International Ocean Discovery Program
Expedition 351 Scientific Prospectus

Izu-Bonin-Mariana Arc Origins

Continental crust formation at intraoceanic arc: foundations, inception, and early evolution

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Abstract

Oceanic lithosphere created at oceanic ridges is returned to Earth's interior at sutures marked by deep-sea trenches in a process called subduction. The formation and destruction of lithospheric plates is a fundamentally important process leading to the creation of most important surface features and a major driver of the physical and chemical evolution of Earth. Although we have a relatively good understanding of the processes accompanying the formation of lithosphere in the so-called "rift-to-drift" cycle, we have minimal direct evidence of how subduction is initiated. This essential component of the global plate tectonic cycle is targeted as one of the major challenges of the new science plan for the International Ocean Discovery Program (IODP).

As an initial step in addressing this challenge, during IODP Expedition 351 we will core and log a prime site in the Amami Sankaku Basin, located <100 km west of the northern portion of the Kyushu-Palau Ridge (KPR), a remnant arc of the intraoceanic Izu-Bonin-Mariana (IBM) arc in the western Pacific on the northern part of the Philippine Sea plate. Over the past several decades, multidisciplinary efforts, including deep-sea drilling, have been made to understand the crustal characteristics and structure, tectonic and temporal evolution, and magma origins of the IBM system since its inception 52 m.y. ago. Subsequently, Site IBM-1 has been identified in the Amami Sankaku Basin where samples of the pre-arc basement can be recovered. We infer a Cretaceous to Paleogene age for the basement, overlain by a pre-arc-inception sediment section and an upper sedimentary sequence recording regional tectonic events accompanying formation of the KPR as a proto-arc at 52 Ma. Additional sedimentary cover recorded the Paleogene volcaniclastic and pyroclastic evolution of the Izu-Bonin arc with diminishing completeness, as the KPR was abandoned as a remnant arc at ~25 Ma, accompanying formation of the Shikoku back-arc basin.

The objectives of Expedition 351 involve the study of both the sediment (oceanic crust Layer 1) and igneous basement (Layer 2) and were established to address a number of fundamental aims. The primary objectives include

1. Determining the nature of the preexisting crust and mantle prior to subduction onset in the middle Eocene,
2. Identifying and modeling the subduction initiation process and initial arc crust formation,
3. Determining the Paleogene compositional evolution of the IBM arc, and
4. Establishing the geophysical properties of the Amami Sankaku Basin.

We also have a number of secondary objectives based on recovering sedimentary records of (1) early Tertiary and possibly Late Cretaceous paleooceanographic conditions in the eastern Tethys–western Pacific, (2) onset and persistence of the East Asia Monsoon and other climate-modulated terrestrial inputs, and (3) an ash record of the evolution of the Ryukyu-Kyushu arc, located west of the Amami Sankaku Basin.

Expedition 351 is conceptually straightforward, targeting a single site involving penetration of a thick sedimentary section overlying oceanic crust of normal thickness. Nevertheless, the water depth (4720 m), sediment thickness (1300 m), and consequent depth into basement (~150 m) impose technical challenges. Relatively short transit times to and from the Amami Sankaku Basin will maximize the time available for scientific drilling and logging operations.

Schedule for Expedition 351

International Ocean Discovery Program (IODP) Expedition 351 is based on Integrated Ocean Drilling Program drilling proposal Number 695-Full2 (available at **iodp.tamu.edu/scienceops/expeditions/izu_bonin_arc.html**). Following ranking by the IODP Scientific Advisory Structure, the expedition 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 and end in Yokohama, Japan, on 30 May and 30 July 2014, respectively. A total of 56 days will be available for the transit, drilling, coring, and downhole measurements described in this report (for the current detailed 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

The formation and destruction of lithospheric plates is a fundamentally important process leading to the creation of the most important surface features and a major driver of the physical and chemical evolution of Earth. Subduction zones marking sites of plate destruction are unique to Earth among the terrestrial planets, but as yet, we do not have a good understanding of how they are initiated beyond the recognition that old (more than ~25 million years) ocean lithosphere is gravitationally unstable with respect to the underlying asthenospheric mantle. Ignorance of this aspect of the plate tectonic cycle contrasts with our relatively advanced level of understanding of oceanic crust creation from initial rifting to development of a mid-ocean ridge. The processes accompanying subduction zone initiation are identified as part of Challenge 11 of the Science Plan of IODP (available at **www.iodp.org/science-plan-for-2013-2023/**). Among a number of hypotheses that have been proposed, two general mechanisms seem particularly relevant to initiation of one of the largest, nominally intraoceanic subduction zones in the western Pacific, that of the Izu-Bonin-Mariana (IBM) system. These mechanisms are induced or spontaneous (Fig. **F1**) (Gurnis et al., 2004; Stern, 2004).

Induced subduction initiation results from continued convergence forced by subducted lithospheric plate (slab) pull along strike of a given system, despite local jamming of the subduction zone by buoyant continental or thickened oceanic lithosphere. Outboard stepping (e.g., incipient plate boundary south of India) or polarity reversal (e.g., Solomon Islands consequent to jamming of the Vitiaz Trench by the Ontong Java Plateau) may develop. Spontaneous subduction initiation occurs when a change in plate motion allows the gravitationally unstable lithosphere to founder along an existing plate boundary; Stern (2004) suggested the IBM system represents an example of spontaneous initiation wherein subsidence of relatively old Pacific lithosphere commenced along a system of transform faults/fracture zones adjacent to relatively buoyant lithosphere. Foundering of the old lithosphere is predicted to induce asthenospheric upwelling in an extensional regime forming boninites and eventual fore-arc ophiolites. The initial record on the overriding plate should be clear: induced subduction likely results in strong compression and uplift shedding debris into nearby basins, whereas spontaneous subduction commences with rifting, spreading, and formation of magmas such as highly depleted, low-K tholeiites and boninites.

Following subduction initiation, further igneous development is fundamental to the creation of an island arc, which in turn is essential to the formation and evolution of continental crust, at least through the Phanerozoic (Davidson and Arculus, 2006). Accretion of arc welts to continental margins with accompanying structural, metamorphic, and magmatic modifications are arguably the most important processes for continuing continental crust evolution. For many trace and minor elements, the continental crust is quantitatively important despite its volumetric insignificance on a planetary scale. Among all the terrestrial magma types, those of island arcs are uniquely similar to the continental crust in terms of trace element abundance characteristics (Taylor, 1967). Furthermore, specific overlap in terms of absolute abundances of the common intermediate (~52–63 wt% SiO_2) rock type of arcs (andesite) and the bulk intermediate silica composition of the continental crust, led Taylor (1967) to propose the “andesite” model for formation of this crustal type.

Testing models of subduction initiation and subsequent arc evolution requires identification and exploration of regions adjacent to an arc, where unequivocally pre-arc crust (basement) overlain by undisturbed arc-derived materials can be recovered. An essential boundary condition for understanding arc evolution and continental crust formation is to know the composition, structure, and age of the crust and mantle that existed before subduction began. This condition derives from the fact that besides slab-derived components (e.g., volatiles and fluid-mobile trace elements), the mantle wedge and overriding plate are important and in some cases volumetrically dominant contributors to the magmas that form the arc. Determining the various net contributions from the mantle wedge and subducted and overriding plates to the magmas forming the arc through time requires that we know the geochemical characteristics of these individual components.

