity record of magmatic evolution during subduction initiation; (2) a test of the hypothesis that FAB tholeiites lie beneath boninites; (3) a record of the chemical gradients within these units and across their transitions; (4) information on how mantle melting processes evolve during subduction initiation from early decompression melting of fertile asthenosphere to late flux melting of depleted mantle, providing key empirical constraints for realistic subduction initiation geodynamic models; and (5) a test of the hypothesis that fore-arc lithosphere created during subduction initiation is the birthplace of supra-subduction zone ophiolites. Deep Sea Drilling Project Site 459 in the Mariana fore arc provides a well-surveyed alternate site of similar age, stratigraphy, and setting that should allow coring of a similar lava sequence to Site BON-1A.

Schedule for Expedition 352

International Ocean Discovery Program (IODP) Expedition 352 is based partly on IODP drilling Proposal 696-Full4 (available at **iodp.tamu.edu/scienceops/expeditions/izu_bonin_forearc.html**). Following ranking by the Integrated Ocean Drilling Program Scientific Advisory Structure, Expedition 352 was scheduled for the research vessel R/V *JOIDES Resolution*, operating under contract with the U.S. Implementing Organization (USIO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Yokohama, Japan, on 30 July 2014 and to end in Keelung, Taiwan, on 29 September 2014. A total of 61 days will be available for the drilling, coring, and downhole measurements described in this report (for the current schedule, see **iodp.tamu.edu/scienceops/**). Further details about the facilities aboard the *JOIDES Resolution* and the USIO can be found at **www.iodp-usio.org/.**

Introduction

Expedition 352 was designed to decode the earliest evolution of arc crust at the Izu-Bonin-Mariana (IBM) arc-trench system. The expedition was based on achieving a full volcanic stratigraphy for the IBM fore arc that will provide a basis for determining the petrogenetic evolution of the magmas that immediately postdate subduction initiation. This in turn will enable us to test hypotheses for the geodynamics of subduction initiation.

The lavas drilled will be the first products of the subduction factory, the crust produced when subduction begins. Crustal production rates at this time are much (perhaps an order of magnitude) greater than those estimated for mature arcs. The mode of crustal production during the initial stages of arc development appears to be the result of extension and seafloor spreading accompanying lithospheric collapse and asthenospheric upwelling (e.g., Stern, 2004) and is quite different from the focused magmatism that characterizes mature magmatic arcs. The early, voluminous volcanism associated with subduction initiation is also responsible for many, perhaps most, ophiolites, themselves key indicators of Earth's changing tectonics and the magmatic, hydrothermal, and tectonic processes that accompany seafloor spreading. The IBM fore arc is an excellent, probably the best, modern analog for supra-subduction zone (SSZ) ophiolites and is the ideal place to probe the structure of infant arc crust. The area has already been studied by drilling, including the highly successful Deep Sea Drilling Project (DSDP) Sites 458 and 459 in the Mariana fore arc (e.g., Natland and Tarney, 1982) and Ocean Drilling Program (ODP) Site 786 in the Izu-Bonin fore arc (e.g., Pearce et al., 1992). However, these sites were drilled as relatively minor parts of drilling legs; there has been no dedicated fore-arc drilling leg, and hence there is no full lava stratigraphy of the detail needed to interpret subduction initiation and make the ophiolite link.

Expedition 352 provides an opportunity to investigate oceanic crustal accretion following the initiation of subduction, the proposed setting of SSZ ophiolites, the most common ophiolite type (Pearce, 2003). The origin of SSZ ophiolites is still debated, however. The original Miyashiro (1973) contention, that ophiolites originated as the roots of island arc volcanoes, was contested in print but never tested. The subduction initiation/infant arc model of Stern and Bloomer (1992) provides a way for near-trench seafloor spreading to produce a SSZ ophiolite, frozen in place to become fore-arc lithosphere, ready to be obducted when buoyant crust enters the trench. The discovery of voluminous basalts in the IBM fore arc overlain by boninites (Reagan et al., 2010) is clear support for the fore-arc origin of SSZ ophiolites, but these basalts have not yet been investigated by IODP. The IBM fore-arc stratigraphy makes it a particularly good place for IODP to realize the important Initial Science Plan objective: "…the validity of the ophiolite model, will only be addressed by direct, in situ sampling of the lower oceanic crust and Moho by drilling. A high priority is to recover intact and tectonically undisrupted sections…" (Bickle et al., 2011). The chosen sites will provide a vertical observatory, enabling study of subduction initiation and comparison of subduction initiation and ophiolite lava sections.

Background

The Izu-Bonin-Mariana system

The IBM system is, as already noted, the type locality for studying oceanic crustal accretion immediately following subduction initiation. It is sufficiently old that it carries a full record of the evolution of crustal accretion from the start of subduction to the start of normal arc volcanism (a ~7 m.y. period) but sufficiently young that the key features have not been excessively disturbed by subsequent erosion or deformation. Intra-oceanic arcs are built on oceanic crust and are sites of formation of juvenile continental crust (Rudnick, 1995; Tatsumi and Stern, 2006). Most active intra-oceanic arcs are located in the western Pacific. Among these, the IBM system stands out as a natural scientific target. This predominantly submarine convergent plate boundary is the result of ~50 m.y. of subduction of the Pacific plate beneath the eastern margin of the Philippine Sea plate. Stretching for 2800 km from the Izu Peninsula, Japan, to Guam, USA (Fig. **F1**), the IBM system (summarized in Stern et al., 2003) has been extensively surveyed and is a very suitable natural laboratory for IODP expeditions aimed at understanding subduction initiation, arc evolution, and continental crust formation. The scientific advantages of studying the IBM were recognized by the U.S. National Science Foundation MARGINS-Subduction Factory experiment as the intra-oceanic arc focus site (the other focus site being the quasicontinental arc of Central America). Most importantly, the IBM fore arc is likely the best site on the planet for studying the initial magmatic products of a subduction zone. We know when subduction and arc construction began (~51–52 Ma; Ishizuka et al., 2011; Reagan et al., 2013), even if the precise paleogeography is controversial, and there is a good time-space record of crustal development.

Petrologic evolution

The petrologic evolution of early stage magmatism in the IBM arc has been reconstructed mainly based on volcanic sections that are exposed on the fore-arc islands (Bonin Islands and Mariana Islands) and that have been recovered from DSDP and ODP fore-arc drill sites. Recent dredging and submersible studies provide additional information (see **"Geology of the fore arc around proposed Sites BON-1A and BON-2A"**). Consequently, we can predict the sequence of magmas likely to characterize the drill site and its surrounding region, which developed prior to establishment of a stable magmatic arc ~150 km west of the trench by the Oligocene. This compositional evolution reflects the reorganization of mantle convection and slab-derived fluid flows in response to the changing behavior of the sinking Pacific plate: from sinking without downdip mantle motion to establishment of true subduction with downdip motion (see **"Tectonic evolution"**). This evolution, from (1) initial seafloor spreading and eruption of mid-ocean-ridge basalt (MORB)-like tholeiites to (2) eruption of boninites to (3) fixing of the magmatic arc ~150 km west of the trench (separated by a broad, dead fore arc) took ~7 m.y. (Ishizuka et al., 2011). The process is reflected in the succession of igneous rocks of the Bonin Ridge, which is described in greater detail below and depicted in the time-space diagram (Fig. **F2**).

Subduction initiation volcanism

Basaltic rocks have been recovered in the IBM fore arc from stratigraphic levels below boninite as described in **"Geology of the fore arc around proposed Sites BON-1A and BON-2A."** These basalts have chemical compositions that are similar to those of normal mid-ocean-ridge basalt (N-MORB), and the term "fore-arc basalt" (FAB) was coined by Reagan et al. (2010) to distinguish them from MORB. Most of the reliable $^{40}Ar/^{39}Ar$ ages and U-Pb zircon ages of FAB from the fore-arc slope east of the Bonin Ridge and south of Guam are identical within error and indicate that FAB magmatism occurred from ~50 to 52 Ma, preceding boninite eruption by at least 2–3 m.y. (Ishizuka et al., 2011). U-Pb zircon ages from gabbros below the FAB indicate that these are contemporaneous (Ishizuka et al., 2011; Reagan et al., 2013) and probably comagmatic. Lavas with compositions transitional between FAB and boninites from Site 458 were dated at 49 Ma (Cosca et al., 1998). FAB and related gabbros are thought to relate to the first magmas produced as the IBM subduction zone began to form (Reagan et al., 2010).

Geochemical data show the similarity of these basalts to MORB, with no (or minor) slab signature. FAB has light rare earth element–depleted rare earth element (REE) patterns, indicating derivation from a moderately depleted lherzolitic upper mantle, similar to that responsible for generating MORB (Fig. **F3**). FAB has low Ti/V ratios (14–16), which distinguish FAB from subducting Pacific MORB (26–32) and from Philippine Sea MORB (17–25) (Fig. **F4**). Chemically and petrographically, Bonin Ridge FAB is indistinguishable from Mariana FAB, which is also considered to be related to subduction initiation and which also predates boninitic volcanism in that region (Ishizuka et al., 2011). This strongly implies that FAB tholeiitic magmatism was associated with fore-arc spreading along the length of the Izu-Bonin-Mariana arc. Like the overlying boninites, the probable source of Mariana FAB was Indian Ocean–type mantle. Low concentrations of incompatible elements and low trace element ratios such as Nb/Yb imply that FAB magmas were derived from depleted mantle and/or were larger degree mantle melts compared to typical Philippine Sea MORB.

Pb isotopic compositions of FAB from the Bonin fore arc show that, like other IBM magmas, they are derived from a mantle with Indian Ocean characteristics, as demonstrated by high $\Delta 8/4$ Pb compared to Pacific MORB. Isotopic characteristics indicate some differences between the mantle sources of Philippine Sea MORB and FAB, including distinctly higher $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ (Fig. **F5**), which may imply the presence of lithospheric mantle with ancient enrichment (Parkinson et al., 1998). Most significantly, there is no evidence that subducted sediments (with elevated $^{207}Pb/^{204}Pb$) affected the source region of these basalts, although some FAB lavas from the Mariana fore arc have Pb isotopic compositions consistent with a weak subduction influence (Reagan et al., 2010). Differences in isotopic and trace element characteristics between IBM FAB and Philippine Sea MORB strongly imply that FAB does not represent the preexisting ocean crust of the West Philippine Basin, trapped prior to subduction initiation, as originally concluded by DeBari et al. (1999) for MORB-like tholeiites recovered from the Izu inner trench wall.

Lavas with compositions that transition upward between FAB and boninite were recovered at DSDP Leg 60 Sites 458 and 459 (the alternate site) and illustrate that FAB and boninite are genetically linked (Reagan et al., 2010). The oldest of these lavas have REE patterns similar to those of MORB but are more enriched in silica and have higher concentrations of “fluid-soluble” elements such as K, Rb, U, and Pb than FAB.

These lavas also have Pb isotopic compositions that are more similar to lavas from the Pacific than those of the Indian plate, supporting the contention that subducted fluids were involved in their genesis. The youngest lavas at Site 458 are strongly depleted in REE, somewhat resembling boninites but less magnesian and more calcic.

Boninitic and high-Mg andesitic volcanism

Boninite volcanism follows FAB volcanism as an integral part of the evolution of the nascent subduction zone. The type locality of boninite is in the Bonin (Ogasawara) Islands, an uplifted segment of the IBM fore arc. Boninites and other early arc lavas are better exposed on the Bonin Islands than anywhere else in the world particularly on the two islands of Chichijima and Hahajima. This is the most important reason that these islands became a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site in 2011 (**whc.unesco.org/en/list/1362/**). $^{40}Ar/^{39}Ar$ dating indicates that boninitic volcanism on Chichijima took place briefly during the Eocene, between 46 and 48 Ma (Ishizuka et al., 2006). A slightly younger volcanic succession is exposed along the Bonin Ridge, including 44.74 ± 0.23 Ma high-Mg andesites (HMA) from the Mikazukiyama Formation, the youngest volcanic sequence on Chichijima, and 44.0 ± 0.3 Ma tholeiitic to calc-alkaline andesites from Hahajima. Four submersible *Shinkai* 6500 dives on the Bonin Ridge Escarpment mapped an elongate constructional volcanic ridge atop the escarpment and recovered fresh andesitic clasts from debris flows along the northern segment of the ridge; they also recovered HMA lava blocks from the escarpment northwest of Chichijima. Three samples of andesite collected from the Bonin Ridge Escarpment range in age from 41.84 ± 0.14 to 43.88 ± 0.21 Ma (Ishizuka et al., 2006).

Boninites from the Bonin Islands are characterized by high MgO at given SiO_2 concentrations, low high-field-strength elements, low Sm/Zr, low REE, and a U-shaped REE pattern (Fig. **F3**). These are "low-Ca boninites" (Crawford et al., 1989) and can be explained by low-pressure melting of depleted harzburgite that was massively affected by slab flux. These boninites are isotopically characterized by high $\Delta 7/4$ Pb, high $^{87}Sr/^{86}Sr$, and low $^{143}Nd/^{144}Nd$ relative to local MORB and FAB sources (Fig. **F5**). In contrast to the FAB mantle source, which was not much affected by subduction-related fluids or melts, the boninite magma source manifests a major contribution from subducted pelagic sediment and oceanic crust. The boninites are also distinct from ~44 Ma lavas exposed on Hahajima Island and recovered by *Shinkai* 6500 diving on the Bonin Ridge Escarpment (Ishizuka et al., 2006). HMA from Chichijima and the Bonin Ridge Escarpment are more similar to relatively enriched boninitic lavas from Site 786

(Pearce et al., 1999) and Guam, including having higher Sm/Zr at a given Zr content and higher REE and Ti concentrations compared to Chichijima boninites (cf. Taylor and Nesbitt, 1994). The HMA are isotopically distinct from the boninites (Fig. **F5**) and were derived from a source mantle that was less affected by fluids or melts derived from the subducted plate.

Post-45 Ma, tholeiitic to calc-alkaline andesites from the Bonin Ridge and ~45 Ma tholeiites from Saipan (Reagan et al., 2008) exhibit strong characteristics of arc magmas: they are depleted in Nb and enriched in fluid-mobile elements such as Sr, Ba, U, and Pb. These characteristics indicate that, by 45 Ma, near-normal configurations of mantle flow and melting, as well as subduction-related fluid formation and metasomatism, were established for this part of the IBM arc-trench system. The Bonin Ridge Escarpment, Mikazukiyama Formation, and Hahajima andesites thus represent a transitional stage from the waning stages of fore-arc spreading (represented by FAB and perhaps boninites) and the stable, mature arc that developed in the late Eocene to early Oligocene. These orthopyroxene-bearing, high-Mg, tholeiitic to calc-alkaline andesites erupted along the Bonin Ridge Escarpment as the arc magmatic axis localized and retreated from the trench. Post-45 Ma andesites (and basalts), unlike Chichijima boninite and HMA, do not show the influence of pelagic sediment melt from the slab (Fig. **F5**); instead, the mantle source seems to have only been affected by hydrous fluid derived mainly from subducted altered oceanic crust. Post-44 Ma lavas are isotopically similar to HMA (Fig. **F5**) and were derived from a mantle source that was less affected by fluids or melts derived from subducted sediments.

Overall, modeling of these data (not shown) indicates that the geochemical and isotopic characteristics of the IBM arc along its entire length evolved in tandem with the formation of a new subduction zone and a new mantle flow regime by (1) initial decompression melting without significant slab flux producing MORB-like basalt and fore-arc spreading (49–52 Ma), (2) mixing of fluids or melts from subducted sediments and oceanic crust into an extremely depleted (harzburgitic) mantle to generate boninites (48–45 Ma), and (3) continued influx of hydrous fluid input into increasingly fertile lherzolitic mantle to generate tholeiitic and calc-alkaline magma (post-45 Ma), marking the time when a mature, stable arc magmatic system was finally established (Ishizuka et al., 2006, 2011).

The observations above, together with the geochronological data summarized earlier, imply that shallow melting of depleted mantle with the aid of hydrous fluids from the newly subducted slab produced boninitic volcanism nearly simultaneously along the entire length of the IBM arc system during the earliest stage of arc evolution. Casey and Dewey (2009) argued that continued spreading, in what is now the West Philippine Basin, requires that the infant arc was lengthening throughout the Paleogene, so that subduction initiation may have started at different times along the IBM arc system. This is an important consideration for understanding how and when the entire IBM convergent plate margin formed but does not diminish the importance of understanding how a new subduction zone began along the Bonin Ridge. Note also that, although we have established a general volcanic stratigraphy, it is evident from Figure F2 that this is a composite stratigraphy based on dredging, submersible grab sampling, and coring at widely spaced localities. There is no reference stratigraphic section to check this subduction initiation stratigraphy and, in particular, identify the nature of the boundaries between the units and demonstrate that units have not been missed. Defining this stratigraphic section is the aim of this expedition.

Tectonic evolution

It has been generally accepted (Bloomer et al., 1995; Pearce et al., 1999; Stern, 2004; Hall et al., 2003) that the IBM subduction zone began as part of a hemispheric-scale foundering of old, dense lithosphere in the western Pacific (Fig. F6). The beginning of large-scale lithospheric subsidence, not true subduction but its precursor, is constrained by the age of igneous basement of the IBM fore arc to have begun in the Eocene, just before 50 Ma (Bloomer et al., 1995; Cosca et al., 1998; Ishizuka et al., 2006). The sequence of initial magmatic products is similar everywhere the fore arc has been sampled, implying a dramatic episode of asthenospheric upwelling and melting associated with arc magmatism and seafloor spreading over a zone that was hundreds of kilometers broad and thousands of kilometers long. It is clear from the extensive geochronology for IBM fore-arc rocks that this episode took place ~45–52 m.y. ago. It is this part of the tectonic history of the IBM arc that Expedition 352 drilling intends to sample.

Interestingly, these time-space trends in IBM fore-arc composition can be found in many ophiolite terranes. The world's largest ophiolite, the Semail ophiolite of Oman/United Arab Emirates has long been known to exhibit a stratigraphy of FAB-like tholeiites overlain by depleted arc tholeiites (e.g., Alabaster et al., 1982), and recent discoveries of boninites in the upper part of the sequence (Ishikawa et al., 2002) confirm the full trend from tholeiite to boninites. Other large, complete ophiolites with complex fore-arc-type stratigraphies involving tholeiites and boninites include the Troodos Massif of Cyprus, the Pindos Mountains in Greece, and the Bay of Islands ophiolite in Newfoundland (Canada), and there are numerous others distributed through most of the world's mountain belts (e.g., Pearce et al., 1984; Dilek and Flower, 2003). Many of these are economically significant, with associated volcanogenic massive deposits and/or podiform chromite mineralization. Dredging and diving along the inner trench wall sampled parts of the SSZ oceanic crust, but the complete lava section at Sites BON-1A and BON-2A is needed to explain the transition from ocean crust to arc volcanism seen in many SSZ ophiolites.