The IBM system is globally important because we have clear evidence for the age (~52 Ma; Ishizuka et al., 2011a) and exact site (Kyushu-Palau Ridge [KPR]) of inception, duration of arc activity, and changes in magmatic composition through time through extensive drilling (ash and pyroclast records) and dredging. We also have intervals where back-arc magmatism accompanied arc activity but at other times overwhelmed that of an isolated volcanic front and vice versa, and less directly, the nature of the sum product of magmatic activity in the form of seismically determined crustal structure. It is possible to identify the oceanic basement on and in which the initial arc products following subduction inception were emplaced. For most arc systems, the age of inception is unknown and the basement is obscured and/or deeply buried. The majority of currently active intraoceanic arcs are located in the western Pacific. For the IBM system, a region in the Amami Sankaku Basin (ASB), where the foundations of the nascent arc can be investigated, has been identified (Fig. F2), and the overlying sediment will preserve evidence of the inception and subsequent evolution of the arc, particularly through the first ~25 m.y. of its history.

There are two primary targets for Expedition 351: (1) the basement and (2) the overlying sedimentary sequence. Recovering oceanic basement samples will allow us to determine the petrological, geochemical, and age characteristics of the preKPR crust in the region, from which we can determine the geochemical composition of the mantle prior to IBM arc inception and growth. The Amami Sankaku basement is likely to be the easternmost fragment of Neotethys (Early Cretaceous or older) crust preserved in the oceans. Overlying the basement is 1300 m of sediment, in which evidence will be preserved for early uplift (compression and unconformities; erosion) or subsidence (basin deepening) associated with subduction initiation. These different responses of the overriding plate during the initial stages of subduction initiation are predicted to result from either forced convergence (uplift) or spontaneous nucleation of the subduction zone. Above the subduction initiation horizon, the explosive ash and pyroclastic fragmental records for at least the first 25 m.y. of the developing arc will be preserved. This record is likely to diminish in intensity and volume following the formation of the Shikoku Basin and eastward migration of the active arc volcanic front away from the KPR. To date, the geochemical data available for these kinds of materials recovered from the fore-arc regions of the IBM system are concentrated in the Neogene (e.g., Straub, 2003), so the record from the ASB will be complementary and significant for resolving the Paleogene history of the arc in greater detail. In addition, the Neogene volcanic history of the adjacent Ryukyu arc will continue to be preserved in the sediment of the ASB. Depending on the age of the basement, there is a possibility that Cretaceous ocean anoxic events (OAEs) (e.g., OAE 3 at 85.8 Ma, OAE 2 at 93–94 Ma, and possibly OAEs 1a–1d between 121 and 98 Ma) could be recovered from the older sediment, providing an important link between the classic European and Pacific locations (Schlanger and Jenkyns, 1976).

The IBM system is an ideal location for tackling the global challenges of subduction inception and evolution of an arc given the wealth of scientific data collected for the system and the potential preservation of critical sites, where by drilling alone, critical records of these fundamental Earth processes can be recovered. We know that a vast number of intraoceanic subduction systems were initiated at ~50 Ma in the western and northern Pacific, likely accompanying global plate reorganization at this time. In addition to the IBM, the Solomons-New Hebrides-Tonga-Kermadec and Aleutians arc systems appear also to have commenced at this time. Although the current geochemical characteristics of the Tonga arc are similar to those of IBM, others, such as the Aleutians, seem persistently geochemically and geophysically distinct. Given this diversity, we know the investigation of arc inception and evolution is a burgeoning field of study. The IBM is a well-constrained, representative end-member of the diversity of arc systems where we can commence this effort.

Background

Geological setting

The northwestern part of the Philippine Sea plate, where proposed Site IBM-1 is located, is composed of the following geologic features: (1) Mesozoic remnant arcs (Daito Ridge group), (2) the West Philippine Basin (WPB), (3) the Eocene–Oligocene KPR, and (4) the ASB.

Mesozoic remnant arcs (Daito Ridge group)

The Daito Ridge group is a complex array of ridges and basins. This comprises three remnant arcs: the Amami Plateau, the Daito and Oki-Daito Ridges, and two ocean basins neighboring these ridges (the Kita-Daito and Minami-Daito Basins) (Fig. F2). Granites and arc volcanics of Cretaceous age (e.g., Matsuda et al., 1975; Hickey-Vargas, 2005) are exposed on the Amami Plateau, which has a crustal thickness of up to 19 km (Nishizawa et al., 2011). Geochemical characteristics of the volcanic rocks are consistent with formation of the plateau by Cretaceous-aged subduction zone magmatism (Hickey-Vargas, 2005). These remnant arcs predate the inception of IBM arc magmatism initiated at 52 Ma (Ishizuka et al., 2006a, 2011a).

The Daito Ridge is generally east–west trending and intersects the KPR at its eastern end (Fig. F2). Low-grade metamorphic rock, sedimentary rock, and some volcanic rock were recovered by dredging, apparently from beneath Eocene sedimentary rock, (Mizuno et al., 1975, 1978; Yuasa and Watanabe, 1977), whereas recent shallow drilling recovered fresh volcanic rock from the eastern part of the Daito Ridge. Two of these drilled samples (andesites), with the distinctive trace element characteristics of arc magmas, yielded $^{40}Ar/^{39}Ar$ ages of 116.9 and 118.9 Ma (Ishizuka et al., 2011b). Both of these ages are significantly older than the KPR volcanism. These results revealed that the Daito Ridge comprises Mesozoic arc rock overlain by middle Eocene sedimentary rock (e.g., Mizuno et al., 1978).

The Oki-Daito Ridge is WNW–ESE trending and ~600 km long. This ridge is characterized by crust ranging from 20 to 25 km in thickness, based on its seismic velocity structure (Nishizawa et al., 2011). A wide bathymetric high west of the Oki-Daito Ridge is the Oki-Daito Rise, which occupies an area of ~200 km^2. The eastern margin of the rise appears to overlap the western part of the Oki-Daito Ridge. The rise is characterized by much thinner crust (10–15 km) compared to the neighboring Oki-Daito Ridge.

The Kita-Daito Basin separates the Amami Plateau and the Daito Ridge. There are irregularly shaped seamounts and ridges in the basin. The Minami-Daito Basin is located between the Daito and Oki-Daito Ridges. This basin has many more bathymetric highs compared to the Kita-Daito Basin, including conical seamounts. Drilling at Deep Sea Drilling Project (DSDP) Site 446 in the western part of the basin recovered basalt sills with $^{40}Ar/^{39}Ar$ plateau ages of 51.3 and 42.8 Ma (Hickey-Vargas, 1998). These basalts are geochemically varied with tholeiitic and alkaline compositions and clearly have ocean-island basalt (OIB)–like geochemical characteristics (Hickey-Vargas, 1998).

West Philippine Basin

The WPB is an ocean basin occupying the western half of the Philippine Sea plate (Fig. **F2**). The Ryukyu and Philippine Trenches mostly bound the western margin of the basin. Between these trenches, the Gagua Ridge separates the WPB from the Huatung Basin, which is a Cretaceous-aged ocean basin (Deschamps et al., 1998, 2000).