The presence of boninites is in itself an important tectonic indicator, requiring a combination of shallow melting, high water content, and depleted mantle. Boninites are defined by the International Union of Geological Sciences (IUGS) to have >52 wt% silica, <0.5 wt% TiO_2, and >8 wt% MgO. They can usefully be distinguished from basalts on a diagram of Ti8 versus Si8 where Ti8 and Si8 refer to the oxide concentrations at 8 wt% MgO (Pearce and Robinson, 2010). On this projection (Fig. **F7**), the earliest lavas are basalts (FAB) that plot in the MORB field. Later lavas (from ~48 to 44 Ma) plot as boninites before compositions eventually become basaltic again with eruptions at, for example, Hahajima. This appears to be a characteristic of subduction initiation, but to properly interpret its tectonic significance we need the full lava stratigraphy to know whether the basalt–boninite transition is gradational or episodic or has both magma sources available simultaneously. Drill core would also enhance the opportunity to obtain glass samples that can be analyzed for volatile and fluid-mobile element concentrations.

After a brief period of spreading, magmatic activity began to retreat from the trench, at the same time changing composition, perhaps first from FAB to boninite and then from boninite to calc-alkaline and tholeiitic arc magmas. Magma evolution was accompanied by migration of the magmatic locus away from the trench. Rare 40–43 Ma adakites were recovered from a Bonin fore-arc seamount. Eventually, perhaps some 10 m.y. after subduction initiation, the locus of magmatism reached the equivalent location of the present magmatic arc. This left vast tracts of infant arc crust "stranded" to form the IBM fore arc, so it cooled and experienced only minor tectonic activity while the arc-basin system continued to evolve magmatically to its present crustal structure (Taylor, 1992). Thus the fore arc was "frozen" in a primitive state and did not evolve into the more complex arc with tonalitic middle crust (Suyehiro et al., 1996). Understanding the formation of fore-arc crust is clearly critical for understanding the formation of subduction zones (and the magmatic responses), growth of arcs, evolution of continental crust, and origins of ophiolite.

Structure and thickness of fore-arc crust

The most detailed trench-orthogonal published images of IBM fore-arc crustal structure in the region of interest come from a seismic refraction/reflection study by Kamimura et al. (2002). This survey was accomplished with two 130 km long, orthogonal arrays of ocean-bottom seismometers (23 in total, in which 106 × 20 kg chemical explosions and 1835 pulses from 2 × 17 L air guns were used as seismic sources) in a region some distance north of the section from Sites BON-1A and BON-2A. In Figure F8, the approximate relative position of proposed drill Sites BON-1A and BON-2A are projected onto the east–west line between ODP Leg 125 Hole 786B and the trench, but it must be recognized that their actual crustal structure may be slightly different than that shown.

With that caveat, we infer from the study of Kamimura et al. (2002) that the crust beneath the proposed drill sites is 6–8 km thick—slightly thicker than normal oceanic crust. In detail, the crust beneath this part of the fore arc can be divided into five identifiable layers (Fig. F5). The first layer (V_P = 1.8–2.0 km/s) is mostly composed of thin sediments; this layer is actually very variable and both Sites BON-1A and BON-2A are chosen to have at least 100 m of sediment in order to facilitate drilling and casing operations of the uppermost part of the holes. The second layer (V_P = 2.6–3.3 km/s) is 1–2 km thick and probably consists of fractured volcanic rocks and dikes; this information contributes to our estimate of 1.25 ± 0.25 km as the likely lava thickness that we will need to drill in order to reach the sheeted dikes.

The third layer (V_P = 4.3–6.1 km/s) varies considerably in thickness, from 2 to 5 km. The velocities of the third layer correspond to those for the "tonalitic" layer in the arc farther west (Suyehiro et al., 1996; Takahashi et al., 1998), with which continuity may exist, though here they are more likely to represent sheeted dikes with perhaps some tonalites. The velocities of the fourth layer vary from 5.8 to 6.4 km/s, indicative of altered gabbroic rocks. The fifth layer, with a velocity of 7.0 km/s, possibly olivine gabbros and troctolites, thins and velocities decrease from west to east. This layer pinches out west of the proposed drill site. The sixth layer comprises the mantle wedge in the west and the plate boundary layer in the east. The velocity of the mantle wedge is 8.0 km/s in the westernmost part of the survey and decreases in velocity toward the trench, with a velocity of ~6.8 km/s immediately beneath the proposed drill site. The velocity of 6.8 km/s is not typical for the mantle and is taken to indicate that the mantle beneath the proposed drill site is pervasively serpentinized.

The best evidence for trench-parallel variations in seismic structure comes from a recent wide-angle seismic experiment along the Bonin fore arc (using densely deployed ocean-bottom seismometers), at a longitude ~20–30 km west of the proposed sites. Figure F9 shows the seismic velocity and reflectivity images of this profile (Kodaira et al., 2010). For ease of description, the model is divided into Units A–E, mainly on the basis of seismic velocity, and laterally continuous reflectors aligned subparallel to isovelocity contours are partly used for defining the layer boundaries.

The structure in the northern half of the model is relevant to Sites BON-1A and BON-2A, which are located ~150 km along the section. It is characterized by thin crust, of similar thickness to that imaged by Kamimura et al. (2002) (Fig. F8). The total thickness of the units with crustal seismic velocity (<7.6 km/s; Units A–C) is less than ~10 km. In particular, the crustal units between Mukojima and Chichijima (230–290 km on the profile) are remarkably thin (<7 km). Reflections from the base of Unit C, which we interpret as the Mohorovicic Discontinuity (Moho), are not remarkably strong in this part of the profile. Another characteristic structure in this part of the profile is layering of the uppermost mantle.

The model of Figure F9 shows the average velocity of the 3 km thick Unit D to be 7.8 km/s. The top and bottom of this unit are not continuously imaged, but reflections from some parts of the boundary are clearly evident, for example at 15 km depth between 50 and 150 km distance. Unit D and its reflectors are interpreted as structural discontinuities within the uppermost mantle because the average velocity of Unit D immediately above the reflectors (7.8 km/s) is too high for crustal material. The petrological significance of this layer could correspond to a pyroxene-rich region inferred to define the crust–mantle transition beneath some arcs (e.g., Tatsumi et al., 2008). Unit E, which is in the deepest part of the well-resolved area, has a velocity higher than 8 km/s, as expected for mantle peridotite.

The model also shows abrupt thickening of the crustal units in the central part of the profile that can be attributed mainly to thickening of Unit C (lower crust). The profile in the southern part is intermediate between the profiles of the northern and central parts. It should be noted that the seismic structure modeled to the north of Chichijima is not fully consistent with a structure recently reported by Takahashi et al. (2009) that crosses the Bonin Ridge. Kodaira et al. (2010) discussed the possibility that this apparent inconsistency is due to the fact that the tomographic modeling of the across-arc profile by Takahashi et al. (2009) did not resolve the abrupt eastward thinning of crust beneath the Bonin Ridge.

Choice of drill sites

The three locations in the IBM fore arc that best enable us to study subduction initiation are (1) the southern Mariana fore arc southeast of Guam, (2) the Mariana fore arc along 18°N (which includes Sites 458 and 459), and (3) the Bonin fore arc along ~29°N. All have their merits. The southern Mariana fore-arc option has the advantage of being the type locality for the work of Reagan et al. (2010), who defined FAB and demonstrated that it underlies boninite, at least at this locality (see also Ohara et al., 2006, 2008). We necessarily rejected this location because of a lack of geophysical site survey information. The Bonin fore-arc option has the advantage of being in the same region as Chichijima (Bonin Island), the type locality for the key boninite rock type. It is part of a complete ophiolite section that has been sampled by dredging and diving (Ishizuka et al., 2011) and has full site survey data (S. Kodaira et al., pers. comm., 2013). The Mariana fore arc at 18°N has the advantage of being drilled during DSDP, so there is already a scientific platform upon which to build. Geophysical surveying including multichannel seismic (MCS) profiling was carried out by Mrosowksi et al. (1982) and Chapp et al. (2008), and further surveying was recently completed by D. Lizarralde et al. (pers. comm., 2013), providing crossing lines at both sites. Both the Bonin and central Mariana fore arcs are therefore good drilling targets.

Two important hypotheses to be tested by drilling are (1) that subduction initiation produces a consistent volcanic stratigraphy (from oldest to youngest): FAB, transitional lavas, low-Ca boninites, enriched HMA and related rocks, and normal arc volcanic rocks (Reagan et al., 2010); and (2) that this sequence was originally stacked vertically before erosion and therefore represents an in situ analog for sections through many supra-subduction zone ophiolites. Final choice of the Bonin locale as the primary drilling target and the central Marianas for contingency was based on the identification of the sheeted dike/FAB contact during *Shinkai* 6500 diving in 2009 along the inner wall of the Bonin Trench, near a location where the drill can spud into a sediment pond and sample the lower part of the fore-arc volcanic succession. We do not know the position of this contact in the Mariana fore arc at 18°N.

We debated whether Sites 458 and 459 or the Bonin fore arc would be the best place to start drilling through the contact of boninites overlying FAB, and two considerations led us to prefer the Bonin fore-arc site: (1) low-Ca boninites are found there, whereas only high-Ca boninites are found overlying Site 458; and (2) most of the boninite–FAB transition zone has already been sampled at Sites 458 and 459. Note, however, that Site 459 offers the opportunity to continue sampling this transition into true FAB and on into related intrusive rocks. Thus Sites BON-1A and BON-2A are best located to test ophiolite models. Site 459 provides a site survey–ready alternate site of near-comparable scientific significance.

Geology of the fore arc around proposed Sites BON-1A and BON-2A

The Bonin Ridge is an unusually prominent fore-arc massif in the Izu-Bonin arc that exposes early arc volcanic rocks on Chichijima, Hahajima, and smaller islands. These outcrops represent the best preserved and exposed sequence of igneous rocks associated with subduction initiation so far found on Earth. However, only part of the subduction-initiation igneous record is preserved on the islands. Submarine parts of the IBM fore arc (of which this ridge is part) contain a more complete record of subduction initiation, but by necessity, these parts have only been investigated by ocean drilling (e.g., Leg 60: Natland and Tarney, 1982; Leg 125: Arculus et al., 1992; Pearce et al., 1992), dredging (Bloomer and Hawkins, 1983), and diving (Ishizuka et al., 2006, 2011). The Bonin Ridge itself has not been drilled but has been investigated by dredging and manned submersible diving.

Figure **F10** summarizes the distribution of rocks sampled during three expeditions: YK04-05, the first manned submersible (*Shinkai* 6500) diving survey of the western escarpment of the Bonin Ridge (Ishizuka et al., 2006); R/V *Hakuho-maru* KH07-2, which dredged 19 stations along the length of Bonin Ridge; and YK09-06 in the proposed Site BON-1A and BON-2A area (Ishizuka et al., 2011). They show the following, in particular:

1. Overall, there is an ophiolite-like sequence in the inner trench wall of lavas, dikes, gabbros, and peridotites.
2. Of the lavas and dikes, MORB-like tholeiites occupy the deepest part of the trench-side slope of the ridge (i.e., the easternmost part of the ridge). These are chemically indistinguishable from FAB as defined by Reagan et al. (2010).
3. Boninites crop out to the west and upslope of the FAB/MORB outcrops.
4. Younger tholeiitic/calc-alkaline basalt to rhyolite outcrops occupy the westernmost part of the Bonin Ridge and are especially well exposed on the western escarpment.
5. This spatial distribution of rock types is also found around 32°N, where boninitic rocks were drilled at Site 786. MORB-like basalts were also recovered near the trench at that latitude by *Shinkai* 6500, although these originally were interpreted as trapped crust of the Philippine Sea plate (DeBari et al., 1999). However,

the Bonin section provides the better drilling location, having a simpler structure and more detailed sampling.

The 2009 diving survey using the submersible *Shinkai* 6500 examined, and better established, the igneous fore-arc stratigraphy exposed on the trench-side slope of the Bonin Ridge (YK09-06 cruise: 24 May–10 June 2009; Ishizuka et al., 2011). Two dive areas were located near the proposed drill sites, shown as boxes in Figure **F10.** The northernmost area near 28°25′N (Area A; see the more detailed map in Fig. **F11**) contains drill Sites BON-1A and BON-2A, located with the help of four dives (1149, 1150, 1153, and 1154) that examined the lower to upper crustal section formed in the earliest stage of oceanic island arc formation.

The deepest dive (1149) sampled gabbro and basalt/dolerite and appears to have traversed the boundary between the two units. The lower slope traversed during Dive 1149 is composed of fractured gabbro, whereas pillow lavas were observed in the uppermost part of this dive at ~6000 m water depth. Dives 1153 and 1154 surveyed upslope of Dive 1149. These two dives found outcrops of numerous diabase dikes, as well as fractured basalt lava cut by dikes, between 6000 and 5500 m water depth. The shallowest dive (1150) recovered volcanic breccia and conglomerate with boninitic and basaltic clasts. The boundary between boninite and basalt is estimated to lie at ~4800 m water depth because no basalt was recovered shallower than this.

Combined with results from other dives and dredging, a relatively simple fore-arc crustal igneous stratigraphy can be envisaged (Figs. **F12, F13**). The section, from bottom to top, consists of (1) mantle peridotite, (2) gabbroic rocks, (3) a sheeted dike complex, (4) basaltic lava flows (FAB), (5) volcanic breccia and conglomerate with boninitic and basaltic clasts, and (6) boninite and tholeiitic andesite lava flows and dikes. The uppermost part of this section is exposed in the Bonin Islands. These observations indicate that almost all of the fore-arc crust down to and deeper than the Moho is preserved and exposed in the inner trench wall of the Bonin Ridge.

Site survey data

The MCS data along the north–south profiles (KT06 and KT07) and the east–west profiles (IBr11 and IBr11n) included in **"Site summaries"** were acquired by JAMSTEC (S. Kodaira, pers. comm., 2013). For MCS data acquisition, a tuned air gun array with a total volume of 7200 $inch^3$ was used, and the seismic waves were recorded by a 444-

channel streamer cable ~6000 m long. Supporting site survey data for Expedition 352 are archived at the **IODP Site Survey Data Bank.**

Scientific objectives

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.

Recent advances in studying the IBM fore arc document important vertical compositional variations within the volcanic sections. We know that the IBM fore arc exposes rocks that formed when this subduction zone began at ~52 Ma (Stern and Bloomer, 1992; Ishizuka et al., 2011). Reagan et al. (2010) documented that the volcanic succession exposed in the inner trench wall of the southernmost Mariana fore arc comprises a volcanic succession that changes from MORB-like tholeiites at the base (FAB) through increasingly arc-like basalts to boninites near the top. They inferred that the 450–700 m sections cored at Sites 458 and 459 in the Mariana fore arc sampled the transition between the FAB and boninite successions. Similar successions are common in ophiolites, which are increasingly recognized as fossil fore arcs (Stern et al., 2012; see below). The significance of this simple succession has not hitherto been appreciated because of a lack of direct information on fore-arc volcanic stratigraphy, mainly because this was not a priority for dredging and diving. The results of Reagan et al. (2010) provide the first reconstruction of this stratigraphy, and this dredging and diving in the Bonin fore arc was undertaken to see whether a similar magmatic stratigraphy was present there. In the area of Sites BON-1A and BON-2A, the results of Ishizuka et al. (2011) support the conclusions of Reagan et al. (2010). Drilling and coring this volcanic succession will provide a crucial test of this hypothesis by providing a more continuous section. It is also important to further constrain the rates at which the fore-arc magmatic succession was emplaced. Evidence so far available indicates that this sequence takes ~7 m.y. to form during subduction initiation, after which magmatic activity retreats ~200 km to the ultimate position of the arc magmatic front. Recovered cores should provide more material for U-Pb zircon, $^{40}Ar/^{39}Ar$, and biostratigraphic age determinations.

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

We expect to find a thick section of FAB at the base of the Bonin fore-arc volcanic succession and a thinner sequence of arc-like and boninitic lavas at the top. To understand the significance of these vertical variations, we need to know how the transition from one magma type to the next takes place: is it a step-function, or is there a slow transition from one magma type to the next? If it is a transition, we need to know whether it is continuous, gradual, and progressive or whether it is accomplished by alternations of one magma type with another. Within the main FAB sequence, we need to know whether there is any evidence that the subduction component increases with stratigraphic height and thus time. A key related question is whether the boninites vary in any systematic way upsection, for example from high-Ca boninite at the base to low-Ca boninite near the top. The nature of these transitions and variations provide important constraints for how mantle and subducted sources and processes changed with time as subduction initiation progressed.

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

Assuming that we are able to accomplish Objectives 1 and 2, we will use the results to better understand how the mantle responds to subduction initiation. For example, a thick basal FAB succession indicates that adiabatic decompression is the most important process at the very beginning of subduction initiation in the IBM system, and an upper section of boninites indicates that flux melting was important just before the transition into normal arc magmatism. Whatever information is obtained from the cores will be used to construct more realistic geodynamic and petrologic models.

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

Much has rightly been made of the highly successful efforts of IODP and its precursors in establishing the architecture and crustal accretion processes associated with mid-ocean ridges of varying spreading rates and linking these to ophiolites. As discussed earlier, however, it now appears that most ophiolites form when subduction begins and are preserved as fore-arc crust until they are obducted. One testable hypothesis is that ophiolites that formed during subduction initiation can be recognized by a volcanic stratigraphy that varies from MORB-like at the base to arc-like or boninitic near the top, similar to the sequence that we expect to recover from the IBM fore arc. Most ophiolites are not well enough preserved or studied to infer volcanic chemostratigraphies, but some are (e.g., Mesozoic ophiolites such as Pindos, Mirdita, Semail, and Troodos and Ordovician ophiolites of the northeast Appalachians and Norwegian Caledonides). Some of these have volcanic stratigraphies that are similar to those of the IBM fore arc. Results from Bonin fore-arc drilling will allow us to prepare a more detailed volcanic chemostratigraphy expected for subduction initiation, which will in turn allow more detailed comparisons with these ophiolites and encourage geoscientists to try to reconstruct the magmatic stratigraphies of other ophiolites.

Drilling and coring strategy

As already noted, we plan to achieve our goal of sampling the full volcanic stratigraphy of the Bonin fore arc by drilling two offset sites (BON-1A and BON-2A; see **"Site summaries"**), each made up of ~750 m of lava overlain by at least 100 m of sediment (Fig. **F14**). The precise location of the sites was constrained by the presence of sediment ponds. Site BON-1A (Line IBr11n, common depth point [CDP] 5364; 28°27.01′N, 142°45.35′E; 4778 m water depth) is designed to first encounter FAB and reach the sheeted dikes, thus drilling the oldest rocks in the sequence. Site BON-2A (Line IBr11, CDP 66252; 28°24.46′N 142°36.55′E; 3137 m water depth) will start in boninites and finish in FAB, completing the sequence. We expect this to enable us to obtain a full section in a single expedition, something that could not be guaranteed with a single 1750 m hole. In the event of either of these being unsuccessful or giving unexpected results, we have identified four contingency sites close to Sites BON-1A and BON-2A and one at Site 459 in the Mariana fore arc (see **"Risks and contingency"**).

Previous experience indicates that engineering conditions at IBM fore-arc sites are likely to be favorable (Fig. **F15**). Drilling at Site 459 penetrated sediments and then basalts similar to those expected at Site BON-1A at a rate of ~700 m in ~6 days. Drilling at Site 458 achieved similar penetration rates to ~450 meters below seafloor (mbsf). Drilling in Hole 786B, which penetrated sediments and then boninites similar to those expected in the upper part of Site BON-2A, drilled to >800 mbsf with a single drill bit in 11 days. This was a particularly stable hole, probably because fluid circulation filled veins and healed fractures. This experience leads us to conclude that drilling without a riser will not face drilling, safety, or environmental problems.

The temperature at the bottoms of the holes should not present a problem: the temperature gradients in outer fore arcs are the lowest on the planet. Temperature measurements to 110 mbsf at Leg 125, Site 792 (about halfway between the trench and the magmatic arc) define a heat flow of 56 mW/m^2, which gives a thermal gradient of 34°/km for the basement rocks. The thermal gradient farther from the arc at Sites BON-1A and BON-2A should be significantly lower, indicating that the temperature at the bottom of a 1000 m deep hole should be <50°C.

In detail, Hole 786B drilling indicates formation hardness changes at 400 and 690 mbsf and implies that an average penetration rate of 46.3 m/day can be achieved. This is equivalent to 1.92 m/h, compared to a typical average of 1.8 m/h, the faster penetration perhaps due to the better cementation of rocks resulting from a long history of fluid circulation. Extrapolation of the penetration curve gives an estimated drilling time for a 1000 m hole of 14–15 days for linear extrapolation and 16–20 days for the more likely nonlinear extrapolation. Of course, unexpected issues such as bit failure or hole instabilities could slow progress.

The scientific goals of this expedition are best achieved by obtaining a full lava stratigraphy. Moreover, for purposes of testing hypotheses and economic constraints, we need to be able to achieve this in a single ~60 day expedition. Ophiolite studies, coupled with the seismic studies reported here, show that the lava thickness is likely to be 1.25 ± 0.25 km, probably beyond that likely to be drilled at one site in a single expedition, especially if casing is needed for hole stability and to provide a legacy. For these reasons, we choose instead to use the offset drilling approach, drilling at both Sites BON-1A and BON-2A. Casing will be used to improve hole stability.

We aim to run the standard set of wireline logs for crustal sections (see **"Downhole measurements strategy"**). The Formation MicroScanner and borehole televiewer are essential for understanding the history of fracturing of, and hence fluid flow in, the fore-arc crust. They are also useful for preparing a complete lithostratigraphic log in the inevitable event of incomplete core recovery and will also help us to understand the structure of the fore arc at the drilled sites. Physical properties tools are needed for synthetic seismograms and ground-truthing seismic images.

The proposed drilling and coring strategy for the primary and alternate sites are presented in Tables **T1** and **T2**, respectively. The time estimates used are based on formation lithologies, depths inferred from seismic and regional geological interpretations, and prior drilling in this area (Legs 60 and 125).

Seismic profiles for all sites are included in **"Site summaries."** Sites BON-1A and BON-2A are expected to recover the lower and upper volcanic stratigraphy, respectively.

Hole A at each site will consist of a jet-in test, the purpose of which is to determine the length of the initial casing string.

Hole B at each site will be cored with the advanced piston corer (APC)/extended core barrel system to the sediment/basement interface (100–250 mbsf). APC cores will be taken with nonmagnetic core barrels until overpull limits are exceeded.

Hole C at each site will start with casing operations: a reentry cone with the initial 16 inch casing string will be installed to the depth determined by the jet-in test, followed by a second 10¾ inch casing string. We will use a two-casing string strategy to save time and also based on what we know from previous drilling in this area. Rotary core barrel coring will extend from the bottom of the casing to the target depth, requiring multiple drill bit changes.

After completing coring in Hole C at each site, the holes will be conditioned, displaced with logging mud, and logged as described in the logging plan (see **"Downhole measurements strategy"**).

For logistical reasons, we aim to drill Holes A and B at Site BON-2A before drilling the full sequence of Holes at Site BON-1A. We then plan to return to Site BON-2A to complete drilling.

Downhole measurements strategy

Downhole logging

The plan for downhole measurements will help meet the scientific objectives of Expedition 352 through the provision of a continuous, in situ data set of physical, structural, and chemical properties. This data set will aid in the characterization of the sites drilled, with the main focus being on the basement intervals. Logging measurements will complement the core data and allow core-log integration, as well as provide the only stratigraphic data for any intervals where core is not recovered.

Combinations of three wireline logging tool strings will be deployed during Expedition 352:

1. The triple combination (triple combo) tool string,
2. The Formation MicroScanner (FMS)-sonic tool string, and
3. The Ultrasonic Borehole Imager (UBI) tool string.

The first run will be the triple combo tool string, which logs total and spectral natural gamma radiation (NGR), porosity, density, borehole diameter, and resistivity. The triple combo also has the option for the deep reading magnetic susceptibility sonde (MSS-B) to be included in the tool string. The combination of these measurements will enable lithologic changes and variations in alteration to be assessed. In addition, the borehole diameter measurements will give a provisional indicator of hole conditions, which is essential for assessing log quality in this and successive tool deployments. The second run will be the FMS-sonic tool string, providing oriented, high-resolution electrical images of the borehole wall and acoustic velocity data. In addition, total NGR, borehole diameter, and General Purpose Inclinometry Tool magnetometer measurements will also be collected during the run. Synthetic seismograms will be generated from a combination of the density and sonic velocity data sets, providing an essential link between the borehole stratigraphy and the seismic sections. The UBI tool provides oriented, high-resolution acoustic amplitude images with 360° borehole wall coverage. Use of the FMS and UBI images in tandem can help detect small-scale structures and lithologic variations and aid in understanding the fracture, and hence fluid flow, history in the fore-arc crust. Further information about the tools and their applications is available at **iodp.ldeo.columbia.edu/TOOLS_LABS/index.html.** Operational time estimates can be found in Table **T1.**

Site BON-1A has a ~260 m sediment overburden that will be cored. In the event of poor core recovery, this interval may be logged with the triple combo tool string prior to installation of the reentry system. Should recovery be good, a basic total NGR log of the interval may be acquired through the casing as part of logging the deep hole. Although the NGR signal obtained through the casing will be attenuated, the data should be adequate for observing broad trends and major changes through the sediment interval. This logging strategy will also be adopted for Site BON-2A, where the sediment overburden is ~120 m.

The basement intervals for Sites BON-1A and BON-2A will be logged with a minimum of two tool strings (triple combo and FMS-sonic) to obtain a combination of standard measurements and borehole imagery. The UBI tool string may be deployed, depending on the condition of the borehole and the availability of time, as a third tool string or in combination with the triple combo.

Formation temperature and core orientation measurements

Formation temperature measurements are planned for the APC sediment intervals at both Sites BON-1A and BON-2A. Three to five measurements per site will be acquired using the advanced piston corer temperature tool, which will allow reconstruction of the thermal gradient at each site.

APC cores will be taken with nonmagnetic core barrels and oriented with the FlexIT tool for paleomagnetic studies. Nonmagnetic core barrels will be used until overpull limits are exceeded.

Risks and contingency

There are a number of risks to achieving the objectives of this program.

Time distribution

The main risk in scientific terms would be a failure to penetrate the oldest volcanic rocks at the lava/sheeted dike boundary. To reduce this risk, we aim to drill Site BON-1A first and, if necessary, drill deeper than planned to achieve our objective. Less time would then be spent at Site BON-2A, and any gap in the lava stratigraphy would be filled in by reference to Site 459 in the Mariana fore arc. We do not, however, believe that this risk is high.

Site BON-1A is deeper or shallower in the lava sequence than expected

We need to retain some flexibility in case lavas at the top of Site BON-1A are not at the expected position within the stratigraphic sequence. If higher in the sequence, we might expect to drill deeper at Site BON-1A and shallower at Site BON-2A. If lower in the sequence, we might expect to drill shallower at Site BON-1A and deeper at Site BON-2A. However, in the latter case, drilling rocks unexpectedly deep in the section (e.g., in lower sheeted dikes and gabbros) would also help meet Objectives 1, 2, and 3, and we would expect to drill at least to bit destruction before moving to Site BON-2A. Although very unlikely, we could penetrate an exciting feature (e.g., the Moho) that would require further deepening of the hole if the shipboard scientists support such a plan.

Hole stability

Poor hole conditions will be dealt with by using frequent high-viscosity mud sweeps and or heavy mud to condition the holes. In addition, each deep hole will be cased down to the sediment/basement interface to improve hole stability. In the case of serious technological problems, however, it may be necessary to relocate a site within the same area in order to achieve the required penetration. For this purpose, a series of contingency sites have been identified close to Sites BON-1A and BON-2A (see **"Site summaries;"** Table **T2**).

- Site BON-3A is an alternate site to Site BON-1A and has been placed close to Site BON-1A at the crossing between Lines IBr11 (CDP 68768) and KT07.
- Site BON-4A is an alternate site to Site BON-2A and has been placed close to Site BON-2A at the crossing between Lines IBr11n (CDP 7817) and KT06.
- Site BON-5A is a generic alternate site placed along Line IBr11 (CDP 66380).
- Site BON-6A is a generic alternate site placed along Line IBr11 (CDP 68100).

Alternate Site 459 (Mariana fore arc)

Sites BON-1A and BON-2A are ideally located, in that they provide the opportunity to spud into sediment and drill the full volcanic sequence in any area that has been well sampled and surveyed. Given the success at Sites 458 and 459 and Hole 786B with 1980s technology, it is unlikely that an alternate site will be needed. However, as noted above, we are fortunate that deeper drilling at Site 459 (Fig. **F15**) provides an alternate to the Bonin fore arc and that the site already has crossing MCS lines. Having been successfully drilled already, new adjacent holes could be drilled to the depth of the existing holes, cased, and then cored. Note that Site 458 has already cored the transition between boninites and FAB, so only one alternate site is needed. This could be useful in the event that we are unsuccessful at drilling in the Bonin region or for certain geological reasons, for example if Site BON-1A does not provide the deep penetration of the lavas sequence that we hope for.

Weather conditions

August and September have a high (20%) typhoon risk and may result in suspension of operations for as many as a few days.

Sample and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations policy (**www.iodp.org/program-policies/**). This document outlines the policy for distributing IODP samples and data and defines the obligations incurred by sample and data recipients. Any policy changes that may occur with the beginning of the International Ocean Discovery Program in October 2013 will be distributed to shipboard and interested shore-based scientists as soon as possible.

All requests for core samples and data must be approved by the Sample Allocation Committee (SAC). The SAC is composed of the Co-Chief Scientists, Expedition Project Manager, and IODP Curator on shore or curatorial representative on board the ship. The SAC will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard sampling.

Scientists are expected to submit data and sample requests using the Sample and Data Request Database (**iodp.tamu.edu/sdrm/**) ~3 months before the beginning of the expedition. Based on shipboard and shore-based research plans submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and cruise objectives. The sampling plan will be subject to modification, depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. Modification of the strategy during the expedition must be approved by the SAC. One goal will be to gain approval for a program of communal sampling for geochemistry and petrology, whereby the same intervals are powdered and split for use by the whole community.

The minimum permanent archive will be the standard archive half of each core. All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurements is unavoidable, but minimizing the duplication of measurements among the shipboard scientists and identified shore-based collaborators will be a factor in evaluating data and sample requests.

If some critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling for the highest priority research objectives.

Following Expedition 352, cores will be delivered to the IODP Kochi Core Center in Kochi, Japan. All collected data and samples will be protected by a 1 y moratorium period following the completion of the expedition, during which time data and samples will be available only to the Expedition 352 science party and approved shore-based participants.

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Table T1. Expedition 352 primary sites and operations plan.

Site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations description	Transit (days)	Drilling, coring (days)	Logging (days)
	Yokohama		Begin expedition	5.0 port call days		
			Transit ~448 nmi to BON-2A at 10.5 kt	1.8		
BON-2A Total depth pending EPSP approval	28°24.46′N, 142°36.55′E	3148	Hole A - Depth check and jet-in test		0.8	
			Hole B - APC/XCB core to basement at ~120 mbsf		0.8	
			Subtotal days on site: 1.6			
			Transit ~8 nmi to BON-1A in DP mode at 1.5 kt	0.2		
BON-1A Total depth pending EPSP approval	28°27.01′N, 142°45.35′E	4789	Hole A - Depth check and jet-in test		0.6	
			Hole B - APC/XCB core to basement at ~260 mbsf		2.5	
			Hole C - Install reentry system to ~265 mbsf		7.6	
			1. Deploy reentry cone and jet-in ~60 m 16″ casing (to ~60 mbsf)			
			2. Drill 14-3/4″ diameter hole into sediment (~260 mbsf) then 10 m into basement			
			3. Deploy 10-3/4″ casing/land hanger in reentry cone, place shoe at ~265 mbsf			
			4. Cement casing shoe/release casing hanger/flush pipe/POOH			
			Hole C - RCB core from 270 to 1010 mbsf - 750 m into basement		15.3	1.3
			1. RCB core basement from 270 to ~1010 mbsf			
			2. Change bits as required			
			3. Condition hole, drop bit on seafloor, and log with triple combo and FMS-sonic			
			Subtotal days on site: 27.3			
			Transit ~8 nm to BON-2A at 10.5 kt	0.1		
BON-2A Total depth pending EPSP approval	28°24.46′N, 142°36.55′E	3148	Hole C - Install reentry system to ~125 mbsf		6.4	
			1. Deploy reentry cone and jet-in ~60 m 16″ casing (to ~60 mbsf)			
			2. Drill 14-3/4″ diameter hole into sediment (~120 mbsf) then 10 m into basement			
			3. Deploy 10-3/4″ casing/land hanger in reentry cone, place shoe at ~125 mbsf			
			4. Cement casing shoe/release casing hanger/flush pipe/POOH			
			Hole C - RCB core from 130 to 870 mbsf - 750 m into basement		12.8	1.3
			1. RCB core basement from 130 to ~870 mbsf			
			2. Change bits as required			
			3. Condition hole, drop bit on seafloor, and log with triple combo and FMS-sonic			
			Subtotal days on site: 20.5			
			Transit ~1133 nmi to Keelung at 10.5 kt	4.5		
	Keelung		End expedition	6.6	46.8	2.6
			Port call: 5.0 / Total operating days: 56.0			
			Subtotal on-site: 49.4 / Total expedition days: 61.0			

All sites pending Environmental Protection and Safety Panel (EPSP) approval. Advanced piston corer temperature tool (APCT-3) measurements to be taken at both primary sites. Nonmagnetic coring equipment to be used when possible (both advanced piston corer [APC] and rotary core barrel [RCB] hole sections). FlexIT orientation tool to be deployed on all APC hole sections starting with Core 1H. Mechanical bit release (MBR) to be run with all RCB bottom-hole assemblies when logging is anticipated. XCB = extended core barrel, DP = dynamic positioning, POOH = pull out of hole, triple combo = triple combination, FMS = Formation MicroScanner.

Table T2. Expedition 352 alternate sites and operations plan.

Site	Location (latitude, longitude)	Seafloor depth (mbrf)	Operations description	Drilling, coring (days)	Logging (days)
BON-3A	28°26.03′N,	4773	Hole A - Jet-in test	0.8	
Total depth	142°46.02′E		Hole B - APC/XCB to basement at ~210 mbsf	2.1	
pending			Hole C - Reentry system - 16″ and 10-3/4″ casing to basement at 210 mbsf	5.3	
EPSP approval			Hole C - RCB core from 220 to 960 mbsf; log with triple combo and FMS-sonic	15.1	1.4
			Subtotal days on site: 24.7		
BON-4A	28°25.46′N,	3141	Hole A - Jet-in test	0.7	
Total depth	142°36.12′E		Hole B - APC/XCB to basement at ~100 mbsf	0.9	
pending			Hole C - Reentry system - 16″ and 10-3/4″ casing to basement at 100 mbsf	4.3	
EPSP approval			Hole C - RCB core from 110 to 850 mbsf; log with triple combo and FMS-sonic	12.4	1.3
			Subtotal days on site: 19.6		
BON-5A	28°24.54′N,	3163	Hole A - Jet-in test	0.7	
Total depth	142°37.04′E		Hole B - APC/XCB to basement at ~160 mbsf	1.4	
pending			Hole C - Reentry system - 16″ and 10-3/4″ casing to basement at 160 mbsf	4.4	
EPSP approval			Hole C - RCB core from 170 to 910 mbsf; log with triple combo and FMS-sonic	12.6	1.3
			Subtotal days on site: 20.4		
BON-6A	28°25.63′N,	4463	Hole A - Jet-in test	0.8	
Total depth	142°43.50′E		Hole B - APC/XCB to basement at ~270 mbsf	2.5	
pending			Hole C - Reentry system - 16″ and 10-3/4″ casing to basement at 270 mbsf	5.3	
EPSP approval			Hole C - RCB core from 280 to 1020 mbsf; log with triple combo and FMS-sonic	14.6	1.4
			Subtotal days on site: 24.6		
DSDP Site 459	17°51.75′N,	4141	Hole A - Jet-in test	1.1	
Total depth	147°18.09′E		Hole B - Reentry system - 16″ and 10-3/4″ casing to basement at 500 mbsf	6.1	
pending			Hole B - Drill ahead to 650 mbsf and RCB core to 1500 mbsf; log with triple combo and FMS-sonic	19.8	1.7
EPSP approval					
			Subtotal days on site: 28.7		

All sites pending Environmental Protection and Safety Panel (EPSP) approval. APC = advanced piston corer, XCB = extended core barrel, RCB = rotary core barrel, triple combo = triple combination, FMS = Formation MicroScanner.

Figure F1. Map of the Izu-Bonin-Mariana (IBM) system showing the locations of proposed drill Sites BON-1A and BON-2A and other locations discussed in the text.