The prominent bathymetric features in the WPB include the broad highs of the Benham Rise and the Urdaneta Plateau (Fig. **F2**). These features are located approximately equidistant from the Central Basin Fault, which is an extinct spreading center. The Benham Rise was drilled on its southeastern flank at DSDP Site 292. A thick plagioclase-porphyritic basalt layer was recovered from beneath Eocene–early Oligocene sediment (Karig, Ingle, et al., 1975). Hickey-Vargas (1998) reported $^{40}Ar/^{39}Ar$ ages of 35.6 and 36.2 Ma for this basalt and OIB-like geochemical characteristics. The Urdaneta Plateau has dimensions of about 300 km × 200 km and consists of two bathymetric highs, with seafloor fabrics similar to overlapping spreading centers or dueling propagators (Deschamps et al., 2008) and $^{40}Ar/^{39}Ar$ ages between 35.87 and 39.79 Ma (Ishizuka et al., in press). These oceanic plateaus within and north of the WPB form age-progressive volcanic chains, which are hypothesized to have been produced by a mantle plume that remained fixed at the spreading center for ~10 m.y. (Ishizuka et al., in press).

The origin of the WPB has long been debated. Hilde and Lee (1984) published magnetic lineation data for this area (Fig. **F3A**). Based on these data, they proposed that spreading from the Central Basin Fault formed the WPB. A spreading direction for the WPB was determined to be northeast–southwest between 60 and 45 Ma at a rate of 44 mm/y. After 45 Ma, the spreading direction changed to a more north–south direction associated with a reconfiguration of the Central Basin spreading center, and the spreading rate decreased to 18 mm/y. The major phase of spreading is inferred to have finished at ~35 Ma.

Other suggestions for the origin of the WPB include that of Lewis et al. (1982), who proposed the basin formed as a back-arc basin behind the east Mindanao-Samar arc, and Seno and Maruyama (1984), who suggested the WPB formed behind the KPR. The hypothesis that the WPB is of back arc origin has been further developed by recent studies (Fig. **F3B, F3C**) (e.g., Fujioka, et al., 1999; Deschamps and Lallemand, 2002, 2003; Okino and Fujioka, 2003), based on new detailed bathymetric and geomagnetic data, mainly acquired around the Central Basin Fault and the northern part of the basin. Combined with the notion that subduction initiation of the IBM arc was contemporaneous to or preceded the opening of the WPB, Hall et al. (1995), Hall (2002), and Deschamps and Lallemand (2002) proposed models assuming the WPB opened between the two subduction zones of the East Philippine and IBM arcs. Deschamps and Lallemand (2002) further proposed rifting started at 55 Ma and spreading ended at 33–30 Ma. The spreading axis was parallel to the East Philippine arc but became inactive when a new spreading ridge propagated from the eastern part of the basin. Spreading of the basin occurred mainly from this new axis, which rotated counterclockwise during its existence.

Another hypothesis for the origin of the WPB is the so-called “trapped basin” model (Fig. **F3D**) (e.g., Uyeda and Ben-Avraham, 1972). Le Pichon et al. (1985) proposed the extinct spreading center of the WPB was a remnant of the North New Guinea-Kula spreading ridge that was captured at 43 Ma. Jolivet et al. (1989) presented a similar, but modified, model, arguing the WPB is a remnant of the Pacific-North New Guinea spreading ridge captured at 43 Ma by inception of a new subduction zone (i.e., the IBM) along a transform fault.

Kyushu-Palau Ridge

The KPR forms the eastern margin of the WPB. It is now a remnant arc separating the WPB from the Shikoku and Parece Vela back-arc basins (Fig. **F2**). The KPR was an active arc in the Eocene and Oligocene (e.g., Mizuno et al., 1977; Shibata et al., 1977; Ishizuka et al., 2011b) and became isolated from the volcanic front of the IBM arc at ~25 Ma through the initiation of rifting and seafloor spreading in the Shikoku and Parece Vela Basins (Ishizuka et al., 2011b). The extinct spreading center of the WPB (Central Basin Fault) is truncated by the KPR at ~15°N. Radiometric ages for samples collected from the northern to central KPR range in age between 43 and 25 Ma but are mostly between 27 and 25 Ma, indicating arc volcanism ended on the KPR at about this time (Fig. **F4**). In other words, back-arc rifting (or spreading) of the Shikoku and Parece Vela Basins initiated at ~25 Ma (Ishizuka et al., 2011b). This interpretation is generally consistent with the estimated timing of rifting and spreading of the Shikoku Basin based on magnetic anomaly data and seafloor fabric observations. Okino et al. (1994) identified a magnetic lineation corresponding to Anomaly 7 in the westernmost (oldest) margin of the basin and suggested spreading started at 26 Ma.

The lack of systematic age variations of volcanic rock along the KPR indicates that rifting was initiated almost concurrently along the entire ridge between 30°N and 11°N. By extension, this means that initiation of the Shikoku and Parece Vela Basins and isolation of the KPR as a remnant arc occurred at about the same time.

Even though the KPR is a remnant half of the IBM arc, the geochemical characteristics of the KPR magmatic lithologies are distinct compared to those of Quaternary age at the IBM arc volcanic front. Whereas the Quaternary IBM arc has clear along-arc geochemical variations (e.g., more enriched isotopic and trace element signatures) (Fig. **F5**) both toward Honshu and the "alkalic volcano province," typified by Iwo Jima at the Izu-Bonin/Mariana intersection in the volcanic front and the rear arc (Bloomer et al., 1989; Ishizuka et al., 2003, 2006b, 2007), the KPR does not show any systematic along-arc variations (Ishizuka et al., 2011b). This observation suggests the magmatic record to be obtained at this expedition's primary site (IBM-1) will be representative of adjacent along-strike KPR arc magmatism and provide us with representative magmatic evolution of this Paleogene stage of the IBM system.

However, there are a couple of locations where distinct geochemical signatures have been obtained. One of these is where the Daito Ridge intersects the KPR. High-K andesite only occurs in this area. These Eocene volcanic rocks from the KPR/Daito Ridge intersection have a distinctly enriched trace element and isotopic character relative to the surrounding KPR samples. In particular, they have higher $^{206}\mathrm{Pb}/^{204}\mathrm{Pb}$ and light versus heavy rare earth element (REE) ratios in combination with small deviations of $^{208}\mathrm{Pb}/^{204}\mathrm{Pb}$ from the Northern Hemisphere Reference Line (i.e., $\Delta^{208}\mathrm{Pb}/^{204}\mathrm{Pb}$) relative to the KPR (Fig. **F6**). Arc magmatism at the KPR/Daito Ridge intersection is thought to have been established on preexisting Daito Ridge crust, which is a Mesozoic remnant arc. Therefore, it is possible the distinct geochemical characteristics of the KPR/Daito Ridge intersection are related to the involvement of sub-Daito Ridge lithospheric mantle or subarc crust, which was metasomatized by a Cretaceous-aged subduction event. This observation demonstrates the critical importance of understanding the geochemical character of the arc basement, part of which will be drilled during Expedition 351 at Site IBM-1.

Amami Sankaku Basin

The initial products of the IBM system are preserved today in two longitudinal belts: (1) one forming the eastern margin of the WPB and abandoned as a remnant arc (the KPR) (Fig. F2) when the Parece Vela-Shikoku Basin opened, and (2) a second belt preserved in the IBM fore arc that is mostly submarine but emerges sporadically as islands, such as Chichi-jima and Guam.

The ASB is bordered to the west across a major north-south–striking fault scarp (Minami-Amami Escarpment [MAE]) by the Amami Plateau, to the south by the Daito Ridge group, and to the northeast by the KPR (Fig. F2). It is important to note the KPR is not oriented parallel to either the Amami Plateau-Daito Ridge or the MAE. Instead, the strike of the KPR is at a high angle to the trends of these features, apparently constructed independently of any preexisting basement fabric. If the MAE represents a fossil transform fault adjacent to an ASB basement formed through seafloor spreading, it appears the initiation of the KPR was independent of preexisting transform fault control.