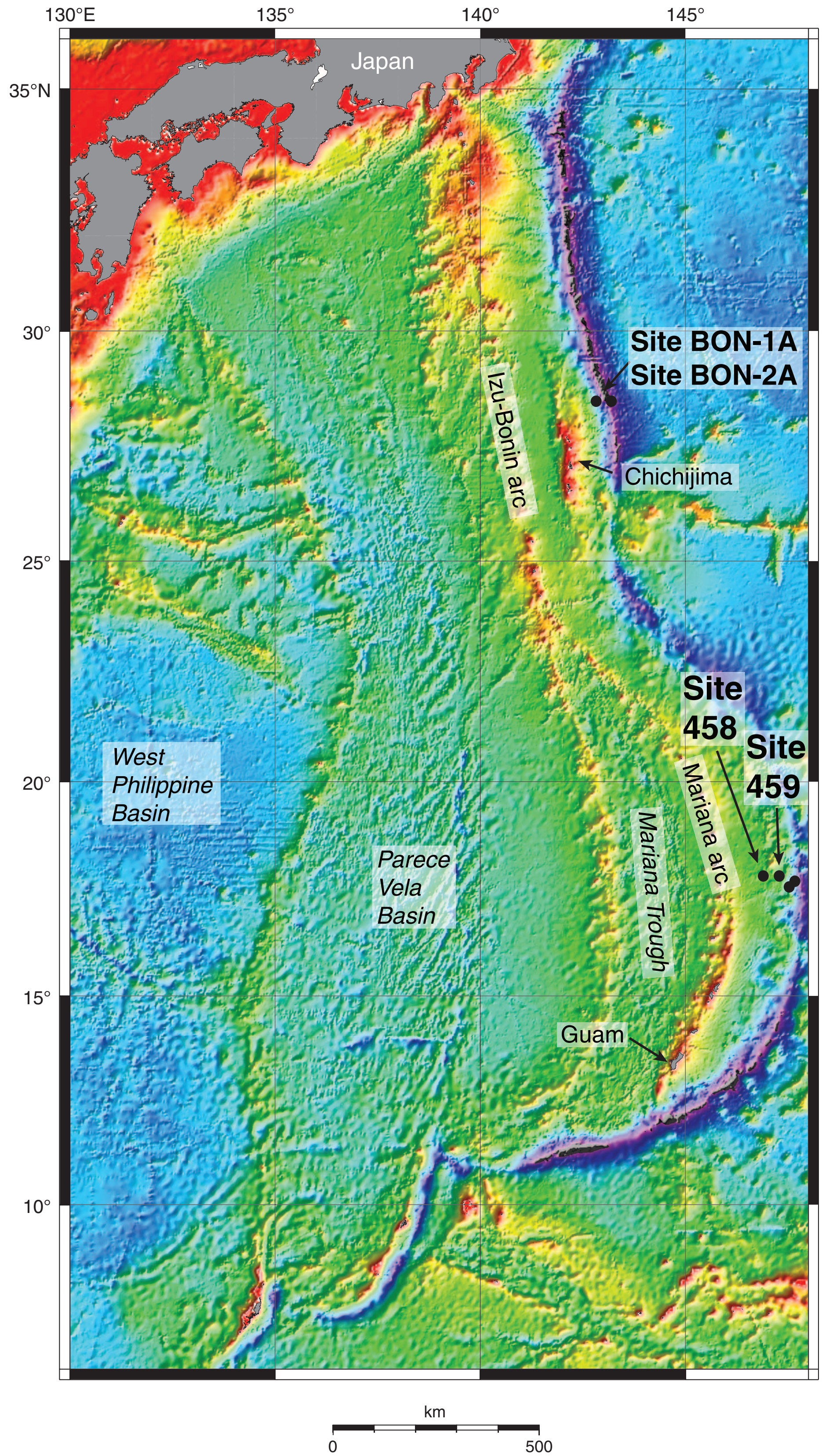


Figure F2. Compilation of $^{40}Ar/^{39}Ar$, K/Ar, and U-Pb zircon dating results for Eocene igneous rocks from the IBM fore arc, modified after Ishizuka et al. (2011). $^{40}Ar/^{39}Ar$ ages are calculated using 27.5 Ma for sanidine from Fish Canyon Tuff (FC3). Data sources other than Ishizuka et al. (2011): a = Cosca et al. (1998), b = Reagan et al. (2008), c = Kaneoka et al. (1970), d = Ishizuka et al. (2006), e = Ishizuka et al. (2011a), f = Reagan et al. (2013). $^{40}Ar/^{39}Ar$ age of Cosca et al. (1998) is calculated using an age of 520.4 Ma for MMHB-1. $^{40}Ar/^{39}Ar$ age of Reagan et al. (2008) is calculated using an age of 27.84 Ma for FC-2 Fish Canyon Tuff. Expedition 352 will focus on the detailed stratigraphy of the 7 m.y. period between these events. DSDP = Deep Sea Drilling Project.

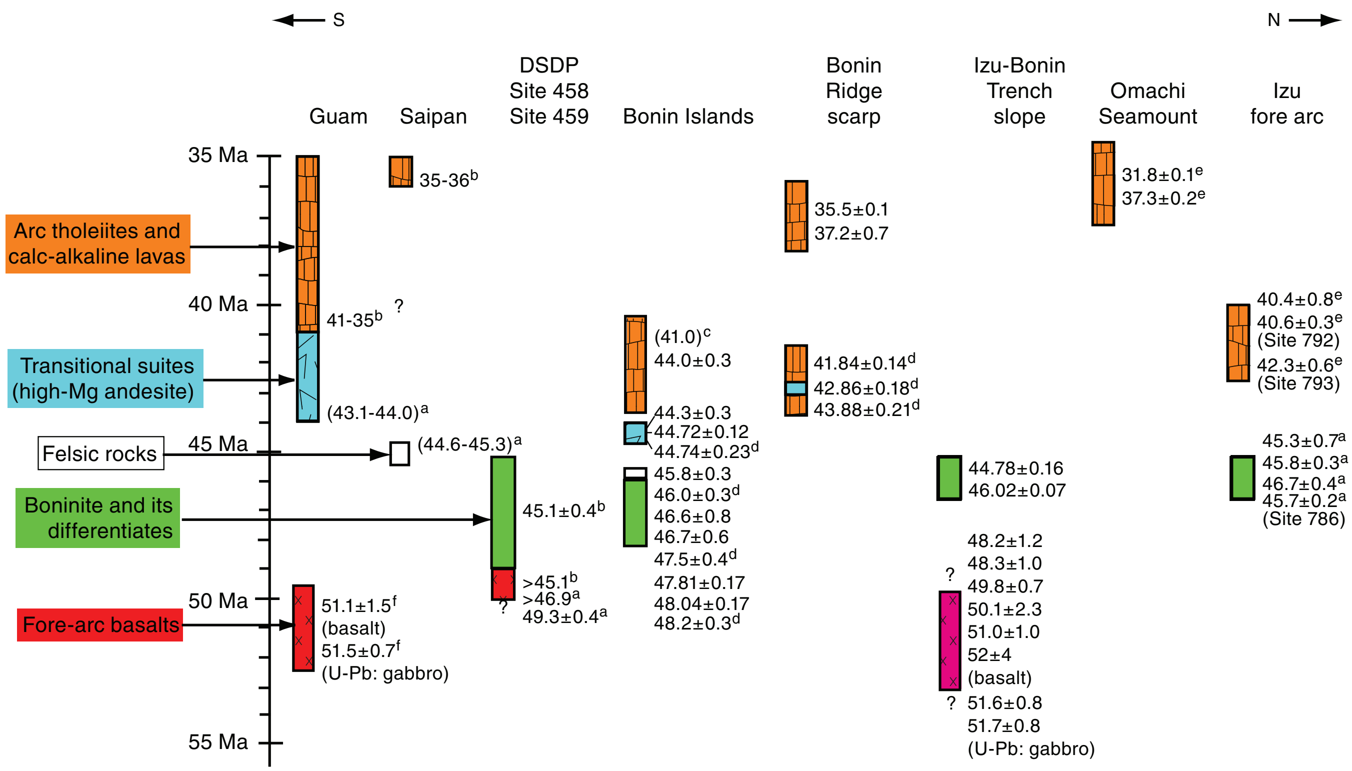


Figure F3. Variations in rare earth element patterns in the Bonin fore arc following subduction initiation. Note the recently discovered MORB-like patterns of the first volcanic products, the fore-arc basalt, and the contrast with the later U-shaped boninite patterns. Expedition 352 will obtain complete information on gradations within and between these units. Data from Ishizuka et al. (2006, 2011).

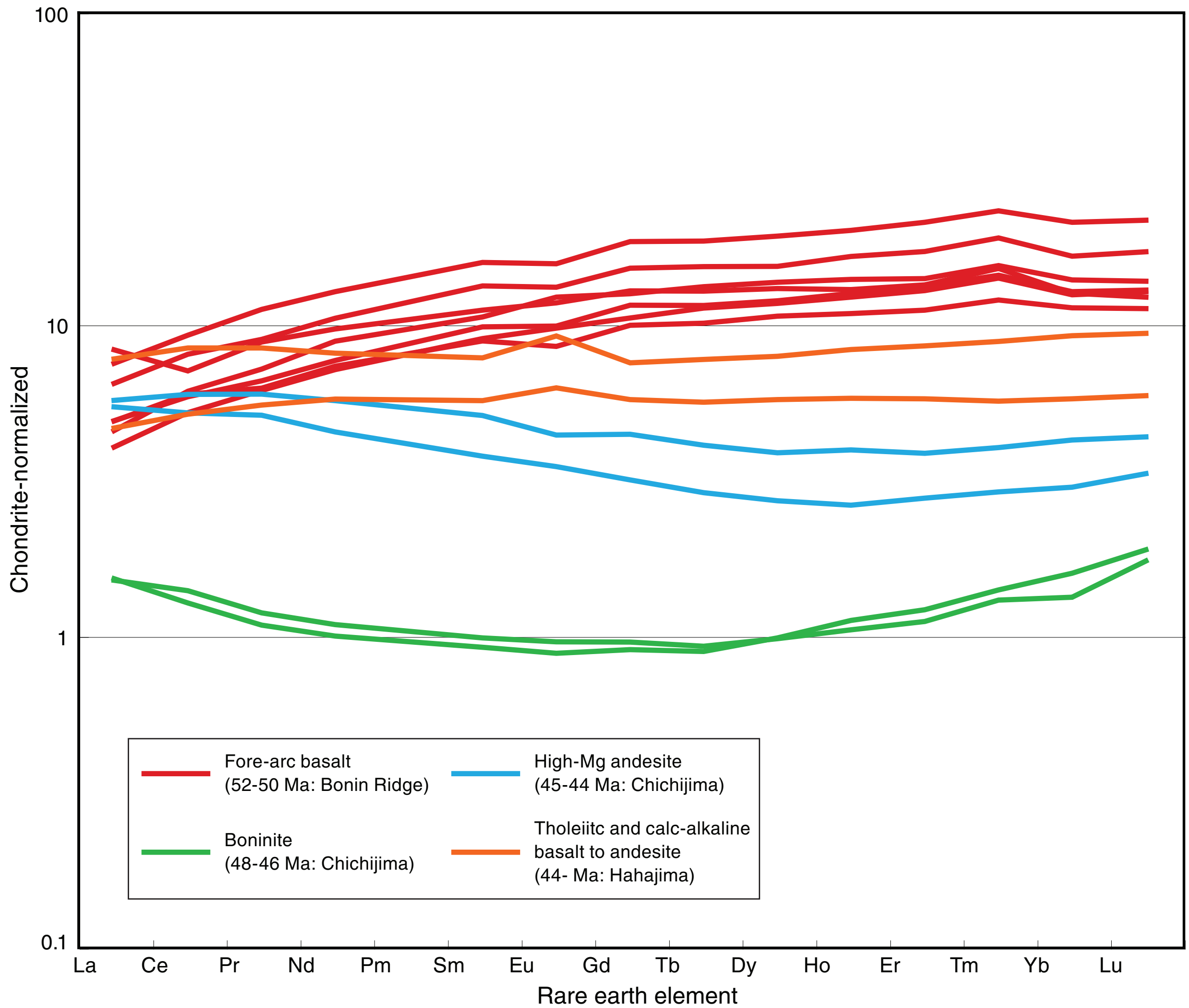


Figure F4. V-Ti systematics (Shervais, 1982) for the lavas erupted following subduction initiation. Note that the earliest lavas to erupt following subduction initiation (the fore-arc basalt [FAB]) is distinct from mid-ocean-ridge basalt (MORB) and from later boninites. These are, however, isolated outcrops: Expedition 352 will provide the full stratigraphy. Data from Ishizuka et al. (2006, 2011).

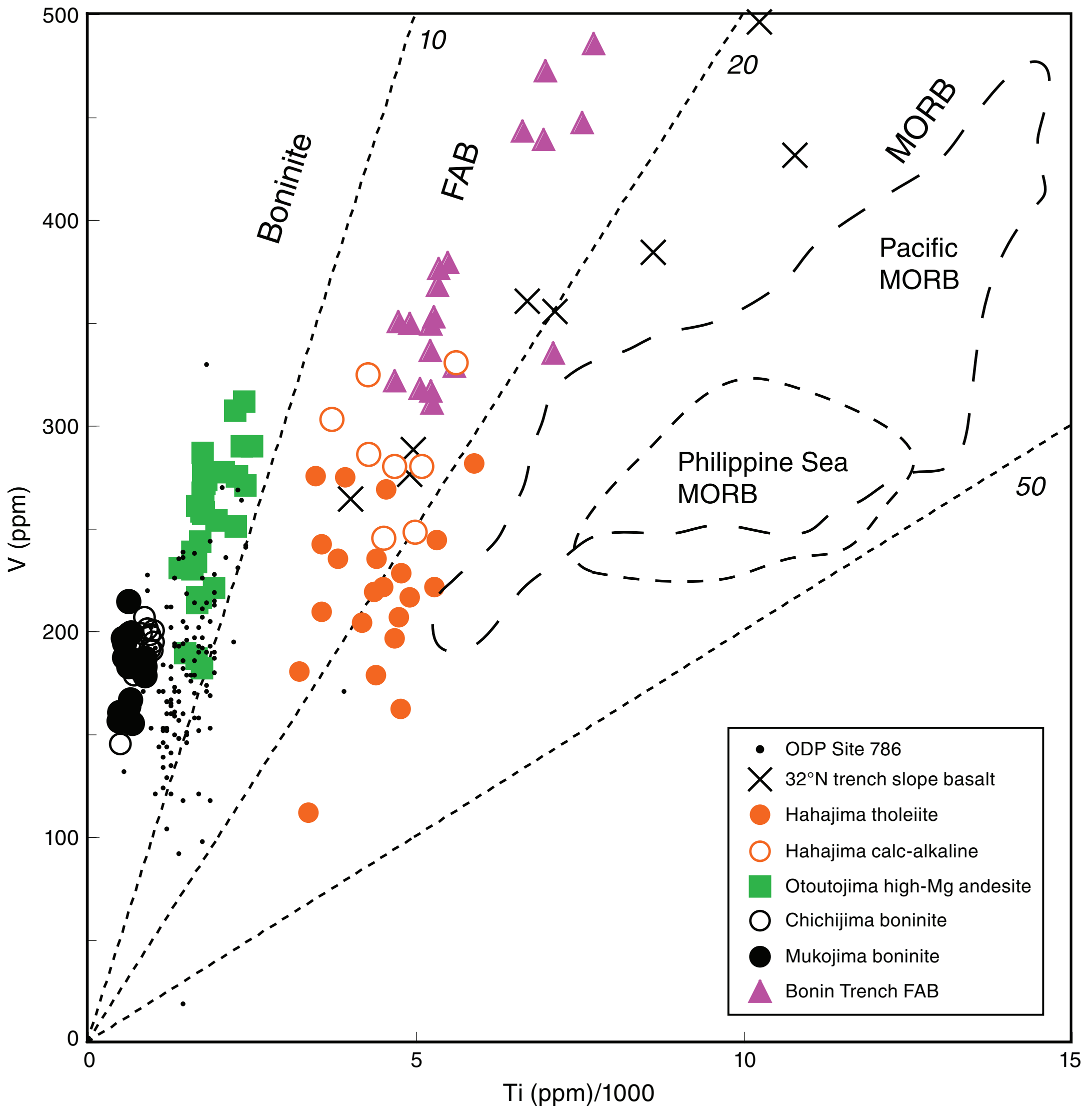


Figure F5. Variations in isotopic compositions highlighting the complex variations in lava chemistry following subduction initiation. A complete stratigraphy will enable a better interpretation of these data in terms of variations in mantle sources and subduction components following subduction initiation. Data from Ishizuka et al. (2006, 2011). HMA = High-Mg andesites, KPR = Kyushu-Palau Ridge, MORB = mid-ocean-ridge basalt, NHRL = Northern Hemisphere reference line.

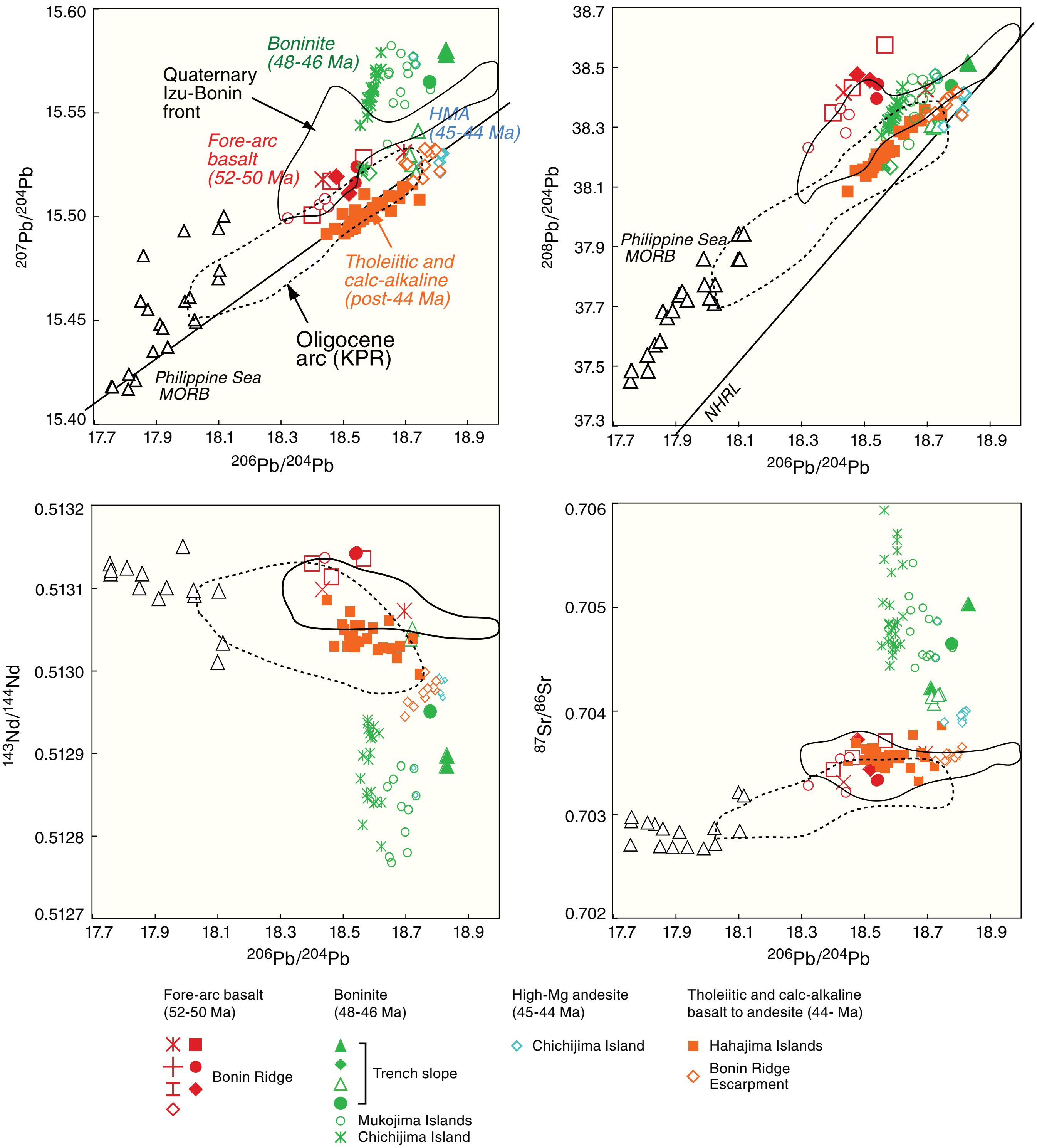


Figure F6. Interpretation of the tectonic evolution of the Bonin Ridge in Ishizuka (2006) based on the concept of Stern and Bloomer (1992). According to this model, subduction initiation is followed by sinking of the slab with slab-parallel subduction and hence normal arc volcanism only beginning later. Later discoveries of fore-arc basalt in the Mariana and Bonin fore arcs (Reagan et al., 2010; Ishizuka et al., 2011) have pushed the infant arc back to 52–45 Ma, the period addressed by this drilling proposal in an attempt to test this model in detail. BRE = Bonin Ridge Escarpment.