The basement of the east Daito Ridge south of the ASB has a ^{40}Ar/^{39}Ar date of 118 Ma (Ishizuka et al., 2011b). Thus, the early ASB sediment and basement are likely to be Early Cretaceous or older (i.e., Neotethyan). A grid of Japanese multichannel seismic (MCS) profiles across the ASB (Japan National Oil Corporation, 1998; Higuchi et al., 2007) reveals a sedimentary section 1–2 km thick. The sediment is underlain by igneous basement, with a Mohorovicic Discontinuity (Moho) reflection a further 2 s two-way traveltime below that is typical of normal oceanic crust.

Reconnaissance of the subseafloor crust along the western margin of the ASB began during a *Shinkai* 6500 dive (337), conducted at the MAE (Fig. F7) in 1996. The dive started at the foot of a 1 km high steep cliff and ascended to the top of the escarpment. Lithologies identified on the dive transect from shallower to deeper parts along the submersible track line were the following: ash turbidite with burrows, altered tuffs, calcareous chalk, scoria, and basalt breccia with calcareous matrixes, all covered with pelagic mud and manganese sediments. Occasional pumice blocks were scattered on the sediment surface. Intact basaltic basement (pillows or sheet flows) was not observed.

Sediment samples obtained during this dive were predominantly pelagic brown mud, indicating deposition below the carbonate compensation depth (CCD). However, calcareous chalk is consistent with a shallower depositional environment for the older lithologies. The topography of the escarpment is a combination of gentler sedimented slopes with steep to occasional overhanging cliffs. A notable slump scar, erosional gulley, and slope failure–induced debris flow and turbidite were seen everywhere along the dive track. These phenomena strongly suggested the occurrence of past slope failure in relation to likely fault movement along the MAE.

Seismic studies/Site survey data

Seismic profiles of Ocean Drilling Program Site 1201

It is useful to examine the seismic and lithologic structures of a recently drilled site in the WPB because of the anticipated shedding of pyroclastic debris and ash from the KPR at the Expedition 351 primary site (IBM-1). One of the objectives of Ocean Drilling Program (ODP) Leg 195 was coring and casing a hole (Site 1201) in the WPB (Fig. **F8**) for the installation of a broadband seismometer as part of the International Ocean Network seismometer net (Shipboard Scientific Party, 2002). Site 1201 lies ~100 km west of the KPR on 49 m.y. old crust (near Chron 21) formed at the Central Basin spreading center of the WPB. We emphasize that although the results from Site 1201 cannot be used to satisfy the specific objectives for Expedition 351, some aspects of the sedimentological processes at the former location are contextually important. As Site 1201 drifted away from the Central Basin spreading center, volcanism ceased and about 0.5 km of sediment was deposited in three stages: (1) quiescent marine sedimentation in deep water into the late Eocene; (2) pelagic sedimentation mixed with, and finally overwhelmed by, volcaniclastic turbidites from the KPR from the late Eocene through the early Oligocene; and (3) waning turbidite deposition, followed by barren, deep-sea pelagic sedimentation below the CCD from the early Oligocene to the early Pliocene, when sedimentation ceased altogether, as reported by Salisbury et al. (2006).

Subsequent to ODP drilling at Site 1201, a new MCS line (D99-2) (Fig. **F8**) has been run northwest–southeast through the site and across the KPR into the Parece Vela Basin. This line is reproduced in Figure **F7.** The most obvious feature of this seismic line is the thickening of the upper part of the sedimentary package toward the prominent topographic high of the KPR and the relative constancy in thickness of the lower parts.

The Japan Oil, Gas, and Metals National Corporation (JOGMEC) acquired extensive MCS reflection data in the northern part of the Philippine Sea plate. These surveys covered a wide area of the IBM-KPR as well as the Amami Plateau and Daito Ridge regions; the major objective of the surveys was to obtain detailed images of the sedimentary and deeper crustal structures. These data provide important information for drilling into the sedimentary and igneous sections, particularly in the ASB.

The interpretation of these profiles coupled with information from DSDP holes (e.g., Holes 296, 445, and 448) and Site 1201 (Fig. **F7**) have resulted in the description of two layers in the ASB; the uppermost layer contains five stratigraphic units (herein referred to as “intervals”) (Table **T1**). The top interval (A; ~110 m thick) is estimated to comprise Pliocene–Pleistocene pelagic sediment. The second interval (B; ~160 m) is suggested to be upper Miocene turbidites, which may come from the KPR but is more likely pelagite given the termination of eruptive activity on the KPR by this time. The third interval (C; ~310 m) is suggested to be lower Miocene turbidites, which may be derived from a by-then magmatically extinct KPR. The fourth interval (D; 490 m) is estimated to be Oligocene and Eocene volcaniclastic turbidites from the KPR. The thickness of Interval D increases eastward toward the KPR with a maximum exceeding 1 km, which is consistent with a prominent source on the ridge. The nature of this section is important because it is likely to also be drilled during IODP Expedition 350 at the rear arc of the still-active IBM arc. Interval E (230 m) is suggested to be pelagic sediment of Eocene or older age; the distribution of this layer is discontinuous across the ASB but present at the primary site of Expedition 351 (Site IBM-1).

Site IBM-1 has been selected at the intersection of two MCS profiles (Lines D98-A and D98-8) obtained by JOGMEC (Figs. **AF1, AF2**) located ~50–80 km southwest of the nearest part of the KPR. The supporting site survey data for Expedition 351 are archived at the **IODP Site Survey Data Bank.**

Scientific objectives

Understanding how subduction zones are initiated and continental crust forms in intraoceanic arcs requires knowledge of the inception and evolution of a representative intraoceanic arc, such as the IBM system. An intraoceanic setting is mandatory to avoid the obscuring geochemical, geophysical, and structural veils of preexisting continental crust and the practicality of depth of recovery of basement sections by drilling. The IBM satisfies these criteria. Understanding the evolution of the IBM system, particularly in the more recent half of its 50 m.y. history, has improved considerably over the past three decades, not the least from studies of ash and pyroclast materials recovered by ocean drilling. However, we have poorer records for the nature of arc development in the first half of the history of the system and very limited understanding of how this (or any other) arc was initiated. Expedition 351 will target, in particular, evidence for the earliest evolution of the IBM system following inception.

Expedition 351 is complementary, yet distinct, to IODP Expeditions 350 and 352. Expedition 350 will examine the history of rear arc volcanism adjacent to the currently active volcanic front of the IBM arc, whereas Expedition 352 will explore the sedimentary and igneous history preserved in the current IBM fore arc, potentially spanning the entire history of the system from inception onward. To some extent, the recovery objectives of the magmatic history of the arc during all these expeditions directly overlap but will also gain the vitally important perspective of across-arc strike recovery and identification of compositional variability of eruptive and potentially intrusive magmatic products.

Our drilling plan for Expedition 351 is conceptually straightforward, targeting a single site involving penetration of a thick section of sediment overlying oceanic crust of normal thickness; nevertheless, the water depth (4720 m), sediment thickness (1300 m), and consequent depth to basement are technically challenging.