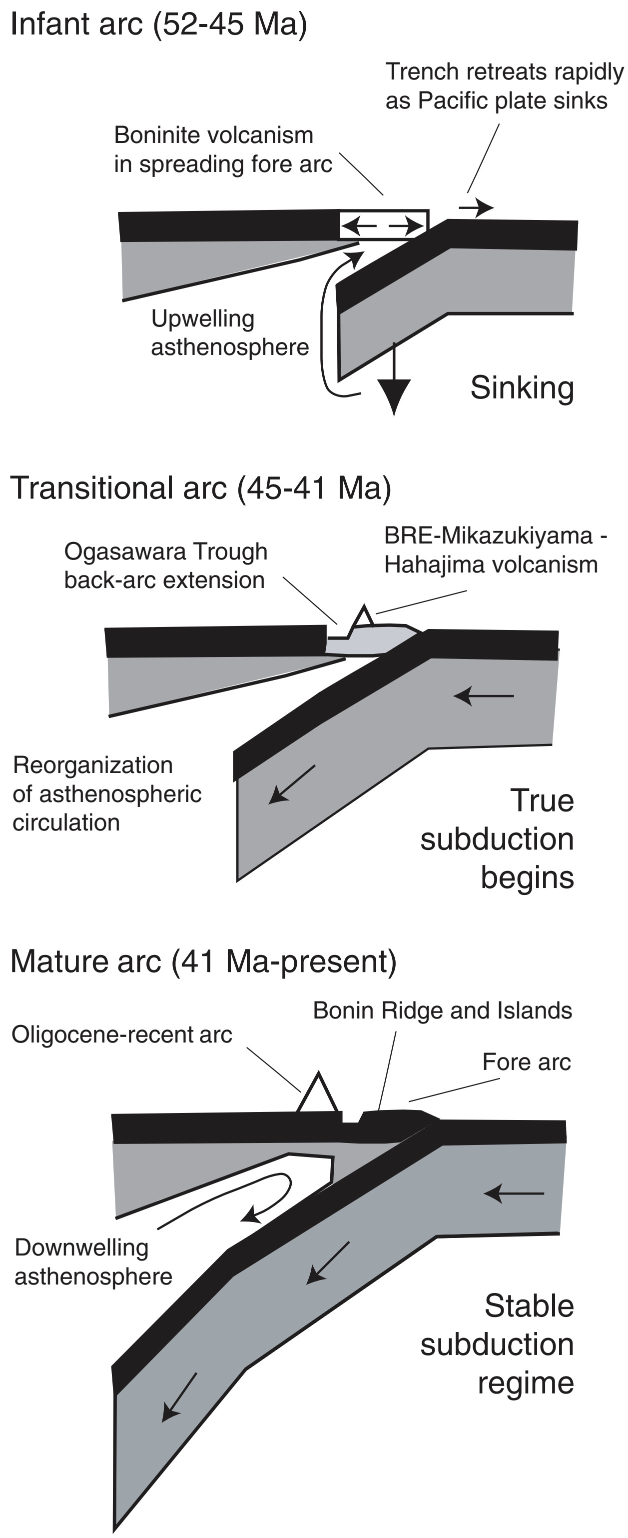


Figure F7. Basaltic vs. boninitic character as a function of the age of the lava following subduction initiation in the Bonin fore arc. Fore-arc basalt (FAB) erupts first and at the end (Hahajima), but otherwise boninites dominate. Boninites are characteristic of subduction initiation, and the full stratigraphy would enable their tectonic significance to be explained better. Data are from Pearce et al. (1999), Reagan et al. (2010), and Ishizuka et al. (2011). MORB = mid-ocean-ridge basalt, IAB = island arc basalt.

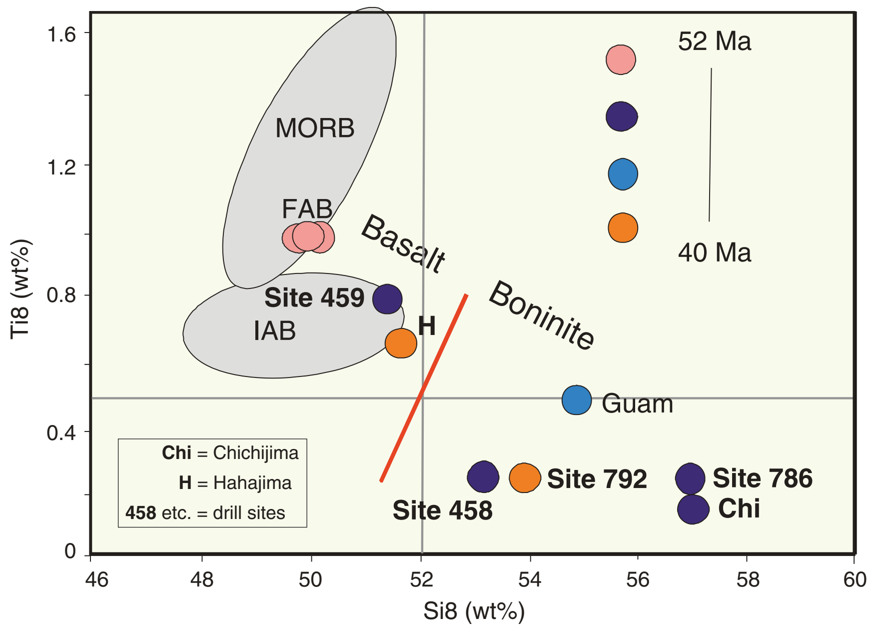


Figure F8. *P*-wave velocity structure obtained by nonlinear inversion along the east–west line of Kamimura et al. (2002), ~150 km north of proposed Sites BON-1A and BON-2A and an equivalent distance south of ODP Site 786 (Fig. F1). BON-1A and BON-2A lie between Site 786 and the point marked "Intersection" if projected onto this section. The colors indicate seismic velocities in km/s and the numerals indicate seismic layers (1 = sediments, 2 = lavas and dikes, 3–4 = gabbroic, 5 = peridotite). Lavas + sheeted dikes at the longitude of Sites BON-1A and BON-2A are as thick as 2 km; hence, we expect to drill a maximum of 1.5 km of lavas to reach sheeted dikes. IBM = Izu-Bonin-Mariana, TSFS = Torishima fore-arc seamount.

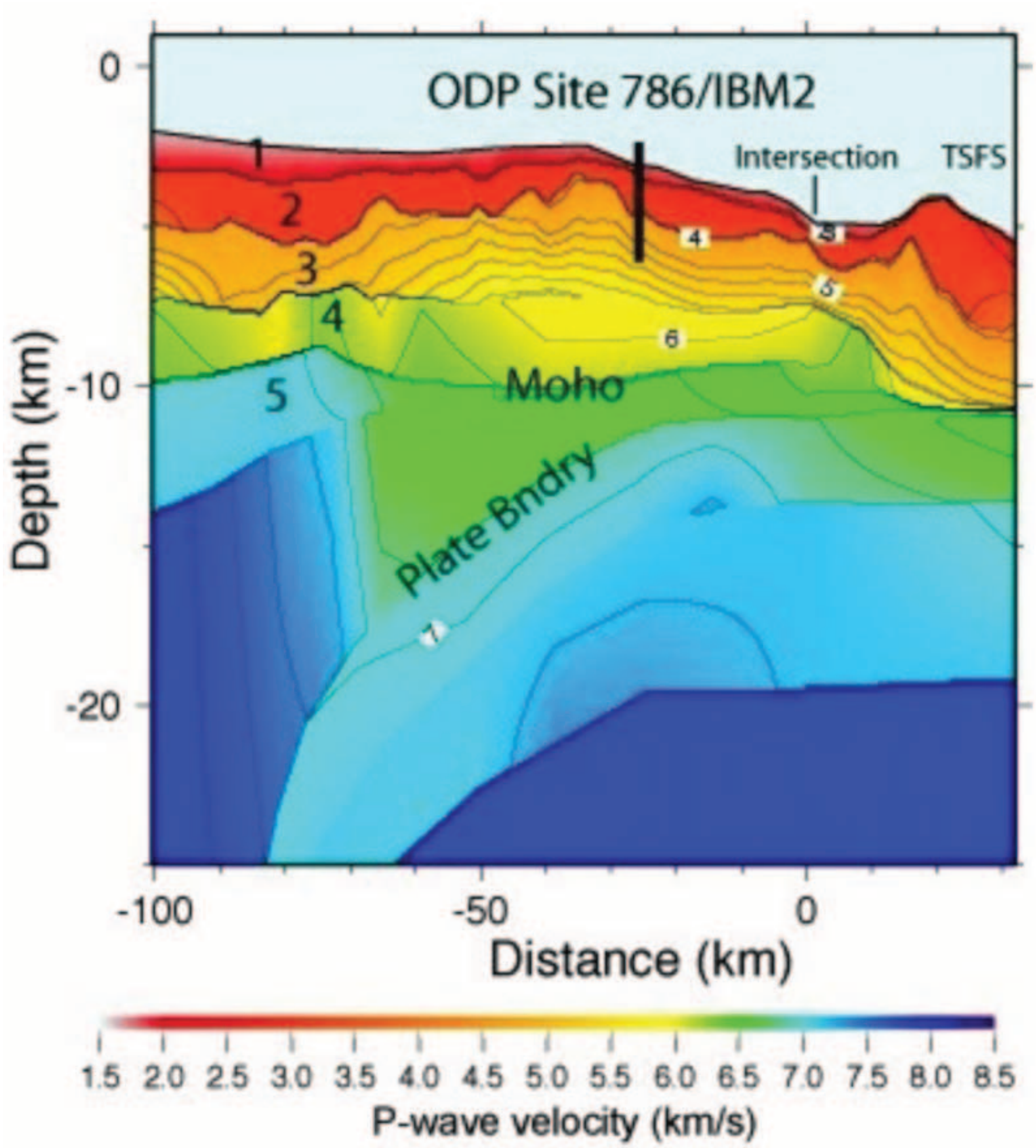


Figure F9. Trench-parallel fore-arc seismic sections from Kodaira et al. (2010). **A.** *P*-wave velocity image. Shaded area = poorly resolved area identified by the checkerboard test. **B.** Reflectivity image superimposed on a layered structure constructed from velocity and reflectivity images. Unit A must consist of sediment, volcaniclastics, and volcanic rocks (Kodaira et al., 2007); Unit B is likely to consist of felsic-to-intermediate plutonic rocks; Unit C is mafic plutonic rocks and amphibolites; Unit D may be pyroxenite; and Unit E is mantle peridotite. The wide-angle ocean-bottom seismometer profile is the near-north–south profile in Figure F1. **C.** *P*-wave velocity model. Proposed Sites BON-1A and BON-2A are located ~150 km along the section and ~30 km to the east.

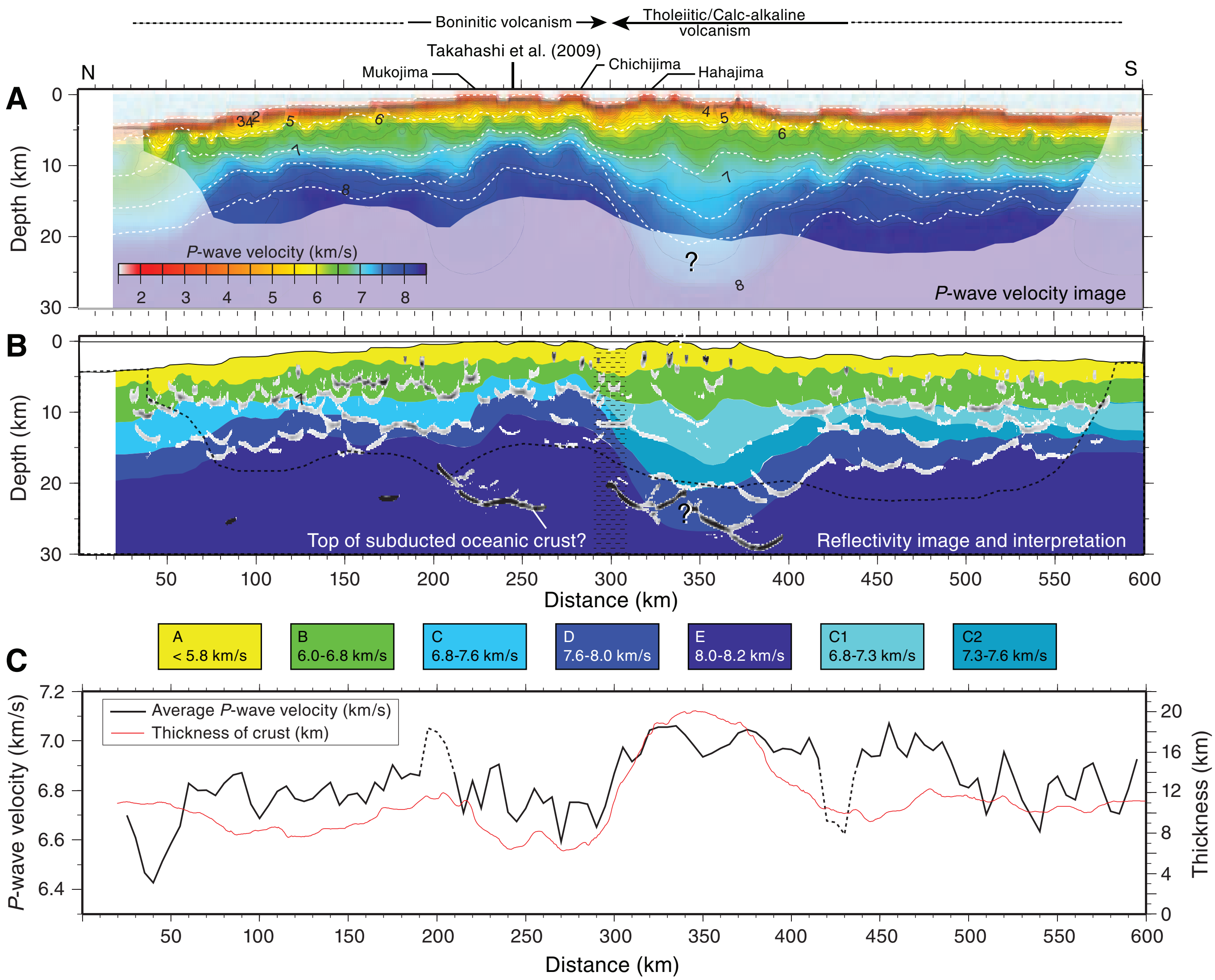


Figure F10. Rock types recovered from dredging and diving expeditions to the Bonin fore arc, showing its ophiolitic structure (after Ishizuka et al., 2011). Proposed drill Sites BON-1A and BON-2A are shown. Boxes depict the areas chosen for more detailed site survey dives (Fig. **F11**).

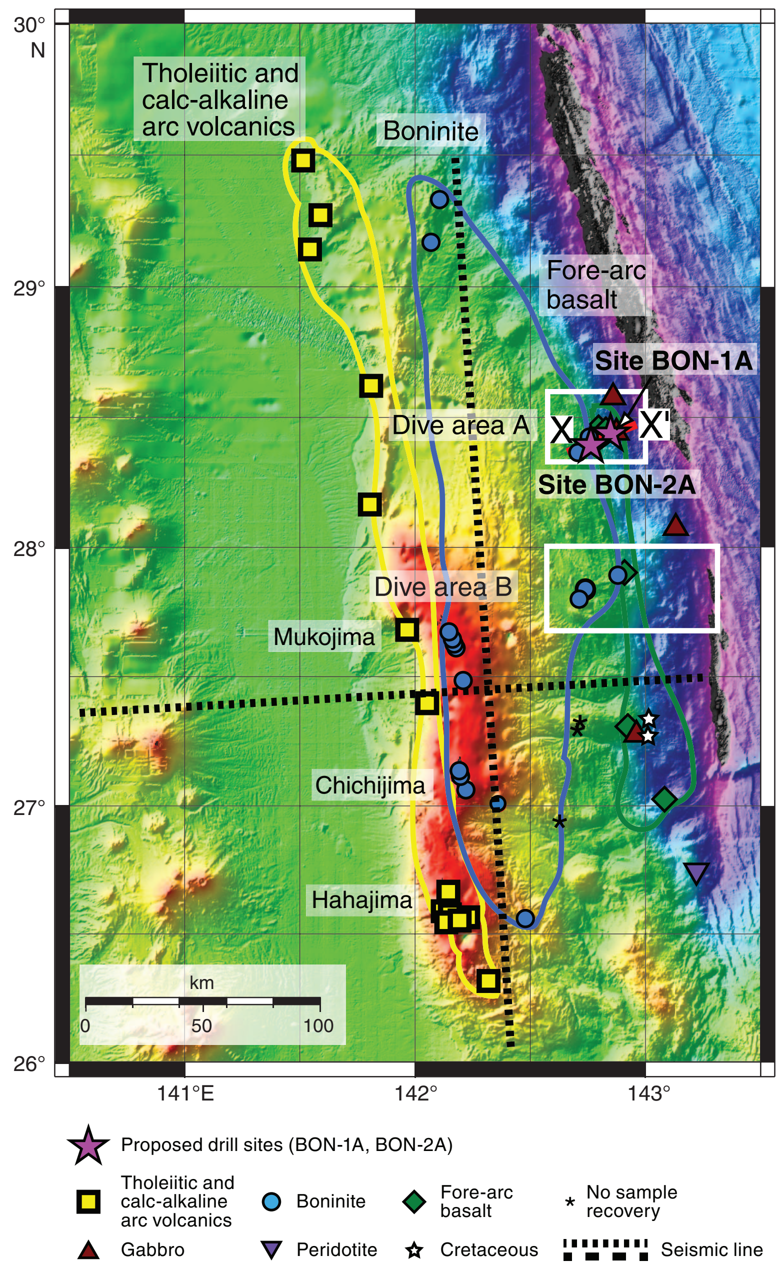


Figure F11. Results of diving site survey cruises to the Bonin fore arc (Miyajima, 2009; Ishizuka et al., 2011). The locations of proposed Sites BON-1A and BON-2A are based on the results from the dive sites illustrated on this figure.

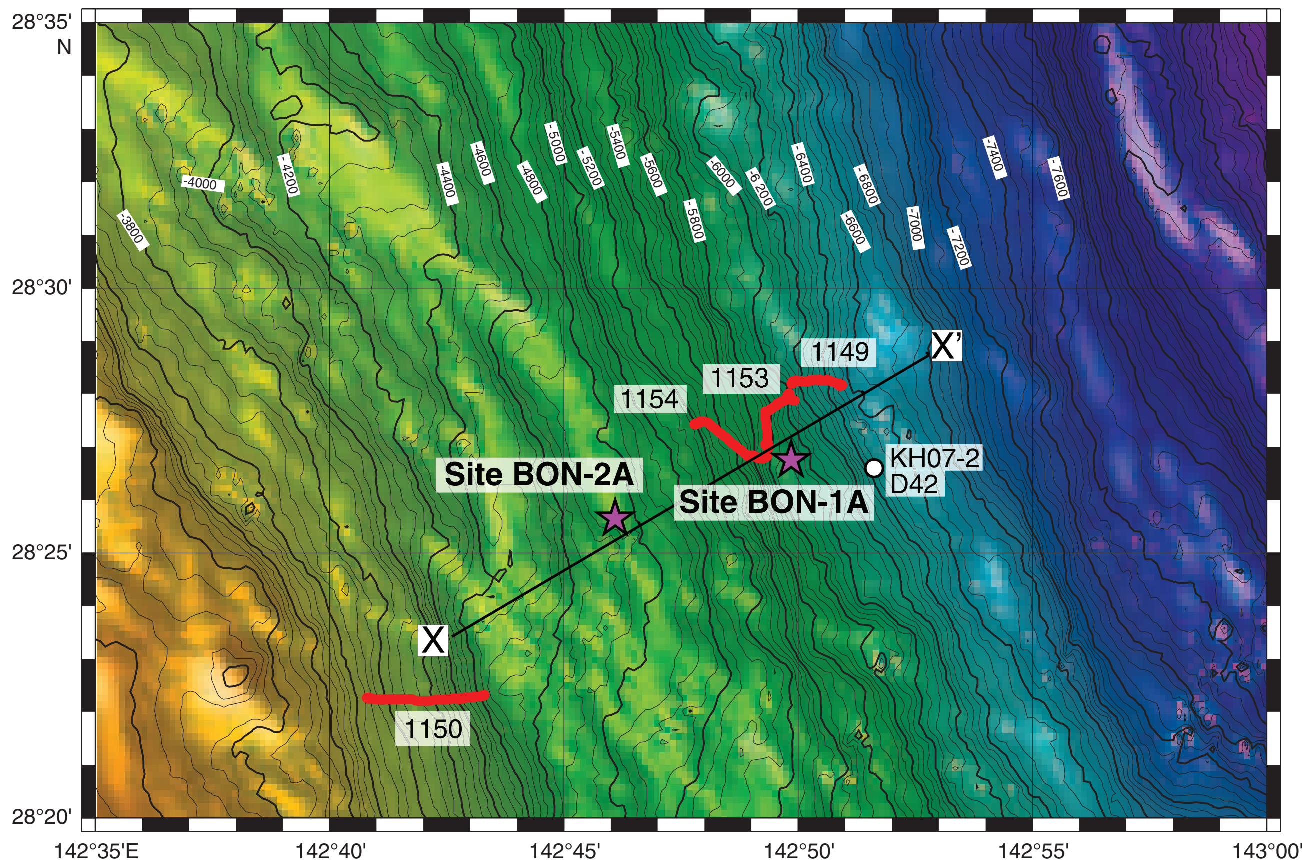


Figure F12. Schematic stratigraphic section (not to scale) expected in the Bonin Ridge drill site area. FAB = fore-arc basalt.

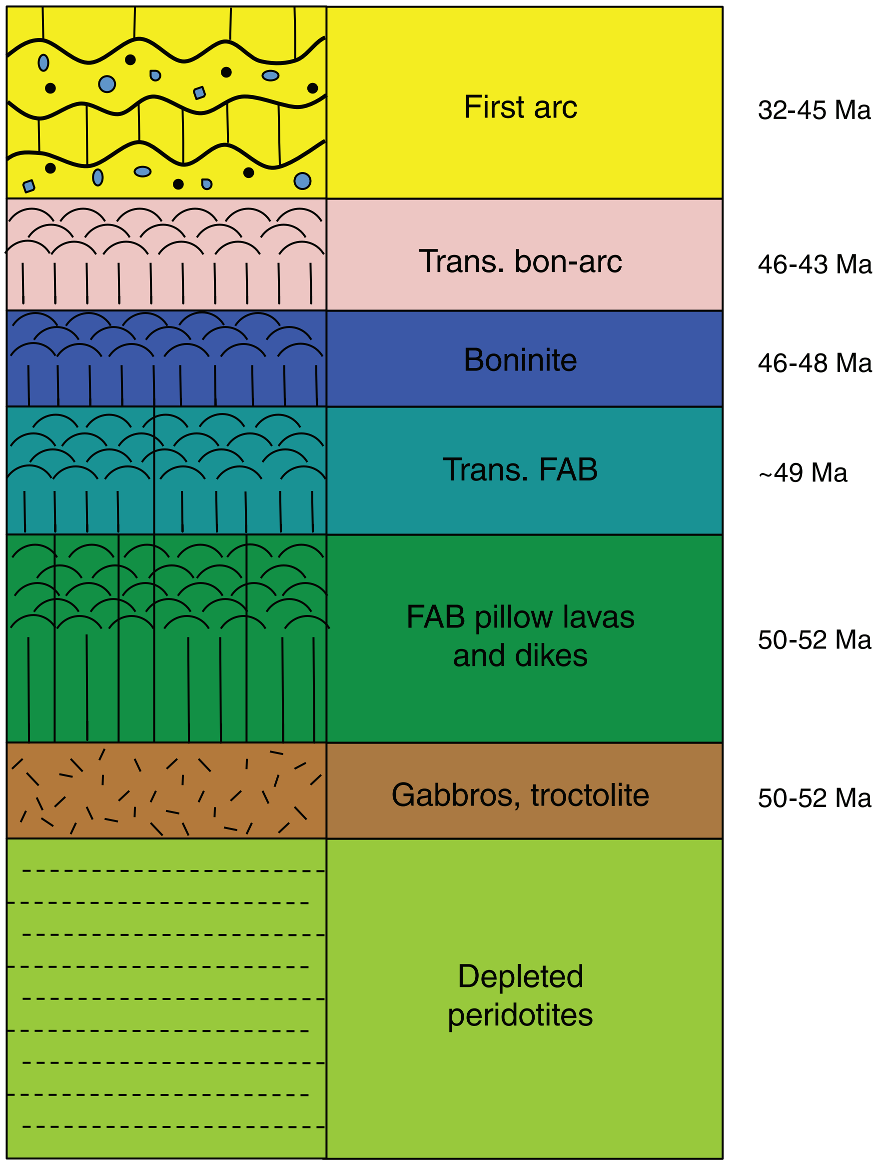


Figure F13. Simplified regional geological map of the drill site area, showing the location of proposed Sites BON-1A and BON-2A (courtesy O. Ishizuka). MORB = mid-ocean-ridge basalt.

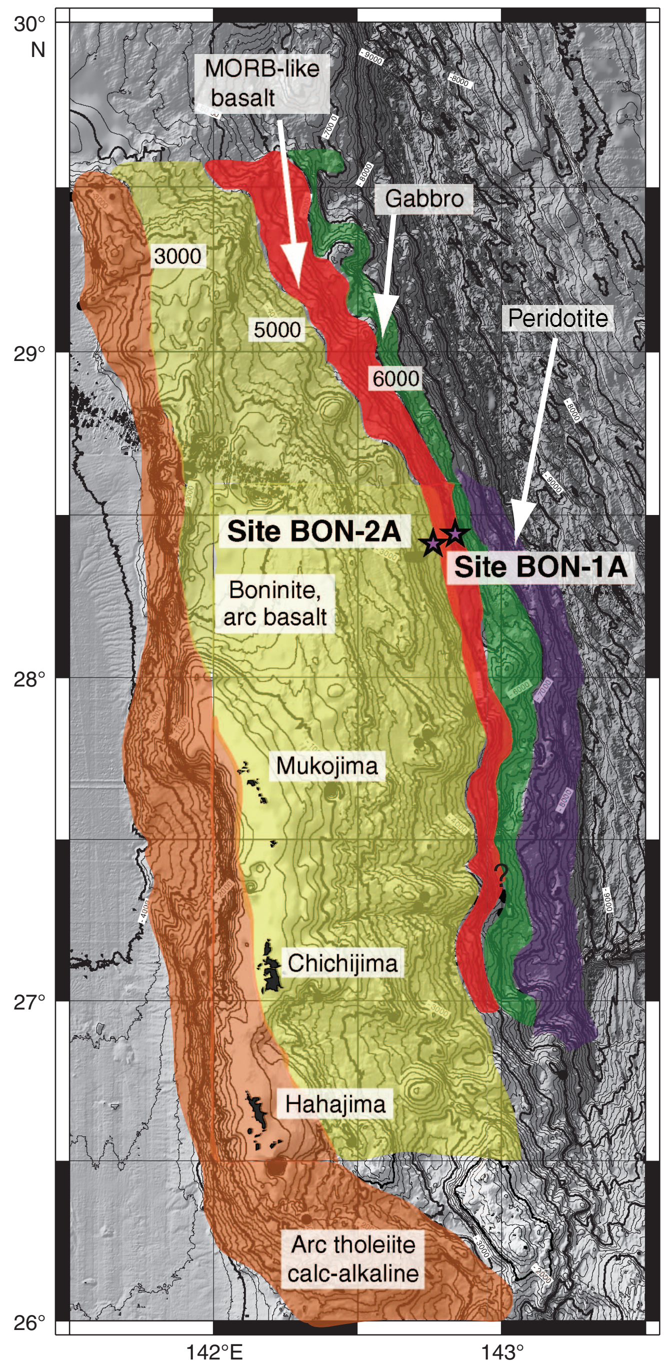


Figure F14. Schematic cross-section showing the location of offset Sites BON-1A and BON-2A. Site BON-1A will drill fore-arc basalt (FAB) lavas into intrusive rocks to record the first magmatic products of subduction initiation. Site BON-2A will drill from boninites into FAB to record the transition from subduction initiation magmatism to normal arc magmatism.

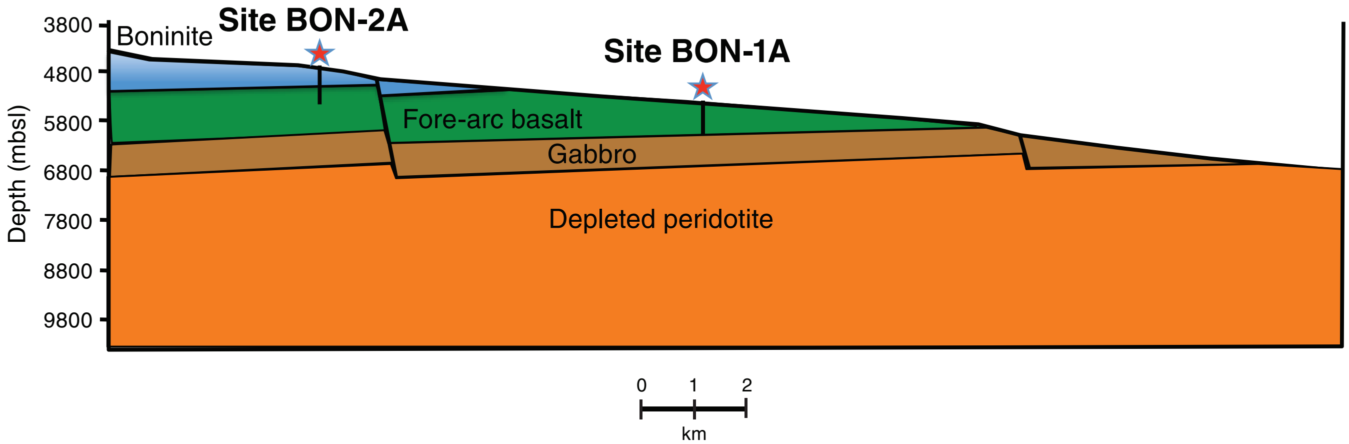
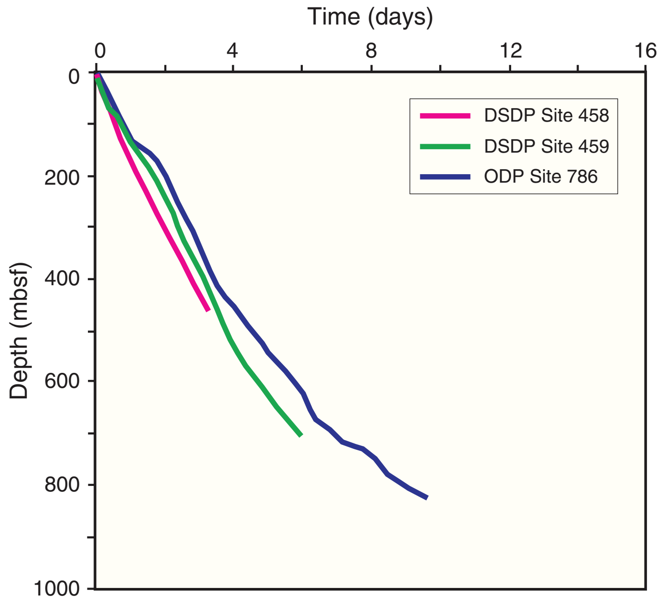


Figure F15. Drilling record for fore-arc Sites 786 (Izu-Bonin fore arc) and 458–459 (Mariana fore arc), as a means of estimating drilling rates for proposed Sites BON-1A and BON-2A, which have similar lithologies.



Site summaries

Proposed Site BON-1A

Priority:	Primary
Position:	28°27.01′N, 142°45.35′E
Water depth (m):	4778
Target drilling depth (mbsf):	1010 (260 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1510 (pending EPSP approval)
Survey coverage:	Line IBr11n CDP 5364, Line KT07 • Track map (Fig. AF1) • Seismic profiles (Figs. AF2, AF3)
Objective:	Characterize lower volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (260 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 265 mbsf) • Hole C: drill without recovery to 270 mbsf, RCB from 270 to 1010 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, basaltic lavas, and sheeted dikes

Site summaries (continued)

Proposed Site BON-2A

Priority:	Primary
Position:	28°24.46′N, 142°36.55′E
Water depth (m):	3137
Target drilling depth (mbsf):	870 (120 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1370 (pending EPSP approval)
Survey coverage:	Line IBr11 CDP 66252, Line KT06 • Track map (Fig. AF1) • Seismic profiles (Figs. AF4, AF5)
Objective:	Characterize upper volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (120 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 125 mbsf) • Hole C: drill without recovery to 130 mbsf, RCB from 130 to 870 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, boninite, and basaltic lavas

Site summaries (continued)

Proposed Site BON-3A

Priority:	Alternate
Position:	28°26.03′N, 142°46.02′E
Water depth (m):	4762
Target drilling depth (mbsf):	960 (210 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1460 (pending EPSP approval)
Survey coverage:	Line IBr11 CDP 68768 • Track map (Fig. **AF1**) • Seismic profiles (Figs. **AF2, AF4, AF6**)
Objective:	Characterize lower volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (210 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 215 mbsf) • Hole C: drill without recovery to 220 mbsf, RCB from 220 to 960 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, basaltic lavas, and sheeted dikes

Site summaries (continued)

Proposed Site BON-4A

Priority:	Alternate
Position:	28°25.46′N, 142°36.12′E
Water depth (m):	3130
Target drilling depth (mbsf):	850 (100 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1350 (pending EPSP approval)
Survey coverage:	Line IBr11n CDP 7817 • Track map (Fig. AF1) • Seismic profiles (Figs. AF2, AF4, AF5, AF7)
Objective:	Characterize upper volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (100 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 105 mbsf) • Hole C: drill without recovery to 110 mbsf, RCB from 110 to 850 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, boninite, and basaltic lavas

Site summaries (continued)

Proposed Site BON-5A

Priority:	Alternate
Position:	28°24.54′N, 142°37.04′E
Water depth (m):	3152
Target drilling depth (mbsf):	910 (160 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1410 (pending EPSP approval)
Survey coverage:	Line IBr11 CDP 66380 • Track map (Fig. AF1) • Seismic profiles (Figs. AF4, AF5, AF8)
Objective:	Characterize upper volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (160 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 165 mbsf) • Hole C: drill without recovery to 170 mbsf, RCB from 170 to 910 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, boninite, and basaltic lavas

Site summaries (continued)

Proposed Site BON-6A

Priority:	Alternate
Position:	28°25.63′N, 142°43.50′E
Water depth (m):	4452
Target drilling depth (mbsf):	1020 (270 m sediment, 750 m basement)
Approved maximum penetration (mbsf):	1520 (pending EPSP approval)
Survey coverage:	Line IBr11 CDP 68100 • Track map (Fig. AF1) • Seismic profiles (Figs. AF4, AF9)
Objective:	Characterize lower volcanic stratigraphy at Bonin fore arc to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: APC/XCB to basement (270 mbsf) • Hole C: reentry system (16 and 10-3/4 inch casing to 275 mbsf) • Hole C: drill without recovery to 280 mbsf, RCB from 280 to 1020 mbsf • FlexIT core orientation measurements • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, basaltic lavas, and sheeted dikes

Site summaries (continued)

Site 459

Priority:	Alternate
Position:	17°51.75′N, 147°18.09′E
Water depth (m):	4130
Target drilling depth (mbsf):	1500 (500 m sediment, 1000 m basement)
Approved maximum penetration (mbsf):	1500 (pending EPSP approval to deepen)
Survey coverage:	MGL1204 Line N CDP 17806 • Track map (Fig. **AF1B**) • Seismic profile (Fig. **AF10**), Mrozowski et al. (1982), and Chapp et al. (2008)
Objective:	Characterize transitional basalt lavas and associated intrusive rocks to investigate subduction initiation processes and test supra-subduction zone ophiolite models
Drilling, coring, and downhole measurements program:	• Hole A: jet-in test • Hole B: reentry system (16 and 10-3/4 inch casing to 500 mbsf) • Hole B: drill without recovery to 650 mbsf, RCB from 650 to 1500 mbsf • Wireline logging (triple combo, FMS-sonic)
Nature of rock anticipated:	Pelagic carbonate with thin ash layers, turbidites, boninite, basaltic lavas, and diabase

Figure AF1. Location of Expedition 352 site survey data and proposed sites. A. Sites BON-1A–BON-6A and Lines IBr11, IBr11n, KT06, and KT07 (S. Kodaira, pers. comm., 2013). (Continued on next page.)