In detail, there are several primary and some secondary objectives of Expedition 351 involving both sediment (oceanic crust Layer 1; see description in **"Seismic studies/Site survey data"**) and igneous basement (Layer 2) (Table **T1**). Overall, the geochemical and geophysical properties of the initial basement (pre-middle Eocene Layers 1 and 2 of the ASB) likely underlie the entire IBM system; these properties are therefore essential for a refined interpretation of the seismic structure obtained for the system.

Primary objectives

1. Determine the nature of the original crust and mantle that existed in the region prior to the beginning of subduction in the middle Eocene (targets: Layers 2 and 1).

An essential boundary condition for understanding the evolution of island arcs is to know the composition, structure, and age of the crust and mantle that existed before subduction began. For example, unlike the case for calculations of the crust formation rate at mid-ocean ridges, estimates of intraoceanic arc fluxes commonly subtract a "standard" 7 km thickness of oceanic crust within the total arc thickness as a probable pre-arc constituent (Reymer and Schubert, 1984; Fliedner and Klemperer, 2000). In addition, the simple assumption is made that Layer 2 of this crust is equivalent to normal mid-ocean-ridge basalt (MORB), despite the evidence for significant variability both compositionally and structurally worldwide of this layer (Cannat et al., 2006). Depending on the mode of arc growth, preexisting nonarc crustal components should contribute geochemically through assimilation and partial melting processes triggered during the passage of later arc magmas and could make up an important part of the lower arc crust. We know that contamination-assimilation processes are commonly established during development of arc magmas, typically only clearly recognizable when strong geochemical contrasts exist between potential contaminant-assimilant and the original magma (Arculus et al., 1983). In general, the presence of basement crust is assumed because recovery of samples from submature arc depths of 15–20 km is impossible. In the case of the proto-IBM system, we have an opportunity to define the geochemical nature of the preexisting basement; absolute trace element abundances together with ratios of these and various isotopic indicators of the basement rocks can then be utilized to quantify models of interaction between ascending IBM arc magmas and the basement.

In the northern IBM case, remarkably, the preexisting oceanic crust exists under 1–1.5 km of sediment in the ASB adjacent to the KPR remnant arc and perhaps also crops out on the lower fore-arc slope of the Bonin Trench (DeBari et al., 1999; Ishizuka et al., 2011a), making possible access to samples of the pre-arc oceanic crustal basement upon which the arc was constructed. We know the age of IBM inception was at ~52–50 Ma (Cosca et al., 1998; Ishizuka et al., 2011a). The ages of initial lithosphere foundering and the change to downdip subduction are consistent with geochronology of the Hawaiian-Emperor Seamount Chain putatively recording the change in Pacific plate motion. Recently published geochronology suggests that the bend in the seamount chain started at ~50 Ma and occurred over a period of ~8 m.y. (Sharp and Clague, 2006).

All of the back-arc basins of the Philippine Sea plate are underlain by asthenosphere of Indian Ocean character, geochemically distinct from mantle sources beneath the Pacific plate now being subducted along its eastern margin (Hickey-Vargas, 1998). In terms of a variety of radiogenic isotopic characteristics (e.g., Pb-Sr-Nd-Hf), the Pacific and Indian Ocean MORB and OIB are distinct (Hofmann, 1997). Their mantle sources, as a consequence, must have contrasting geochemical compositions, at least in terms of the ratios of parent/daughter pairs of isotopic systems. Although the origins and development of these characteristics are controversial (e.g., Mahoney et al., 1998, and references therein), it appears breakup and dispersal of the Gondwanan continental lithospheric fragments during the Paleozoic through to present have exposed asthenospheric mantle beneath the Indian Ocean that has been significantly modified geochemically compared with that of the sub-Pacific mantle. Juxtaposition of the Indian and Pacific MORB-source mantle types across a single one of a dense network of anomalously deep transform faults at the Australian-Antarctic Discordance (AAD) was explored, for example, during ODP Leg 187 (Kempton et al., 2002). The extent of Indian-type mantle migration eastward into the Pacific domain is not fully constrained, but the present locus of the IBM and former Vitiaz arc systems appear to mark a present-day limit. Possibly, the initiation of these arcs was in some way controlled by the juxtaposition of Pacific- and Indian-type mantles (e.g., localized by the type of transform fault cluster exposed at the AAD).

It is nevertheless clear the initial construction of the IBM arc, rather than developing solely upon oceanic crust, transected the present-day series of Cretaceous–Paleocene ridges (e.g., Amami Plateau and Daito and Oki-Daito Ridges) and intervening basins that formed, at least in part, an arc–back-arc system (Taylor and Goodliffe, 2004; Hickey-Vargas, 2005; Ishizuka et al., 2011b) (Fig. F2). Recent isotopic results for the Amami Plateau indicate the Philippine Sea plate also contains Pacific Ocean-type lithosphere, and the nature of the lithosphere on which the proto-IBM arc was built was likely diverse in character (Hickey-Vargas et al., 2008). It may be that decoding the nature of the magma source in the upper mantle that existed immediately before the IBM arc inception is a key to understanding the cause of the initiation of subduction zones and intraoceanic arc formation. It is also possible, of course, that the basement of the ASB is of back-arc character, generated from upper mantle that was contaminated by Cretaceous subduction processes. These questions can only be resolved by recovering and studying samples of the ASB basement.

2. Identify and model the process of subduction initiation and initial arc crust formation (target: Layer 1).

According to the model of forced subduction initiation, the nucleating margin will first undergo compression and localized uplift; the Macquarie Ridge complex (MRC) south of New Zealand is a present-day example. Some segments of the margin may be forced above sea level (such as at Macquarie Island along the MRC). Models show that the magnitude and horizontal wavelength of uplift are dependent on the age of the overriding plate, and knowledge of this age (see primary Objective 1 basement and also from ages of deepest sediment overlying the basement at Site IBM-1, this objective) is an important geodynamic input (Gurnis, et al., 2004). The self-nucleating model does not predict such a phase of uplift but predicts early extension. Understanding the response of the overriding plate during the initial stages in formation of the new subduction zone is thus essential for testing first-order competing proposals for subduction initiation.

The sedimentary sequence developed during subduction initiation to be recovered from the ASB at Site IBM-1 is crucial with respect to understanding the tectonic, petrologic, and geochemical consequences of the critical stages of arc inception. Depending on the wavelength of structural disturbance to the overriding plate, we anticipate erosion of crustal materials derived from the ridges and plateaus around the western and southern margins of the ASB. Sufficient geochemical and geochronological data have been collected (Ishizuka et al., 2011b, in press; Tani et al., 2012) for these crustal sources that the materials shed into the ASB at this time will be recognizable in recovered cores at Site IBM-1. Similarly, uplift along the present trace of the KPR at the northeastern margin of the ASB may have reworked preinception sediment, and this together with juvenile arc-inception volcaniclastic materials will also be recognizable in cores. Any paleontological monitors of seafloor depth changes through subduction initiation and later periods of time will be critical for analyses of bathymetric changes to the ASB seafloor (e.g., changes in the CCD as well as the nature and preservation of benthic foraminifers).

The character of the earliest juvenile magmatic outputs of the nascent IBM arc recovered from the sedimentary sequence at Site IBM-1 is of first-order importance for (1) constraining the composition of the mantle wedge at this stage of arc development, (2) determining the nature of subducted inputs, and (3) comparing with the magmatic sequences recovered so far by drilling and dredging in the current fore arc (e.g., Reagan et al., 2010) to be sought during Expedition 352. We have an opportunity to explore possible across-strike variations in the nature of juvenile arc magmatic outputs and to establish whether the sequence recognized for the fore arc from earliest MORB-like “fore-arc basalt” through boninite to the temporally more enduring and apparently stable output of island arc tholeiitic types, which also existed at the western margin of the earliest IBM arc.