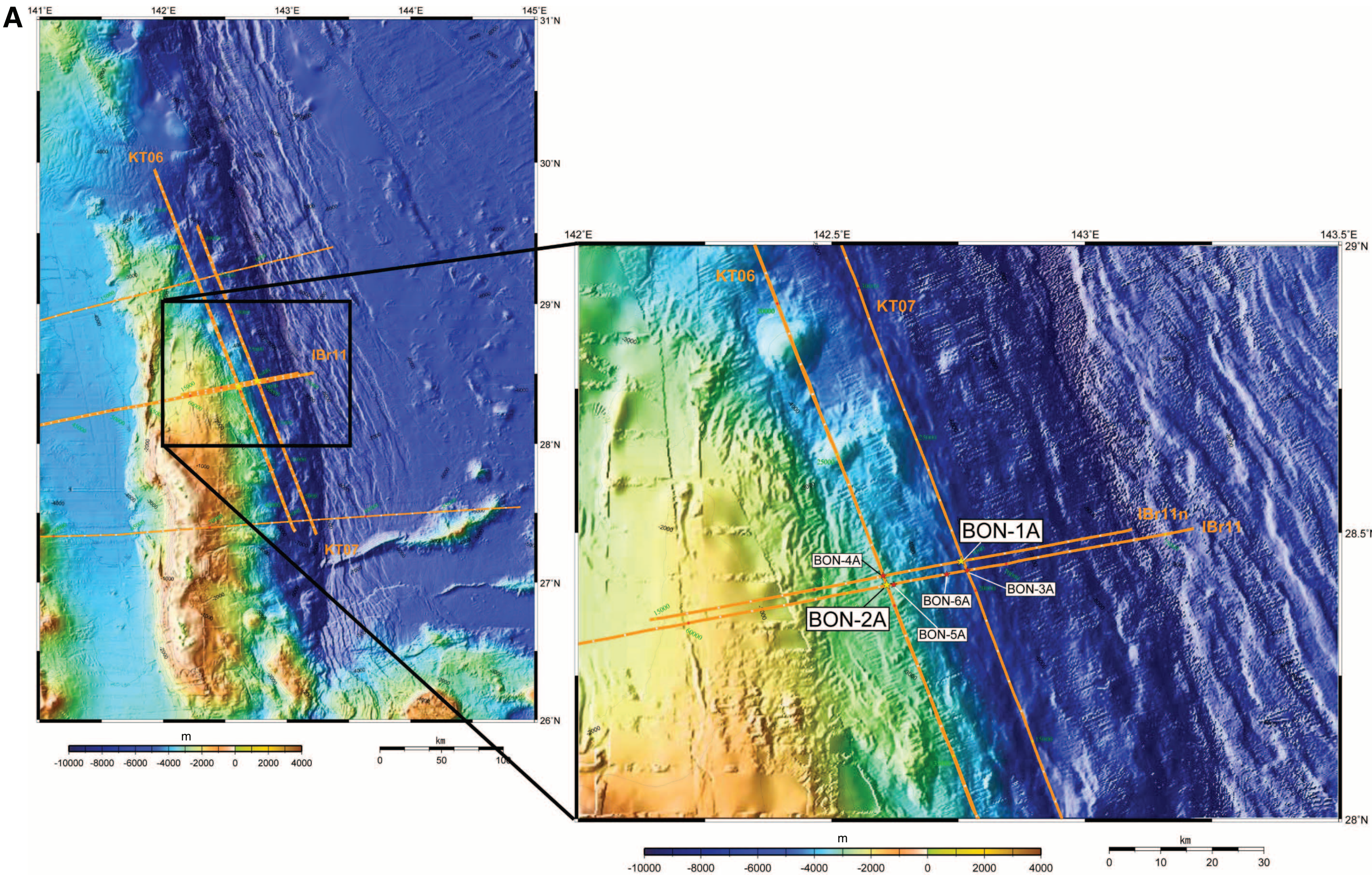


Figure AF1 (continued). B. Deep Sea Drilling Project Site 459 and MGL1204 Line N (D. Lizarralde, pers. comm., 2013).

B

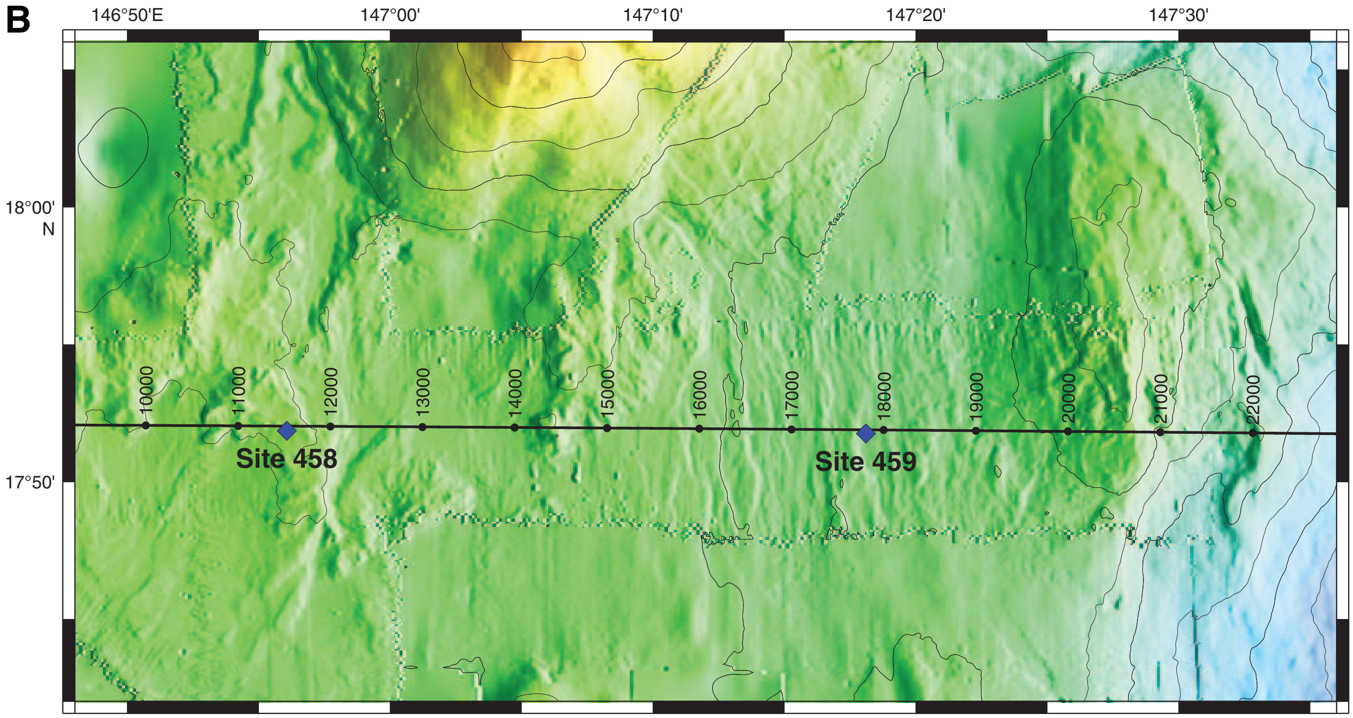


Figure AF2. Proposed primary Site BON-1A and alternate Sites BON-3A and BON-4A. **A.** Line IBr11n. **B.** Line KT07. CDP = common depth point. (S. Kodaira, pers. comm., 2013)

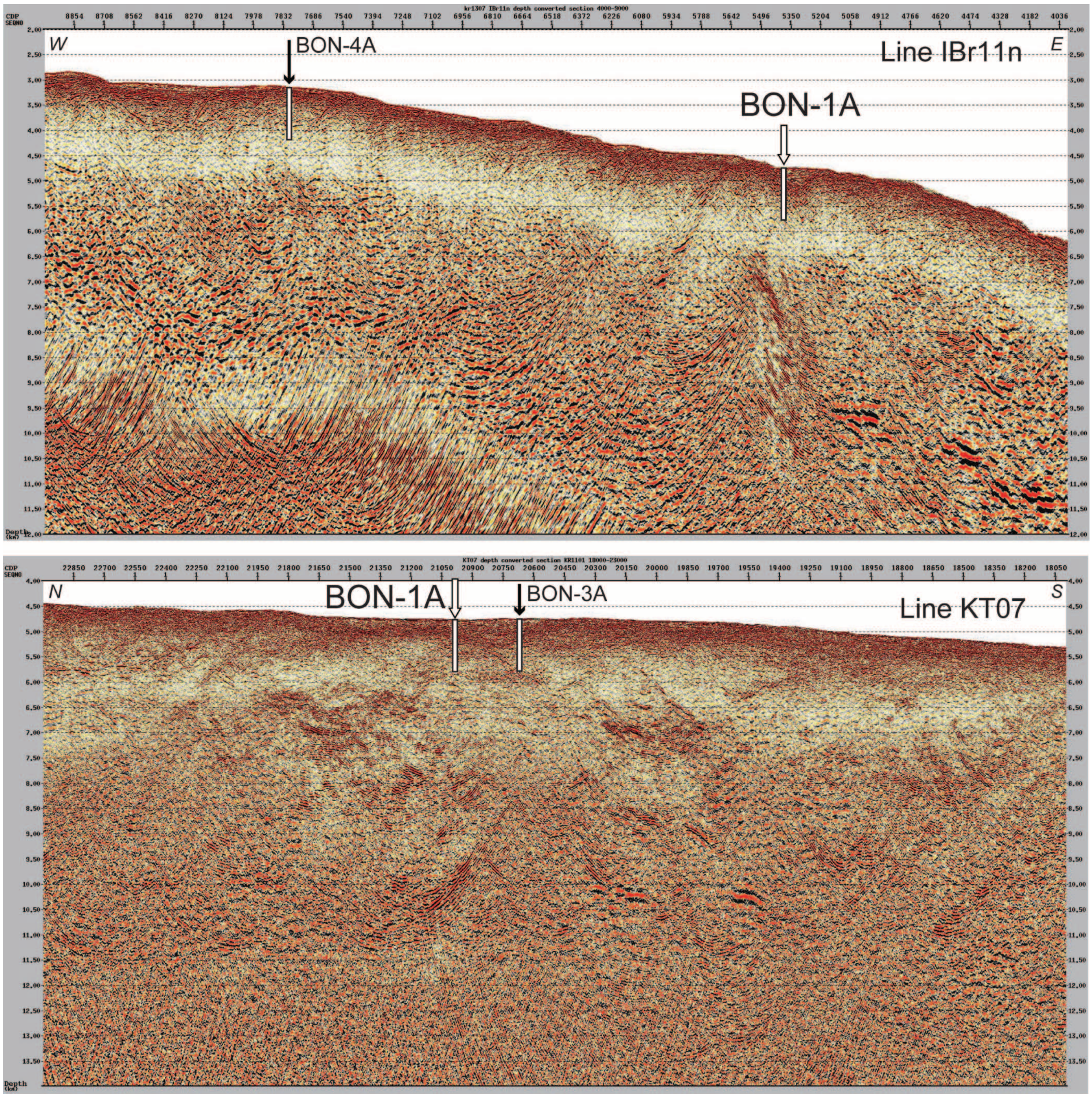


Figure AF3. Proposed primary Site BON-1A (Line IBr11n, common depth point [CDP] 5364). **A.** Line IBr11n. **B.** Line KT07. (S. Kodaira, pers. comm., 2013)

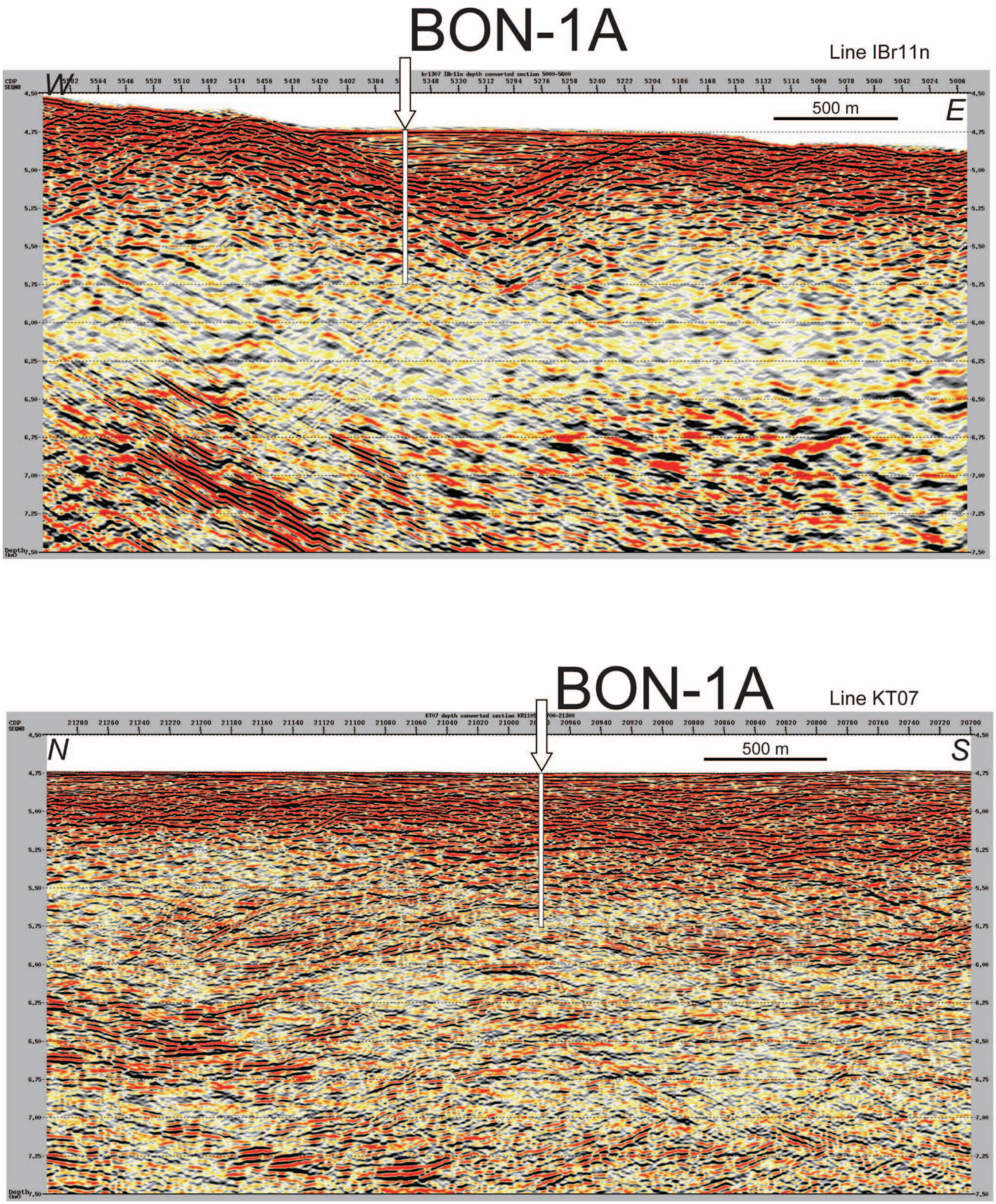


Figure AF4. Proposed primary Site BON-2A and alternate Sites BON-3A, BON-4A, BON-5A, and BON-6A. **A.** Line IBr11. **B.** Line KT06. CDP = common depth point. (S. Kodaira, pers. comm., 2013)

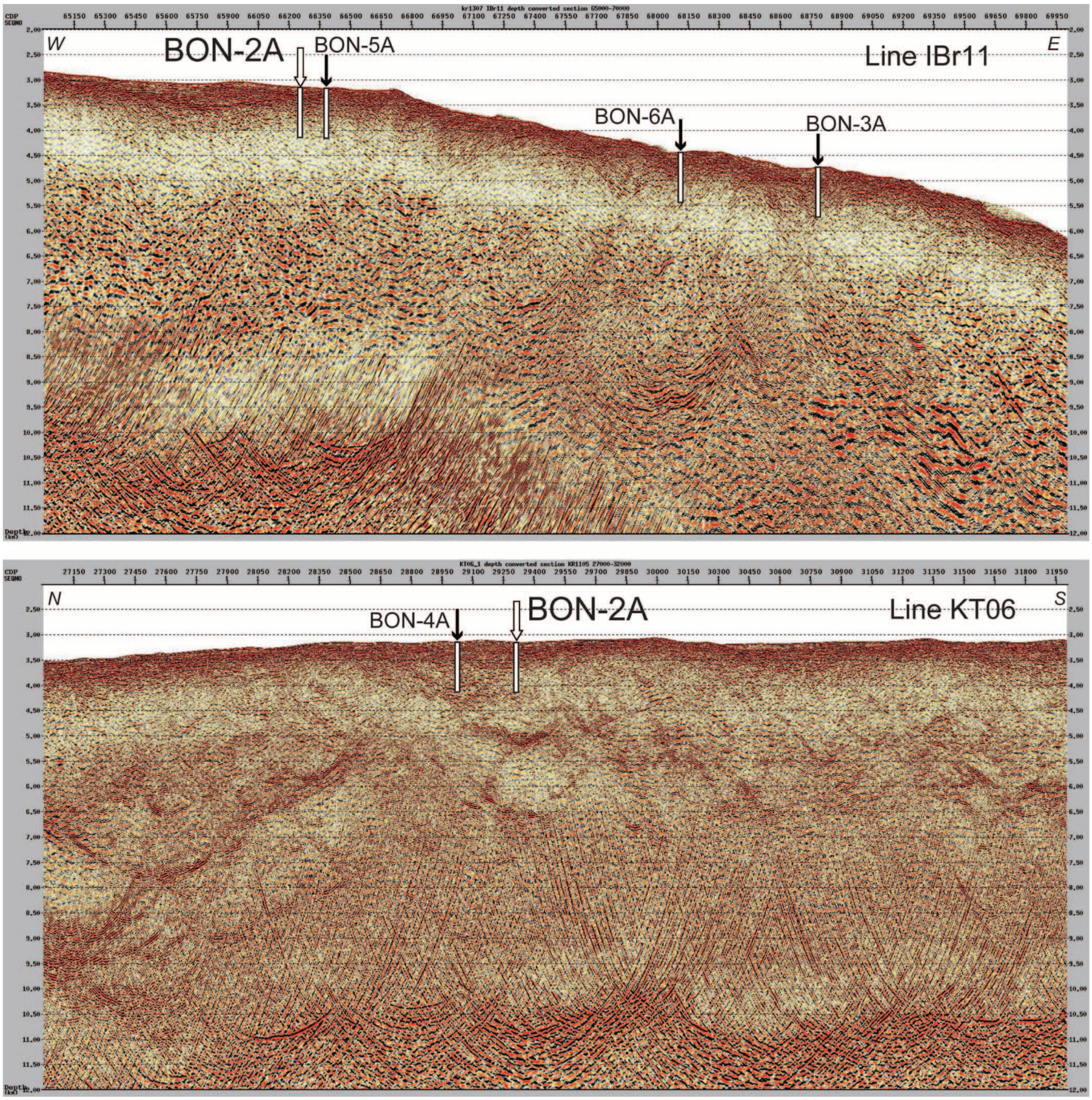


Figure AF5. Proposed primary Site BON-2A (Line IBr11, common depth point [CDP] 66252) and alternate Sites BON-4A and BON-5A. **A.** Line IBr11. **B.** Line KT06. (S. Kodaira, pers. comm., 2013)

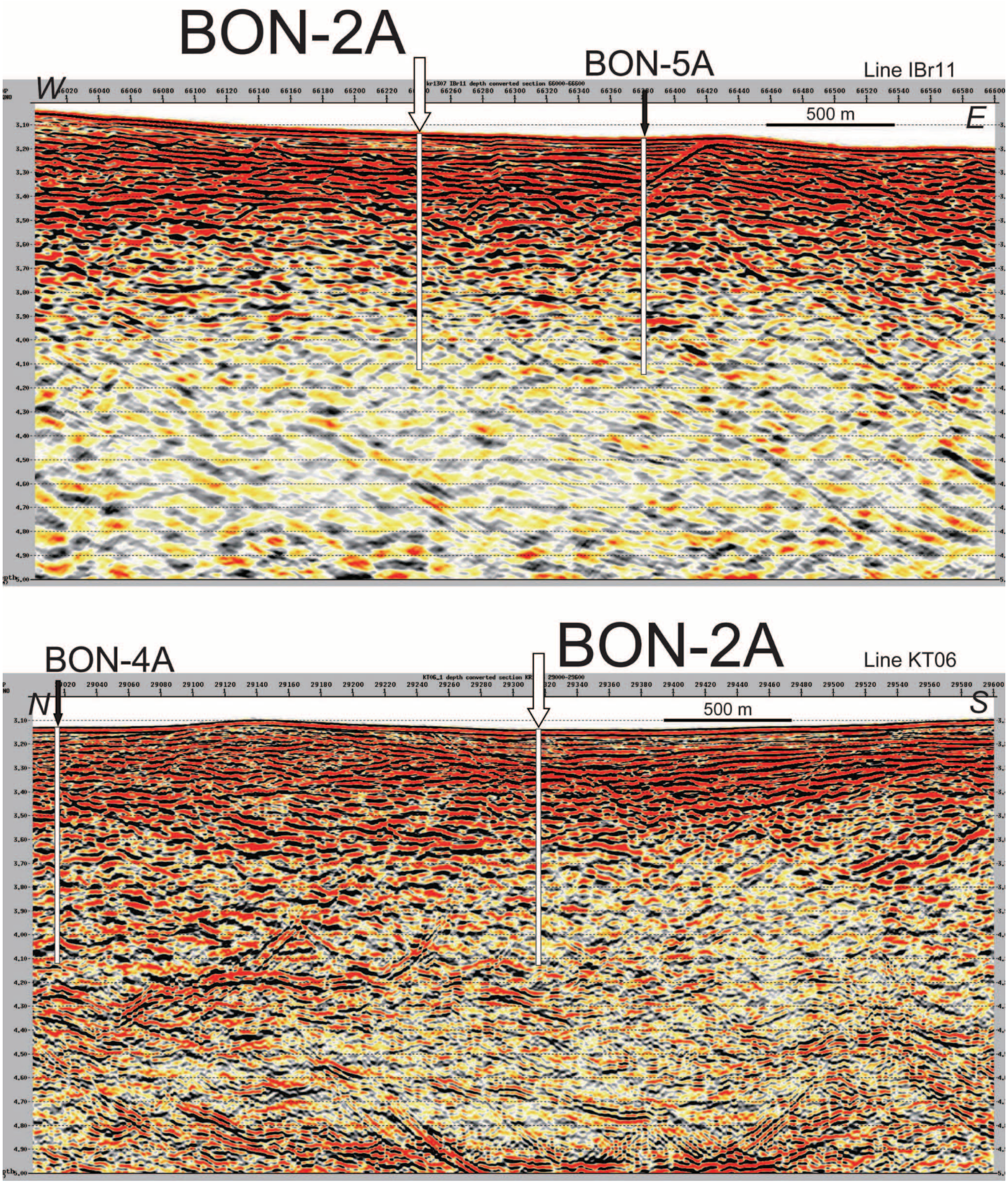


Figure AF6. Proposed alternate Site BON-3A (Line IBr11, common depth point [CDP] 68768) (S. Kodaira, pers. comm., 2013).