In addition to chemical compositions and ages of fragmental materials deposited in the ASB concurrent with arc initiation, direct structural analysis of the cores will be a first-order requirement providing evidence for prevailing tension (normal faults), compression (thrust faults), or potentially tranquil tectonic environments. Evidence for temporal variations in these conditions will also be sought in order to model the state of stress in the overriding plate during arc initiation.

3. Determine the compositional evolution during the Paleogene of the IBM arc (target: Layer 1).

The complete tephra record of fore-arc/arc/back-arc volcanism subsequent to arc initiation in the middle Eocene to the isolation of the KPR as a remnant arc accompanying inception of the Shikoku back-arc basin at ~25 Ma (and possibly sporadically thereafter) will be obtained at Site IBM-1. Comprehensive analytical data exist for Neogene ash and pyroclastic materials recovered from the IBM fore arc (e.g., Bryant et al., 1999; Straub, 2003; Straub et al., 2004) and indicate remarkable stability (a function of subducted slab inputs, mantle wedge replenishment, and overriding plate inputs) of the northern part of this system, but the Paleogene record is sparse. In combination with the known Eocene–Recent lava/plutonic products (Ishizuka et al., 2011b), the ash and pyroclast record during this interval will allow us to determine the output variation through time along a transect of the northern IBM arc compared to Pacific plate inputs.

4. Establish geophysical properties of the ASB (targets: Layers 1 and 2).

The basement of the IBM arc comprises sedimentary and underlying igneous rock types that will become accessible for direct geophysical measurements through study of recovered cores and downhole logging at Site IBM-1 during Expedition 351. Following publication of the seminal seismic cross section obtained by Suyehiro et al. (1996), several other across- and along-strike seismic surveys have expanded our knowledge of the velocity structure of the IBM system (e.g., Kodaira et al., 2007). Recovery and analysis of core samples, together with comprehensive downhole logging of physico-chemical-structural properties of the pre-arc basement and overlying Layer 1, will clearly advance our understanding of the overall nature of the arc structure, permitting reliable estimates of age-composition characteristics of crustal units and enabling refined calculation of the critically important question of arc crustal growth rates.

There has been a long-standing debate concerning the initial geographic orientation and locations of the IBM system during subduction initiation (argued to be ~90°) and its subsequent postulated 90° clockwise rotation to a present-day north–south strike during 50 m.y. (Hall et al., 1995; Yamazaki et al., 2010, and references therein). Among the primary objectives of Expedition 351 will be establishing the magnetic declination and its putative change as a function of time for both the ASB basement and overlying sediment of Layer 1. Although these measurements are technically challenging, there is a particular advantage offered at Site IBM-1 in attempting magnetic orientation measurements because of the apparently relatively undisturbed character of the strata forming Layer 1. The initial orientation of the IBM system and any subsequent rotations are important with respect to establishing the boundary conditions for subduction initiation and later plate interactions.

Secondary objectives

1. Recover sedimentary records of paleoceanographic conditions from Pliocene–Pleistocene to early Tertiary and possibly Late Cretaceous in the eastern Tethys–western Pacific (target: Layer 1).

The paleographic position of the ASB adjacent to Cretaceous-aged arcs and back-arc basins potentially provides an excellent opportunity to recover records of paleoceanographic conditions in the far eastern Tethys–western Pacific in the Late Cretaceous (and possibly older) through to the Tertiary. Among the exciting opportunities offered by penetration of the full thickness of oceanic crustal Layer 1 at Site IBM-1 are the transection of the Cretaceous/Tertiary boundary, the organic-rich shales of OAEs, the Paleocene/Eocene Thermal Maximum, and Eocene hyperthermals. If found, these records would be valuable, as there are very few sections recovered from this region. For example, Cretaceous OAEs would provide important constraints on the prevalence of anoxia at an extreme eastern meridional location compared with the classic Tethyan sites.

2. Recover sedimentary records of onset and persistence of the East Asian Monsoon and other climate-modulated land-sea correlations (target: Layer 1).

Integrated Ocean Drilling Program Expedition 346 will conduct two latitudinal transects (Japan Sea and northern East China Sea) to test hypotheses concerning tectonic linkages with the onset of the Asian Monsoon. Site IBM-1 is located to the southeast of the scheduled drilling sites in the East China Sea and may be complementary to those of Expedition 346. Although our site is distal from the Yangtze River discharge, a record of fluvial input is possible. Furthermore, potential aeolian inputs to the ASB include loess from east Asia. Thus, high-quality sediment recovered by advanced piston corer (APC) coring at Site IBM-1 should provide additional important information regarding timing and geographic distribution of terrestrial material in the western Pacific marine record.

3. Recover an ash record of the evolution of the Ryukyu-Kyushu arc (target: Layer 1).

Subduction of the Philippine Sea plate, on which the ASB now is situated, takes place in part along the Ryukyu-Kyushu arc to the northwest of Site IBM-1 (Fig. **F2**). We anticipate an ash record from this arc to be preserved within the sediment at Site IBM-1. Some particularly significant explosive events from the Ryukyu-Kyushu arc produced extensive ash deposits that are used as stratigraphic marker horizons in the Japanese islands. In addition to this feature, the temporal evolution of the Ryukyu-Kyushu arc located on the east Asian continental margin will provide important complementary evidence of arc evolution with the IBM system.

Drilling and coring strategy

To achieve the scientific objectives of Expedition 351, the chosen site location had to fulfill the following criteria:

- There must be remnants of drillable oceanic crust that existed in the region immediately before arc inception.
- The initial IBM magmatic record should be preserved and include geological evidence for inferring the tectonic setting at subduction initiation.
- Temporal variations of magmatism in the rear IBM arc should be preserved as a sequence of volcaniclastic sediment and tephra.
- To highlight the temporal evolution of the IBM arc crust, the effect of along-strike variation should initially be minimized or well understood.

The selected primary site (IBM-1) in the ASB, between the KPR and the Amami Plateau (Fig. **F2**), best meets the above criteria.

The overall operations plan for Site IBM-1 is summarized in Table **T2.** The operations time estimates are conservative and based on formation lithologies and depths inferred from seismic and regional geological interpretations, including prior drilling in the region at DSDP Sites 296, 445, and 448 and ODP Site 1201. We have approval from the Environmental Protection and Safety Panel (EPSP) to drill at Site IBM-1 to a total depth of 1600 meters below seafloor (mbsf) in case the velocity estimates are incorrect. We used this approved total depth during operations planning to ensure we would have enough time to drill to and core the igneous basement, which is one of the scientific objectives of this expedition. If the velocity estimates are correct, then the total depth of penetration will likely be closer to 1450 mbsf.

After departing from Yokohama, Japan, we will transit for ~2 days to Site IBM-1 and prepare for drilling operations. Our primary operations plan consists of drilling at Site IBM-1 to recover ~1300 m of sedimentary cover and ~150 m of basement. Based on previous sites in the area (Sites 296, 445, 448, and 1201), the sedimentary layers overlying basement are anticipated to consist of Pliocene–Pleistocene pelagic sediment, Miocene turbidites, Oligocene/Eocene volcaniclastic turbidites, and pelagic sediment of Eocene or older age (Table T1). The oceanic basement is likely to be Early Cretaceous age or older (i.e., Neotethyan).

First, Hole A will be cored to refusal using the APC followed by the extended core barrel. A jet-in test (Hole B) will then be conducted to determine a casing depth for the 20 inch conductor casing to be washed in with the reentry cone. After changing the bottom-hole assembly, we will then establish a new pilot hole in Hole C and core with the rotary core barrel (RCB) to ~900 mbsf to establish surface casing points and to determine actual basement contact depth. In Hole C, we will also drop a free-fall funnel (FFF) as part of our contingency plan (see **"Risks and contingency"**) to allow us to potentially reenter the hole. Finally, Hole D will be a reentry hole that includes penetrating ~150 m or more into the basement with the RCB. Based on drilling experience from ODP Leg 126 (Sites 787, 792, and 793), the sedimentary sections older than the Oligocene are likely to be well lithified and may not require casing below that depth (~600 mbsf). Actual casing points (casing string lengths) required will be determined while coring the RCB pilot Hole C.

Logging/Downhole measurements strategy

Logging will play an important role in achieving the scientific objectives of Expedition 351. Previous drilling in similar environments, particularly during ODP Legs 125 and 126, has achieved only partial recovery in some intervals. Downhole data will complement core measurements by determining the characteristics of lithologic units in any intervals where core recovery is poor. In addition, wireline logging data can be compared to analyses of discrete core samples. The gamma ray tool should clearly distinguish lithologic units, including those comprising pyroclastic debris, and aid with the reconstruction of paleo-oceanographic conditions in the late Mesozoic, including possible ocean anoxic events. The magnetic susceptibility sonde (MSS) will further help identify and delineate volcaniclastic units. The Formation MicroScanner (FMS) electrical images will help to characterize any structural deformation as well as the deposition sequences, particularly to delineate sedimentary packages, their thickness and direction, and provide evidence of how the upper plate responded to subduction initiation. Check shots with the Versatile Seismic Imager (VSI) will be acquired, and synthetic seismograms can be generated using density and velocity logs. The results from which will allow the drilled boreholes to be tied into the site survey data.

Three primary logging strings will be deployed (see **iodp.ldeo.columbia.edu/TOOLS_LABS/tools.html** for more details regarding logging tools). First, the traditional triple combination ("triple combo") tool string (gamma ray, porosity, density, and resistivity) will be run with the MSS to provide a full characterization of the formation and of hole conditions. The FMS-sonic tool string will record compressional and shear velocity and capture high-resolution electrical images of the borehole. Finally, the VSI tool will be used to acquire the check shot survey. It will be anchored to the side of the borehole at fixed intervals (20–100 m) to record the waveforms generated by a seismic source (a Sercel G-gun 250 inch × 250 inch × 250 inch parallel cluster) held ~7–11 m below the sea surface. The order of deployment of the last two strings will depend on the requirement to limit operation of the seismic source to daylight in order to be able to monitor the presence of protected species and interrupt operations if necessary. There is a possibility that the Ultrasonic Borehole Imager (UBI) will be run where borehole conditions allow (i.e., the hole is "in gauge"; ≤11 inch diameter). The UBI provides high-resolution acoustic amplitude images with 100% borehole wall coverage. The high-resolution FMS and UBI images will allow detection of small-scale fractures and lithologic variations, enable the tilt of units to be evaluated, and highlight borehole breakouts for regional stress analysis. The General Purpose Inclinometry Tool will be deployed with both image tools to collect accelerometer and magnetometer data, which will allow orientation of the images and provide information about borehole geometry. Additionally, pending funds, tool availability, and available operations time, a borehole magnetometer (either the third-party Göttingen Borehole Magnetometer [GBM] or Lamont Multisensor Magnetometer Module [MMM]) may be deployed as a separate run to obtain three-component magnetic field measurements in order to investigate rotational history.

The main logging operations are currently planned to take place after full completion of coring in the RCB pilot hole (Hole C) and in the reentry hole (Hole D following coring and casing operations). However, depending on the drilling scenario (see **"Drilling and coring strategy"** and **"Risks and contingency"**) and based on the progress of coring and on drilling conditions, it may be necessary to adapt this plan.

Risks and contingency

There are a number of challenges associated with drilling operations in deep water that could impact the drilling and coring strategy of this expedition. Primary among these is stress on the very long drill string (>6000 m), resulting from the deep water and our goal of drilling to at least 1450 mbsf. One factor that will influence the drill string stress will be the on-site weather/sea state and the resulting heave behavior of the ship. Expedition 351 has been scheduled to take place during the boreal summer. Severe weather, such as typhoons, may occur and could adversely affect operational efficiency. Although we are not sailing during the peak typhoon season (late August–September), the expedition could experience some waiting on weather delays depending on conditions during critical operations, such as casing/reentry deployment, tripping long drill strings, and/or RCB basement coring at depth.

Furthermore, the nature of the sediment may present risks that could affect core/logging operations, core recovery and quality, rate of penetration, and hole stability. However, the sediment is presumably well stratified, and as previously stated, sections older than the Oligocene (~600 mbsf) are likely to be well lithified.

To address the inherent risks, we have several contingency plans that are mainly constrained by the time available to accomplish operations:

1. If we have to stop operations at Site IBM-1 relatively early into the expedition, we intend to transit and drill one of the similar alternate sites (IBM-1A or IBM-1B) (Fig. AF1, AF3). Operations would then proceed at the alternate site (Table T3) following a similar strategy to the primary site. A total depth of 1600 mbsf for alternate Sites IBM-1A and IBM-1B has been approved by the EPSP.
2. If we have to end operations at Site IBM-1 far enough into the expedition that drilling either alternate Site IBM-1A or IBM-1B would not allow us to reach the lower sedimentary section and/or basement, we have two alternatives. In the first scenario, we would return to the RCB pilot hole (Hole C) and attempt to reenter the hole via the FFF. If we are not able to continue coring in Hole C (e.g., the hole has collapsed), we intend to move to our third alternate site (IBM-1C; pending EPSP approval). Although the entire sedimentary sequence is still present at this site, the sediment thickness is ~70% of Site IBM-1 (Fig. AF3). Furthermore, as another time-saving measure, we are seeking EPSP approval to drill through the upper sediment without coring until the depth at which we had to cease coring at Site IBM-1. This would allow us to reach the lower sediment column and basement much more quickly (Table T3). The rationale is that the up-

per sedimentary section has been cored at the primary site, which is only 7.3 km away, so there is not much to be learned by additional sediment coring.

3. Finally, there is a request to drill a geotechnical hole at Site IBM-4GT (Table **T3;** Fig. **AF4**) to aid in preparations for a future riser expedition on the D/V *Chikyu*. Operations at this site will only be considered if Expedition 350 does not manage to drill here, sufficient time is available, and/or further drilling at the primary and alternate sites is not possible.

The overall proposed strategy should allow enough flexibility during the expedition to enable us to fulfill the scientific objectives.

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the current Integrated Ocean Drilling Program Sample, Data, and Obligations policy posted on the Web at **www.iodp.org/program-policies/.** Any policy changes that may occur with the beginning of the International Ocean Discovery Program will be distributed to the Shipboard Scientific Party and shore-based collaborators as soon as possible. The document outlines the policy for distributing IODP samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of co-chief scientists, staff scientist, and IODP curator on shore and curatorial representative on board the ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postcruise sampling.

Shipboard scientists are expected to submit sample requests (at **smcs.iodp.org/**) no later than 3 months before the beginning of the expedition. This timing is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Based on sample requests (shore-based and shipboard), 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. The SAC must approve modifications of the sampling strategy during the expedition.