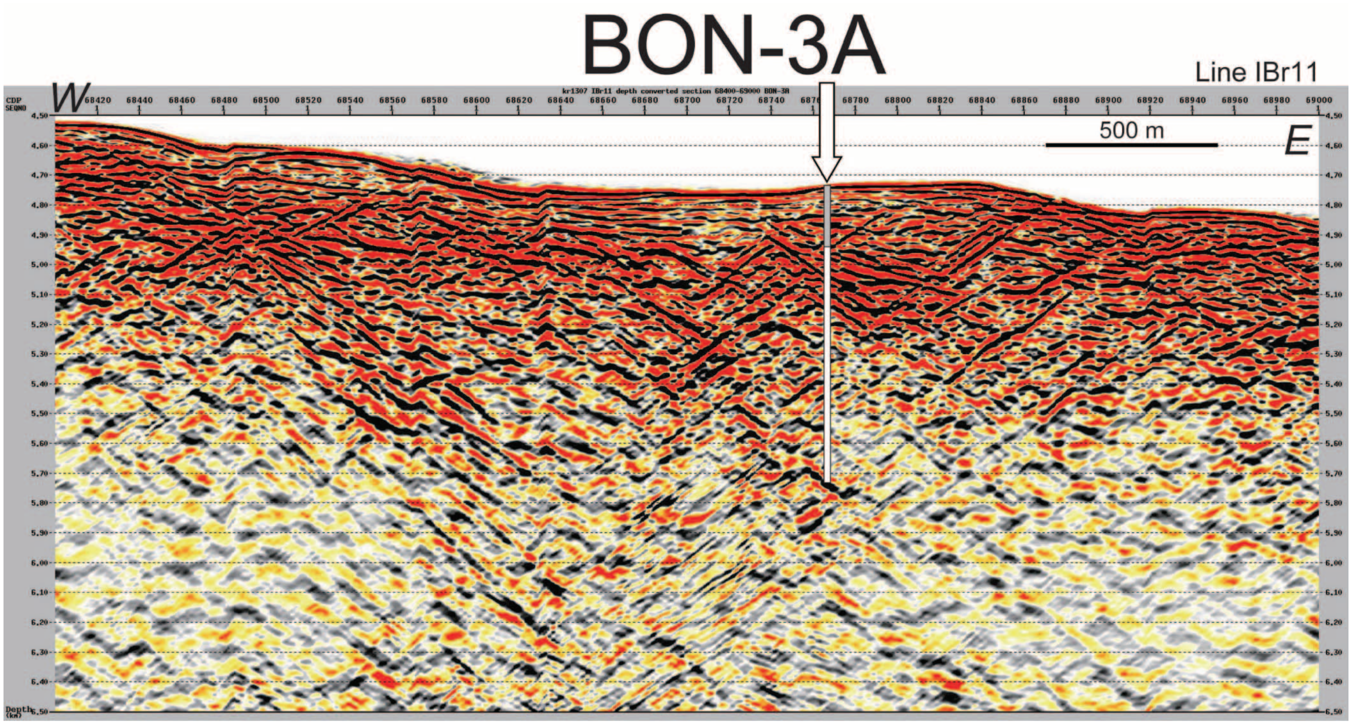


Figure AF7. Proposed alternate Site BON-4A (Line IBr11n, common depth point [CDP] 7817) (S. Kodaira, pers. comm., 2013).

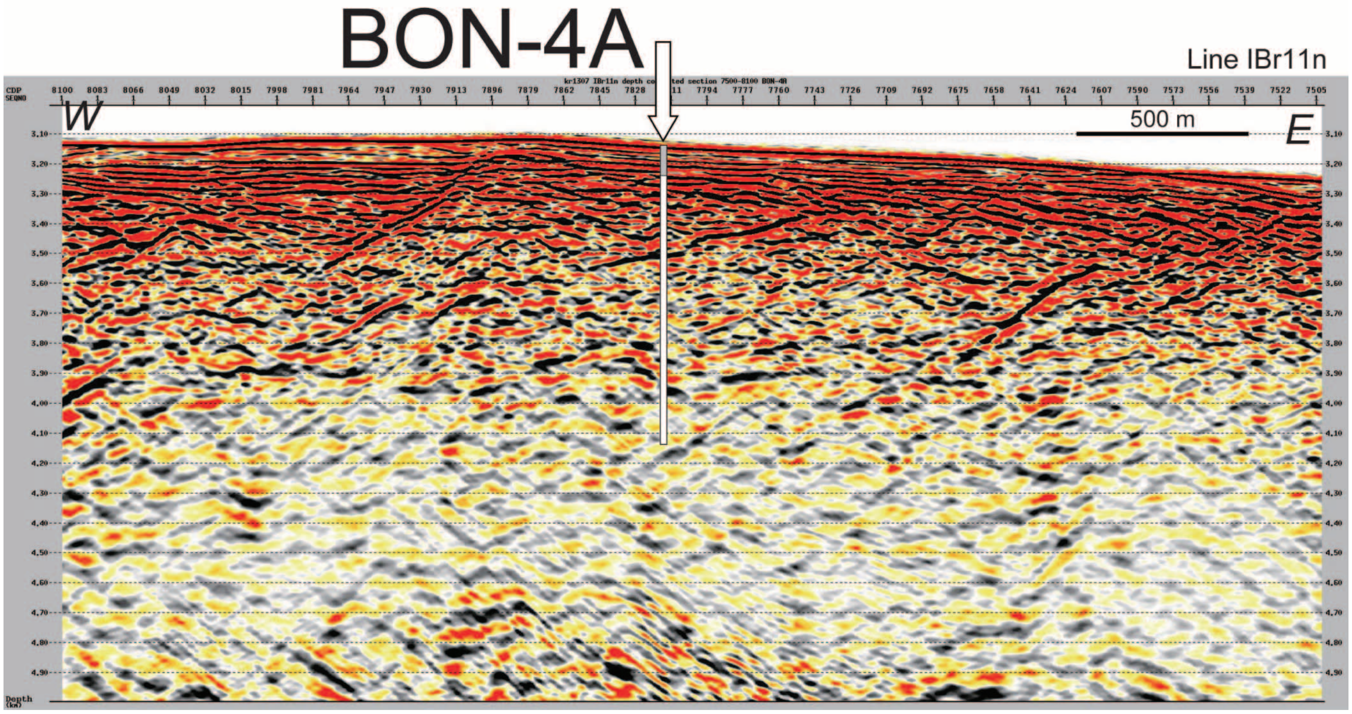


Figure AF8. Proposed alternate Site BON-5A (Line IBr11, common depth point [CDP] 66380) (S. Kodaira, pers. comm., 2013).

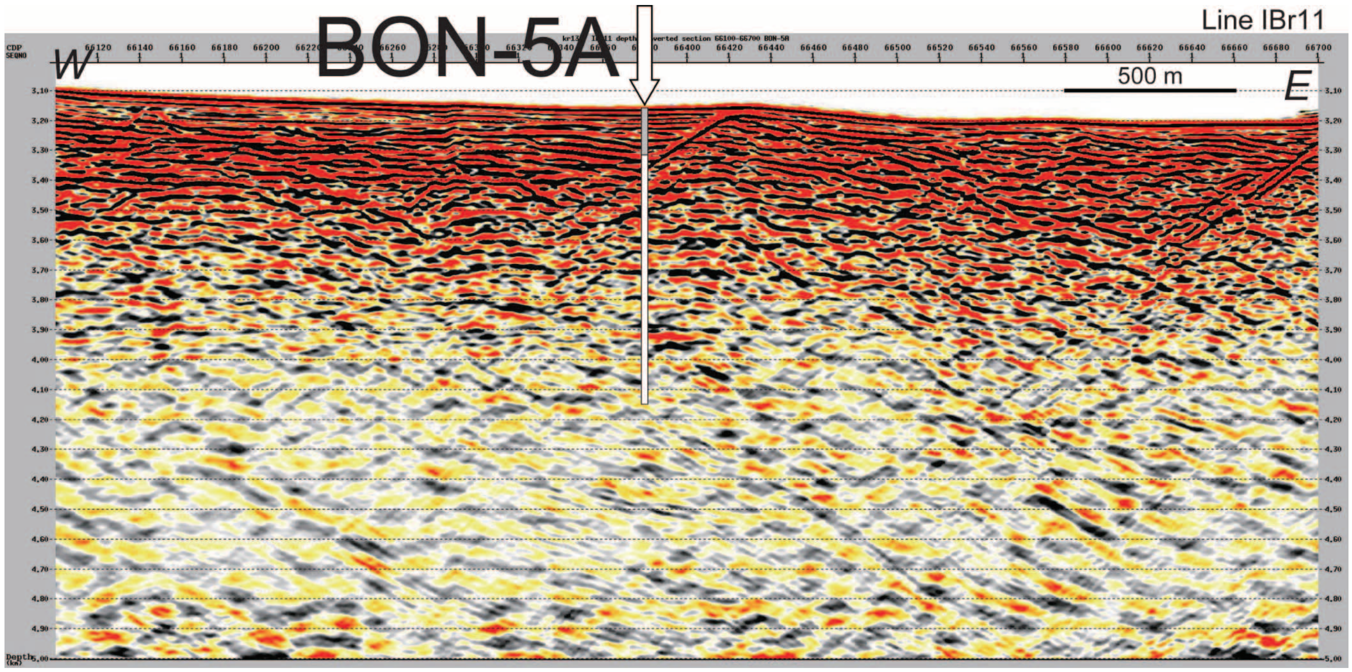


Figure AF9. Proposed alternate Site BON-6A (Line IBr11, common depth point [CDP] 68100) (S. Kodaira, pers. comm., 2013).

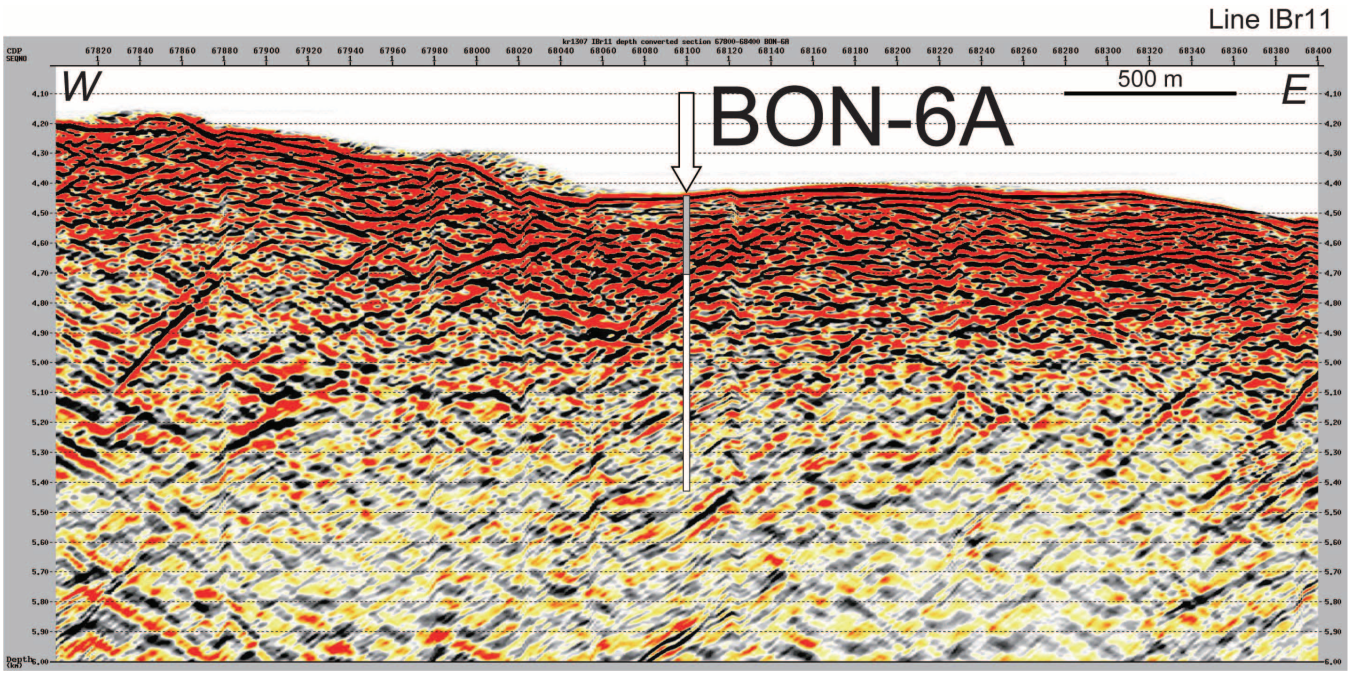
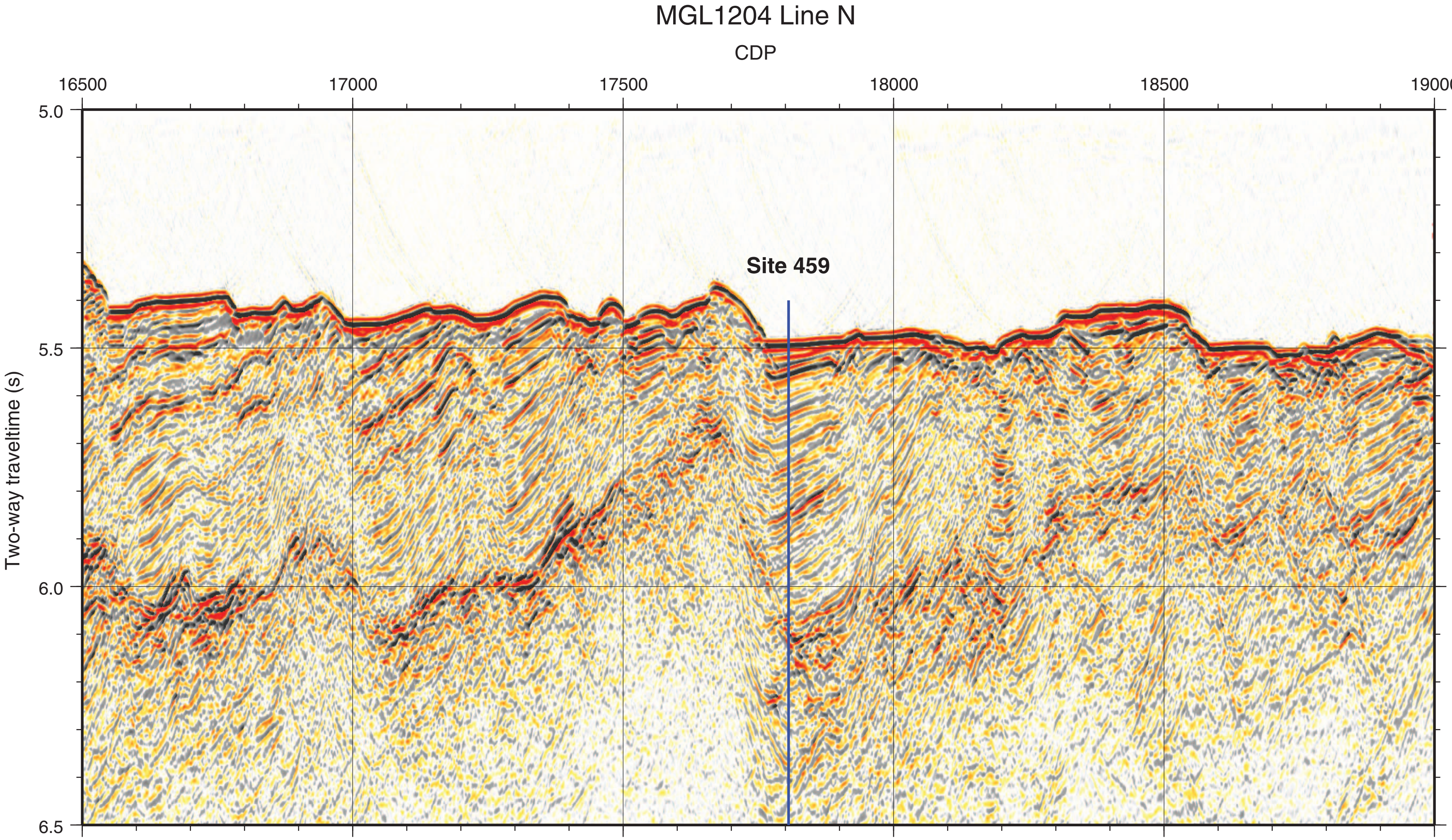


Figure AF10. Proposed alternate Site 459 (MGL1204 Line N, common depth point [CDP] 17806) (D. Lizarralde, pers. comm., 2013).



Expedition scientists and scientific participants

The current list of participants for Expedition 352 can be found at: **iodp.tamu.edu/sciencops/precruise/izuboninforearc/participants.html.**