All personal sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other sample requests, and the cruise objectives. Some redundancy of measurements is unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests. All shipboard scientists and approved shore-based requesters are expected to collaborate and cooperate within the framework of this plan. Sampling for individual scientist's postexpedition research may be conducted during the expedition or may be deferred until after the expedition. This decision will be made during the expedition.

If critical intervals are recovered (e.g., ash layers, Cretaceous OAEs), there may be considerable demand for samples from a limited amount of cored material. These intervals may require modifications to the sampling plan (e.g., special handling, reduced sample size, or deferring of sampling to postexpedition), coordinated by the SAC before the critical intervals are sampled.

Following Expedition 351, cores will be delivered to the Integrated Ocean Drilling Program Kochi Core Center in Kochi, Japan. All collected data and samples will be protected by a 1 y postexpedition moratorium, during which time they will be available only to the Expedition 351 science party and approved shore-based participants. This moratorium will extend either 1 year from the end of the expedition or, if a post-expedition sampling party is deemed necessary, 1 y following the completion of the sampling party.

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Table T1. Stratigraphic layers expected at Site IBM-1.

Layer	Interval	Depth (mbsl)	Age	Thickness (m)	Lithology
1	A	4720–4830	Pliocene/Pleistocene	110	Pelagite
	B	4830–4990	upper Miocene	160	Turbidite
	C	4990–5300	lower Miocene	310	Turbidite
	D	5300–5790	Oligocene/Eocene	490	Turbidite
	E	5790–6020	Eocene or older	230	Hemipelagite
2		>6020	Mesozoic		Basement

Table T2. Operations plan for primary Site IBM-1.

Site No.	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Transit (days)	Drilling Coring (days)	WL Log (days)
Yokohama, Japan			**Begin Expedition** 5.0	**Port Call Days**		
			Transit 562 nmi from Yokohama to Site IBM-1 @ 10.5 kt	2.2		
IBM-1	27.383518°N	4731	**Hole A**: APC/XCB to ~200 mbsf		2.7	
	134.31837°E		**Hole B**: Jet-in test		0.7	
			Hole C: RCB pilot hole to ~900 mbsf (establish casing points)		9.0	
			- Wireline log pilot hole with triple combo, FMS-sonic, & VSP tool strings			2.1
			Hole D: Reentry hole with triple casing string		34.2	
			Set reentry cone with ~60 m of 20" 94 lb/ft conductor casing			
			Drill 22" diameter hole and set ~400 m of 16" 75 lb/ft casing			
			Drill 14-3/4" diameter hole and set ~700 m of 10-3/4" 40.5 lb/ft casing			
			- RCB core from ~600 to ~1450 mbsf (~850 m of sediment)			
			- RCB core from ~1300 to ~1600 mbsf (~150 m of basement)			
			- Wireline log open hole with triple combo, FMS-sonic, & VSP tool strings			2.9
			Subtotal days on site: 51.6			
			Transit 562 nmi from Site IBM-1 to Yokohama @ 10.5 kt	2.2		
Yokohama, Japan			**End Expedition**	**4.4**	**46.6**	**5**

Port Call:	**5.0**	**Total Operating Days:**	**56.0**
Sub-Total On-Site:	**51.6**	**Total Expedition:**	**61.0**

Seafloor depth corrected to rig floor dual elevator stool or meters below rig floor. No time or money has been budgeted for logging while drilling or measurement while drilling. Deep water coupled with reentry cone/long casing string operations and significant penetration targets below seafloor could result in high drill string stress; therefore, calm sea states and low heave will be critical in undertaking certain operations such as reentry cone and casing string deployments. Some lost time waiting on weather/sea state may be experienced. APC = advanced piston corer, XCB = extended core barrel, RCB = rotary core barrel. WL = wireline logging, FMS = Formation MicroScanner, VSP = vertical seismic profile.

Table T3. Contingency operations plan for alternate sites.

Site No.	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Transit (days)	Drilling Coring (days)	WL Log (days)
IBM-1A	27.469769°N	4671	**Hole A**: Jet-in test		1.1	
	134.28768°E		**Hole B**: APC/XCB to ~200 mbsf		2.1	
			Hole C: RCB pilot hole to ~900 mbsf (establish casing points)		8.7	
			- Wireline log pilot hole with triple combo, FMS-sonic, & VSP tool strings			2.0
			Hole D: Reentry hole with triple casing string		31.7	
			Set reentry cone with ~60 m of 20" 94 lb/ft conductor casing			
			Drill 22" diameter hole and set ~400 m of 16" 75 lb/ft casing			
			Drill 14-3/4" diameter hole and set ~700 m of 10-3/4" 40.5 lb/ft casing			
			- RCB core from ~600 to ~1450 mbsf (~850 m of sediment)			
			- RCB core from ~1300 to ~1600 mbsf (~150 m of basement)			
			- Wireline log open hole with triple combo, FMS-sonic, & VSP tool strings			2.8
			- Contingency (possible WOW/sea state delays)		3.2	
			Subtotal days on site: 51.6			
IBM-1B	27.459276°N	4661	**Hole A**: Jet-in test		1.1	
	134.508459°E		**Hole B**: APC/XCB to ~200 mbsf		2.1	
			Hole C: RCB pilot hole to ~900 mbsf (establish casing points)		8.7	
			- Wireline log pilot hole with triple combo, FMS-sonic, & VSP tool strings			2.0
			Hole D: Reentry Hole with triple casing string		31.7	
			Set reentry cone with ~60 m of 20" 94 lb/ft conductor casing			
			Drill 22" diameter hole and set ~400 m of 16" 75 lb/ft casing			
			Drill 14-3/4" diameter hole and set ~700 m of 10-3/4" 40.5 lb/ft casing			
			- RCB core from ~600 to ~1450 mbsf (~850 m of sediment)			
			- RCB core from ~1300 to ~1600 mbsf (~150 m of basement)			
			- Wireline log open hole with triple combo, FMS-sonic, & VSP tool strings			2.8
			- Contingency (possible WOW/sea state delays)		3.2	
			Subtotal days on site: 51.6			
IBM-1C	27.318412°N	4741	**Hole A**: Drill to 900 mbsf (assuming already cored to this depth)		18.0	
	134.341389°E		- RCB core from ~900 to ~1300 mbsf (~400 m of sediment)			
			- RCB core from ~1300 to ~1450 mbsf (~150 m of basement)			
			- Wireline log with triple combo, FMS-sonic, & VSP tool strings			2.4
			Subtotal days on site: 20.4			
IBM4-GT	32°23.8854'N	1788	**Hole A**: APC to 150 mbsf		1.4	
Geotechnical	140°21.9288'E		(Note: Additional transit time required for Expedition 351 is ~0.2 days)			
hole						

Seafloor depth corrected to rig floor dual elevator stool or meters below rig floor. No time or money has been budgeted for logging while drilling or measurement while drilling. Deep water coupled with reentry cone/long casing string operations and significant penetration targets below seafloor could result in high drill string stress; therefore, calm sea states and low heave will be critical in undertaking certain operations such as reentry cone and casing string deployments. Some lost time waiting on weather (WOW)/sea state may be experienced. APC = advanced piston corer, XCB = extended core barrel, RCB = rotary core barrel. WL = wireline logging, FMS = Formation MicroScanner, VSP = vertical seismic profile.

Figure F1. Schematic of induced versus spontaneous subduction initiation models (after Stern, 2004).

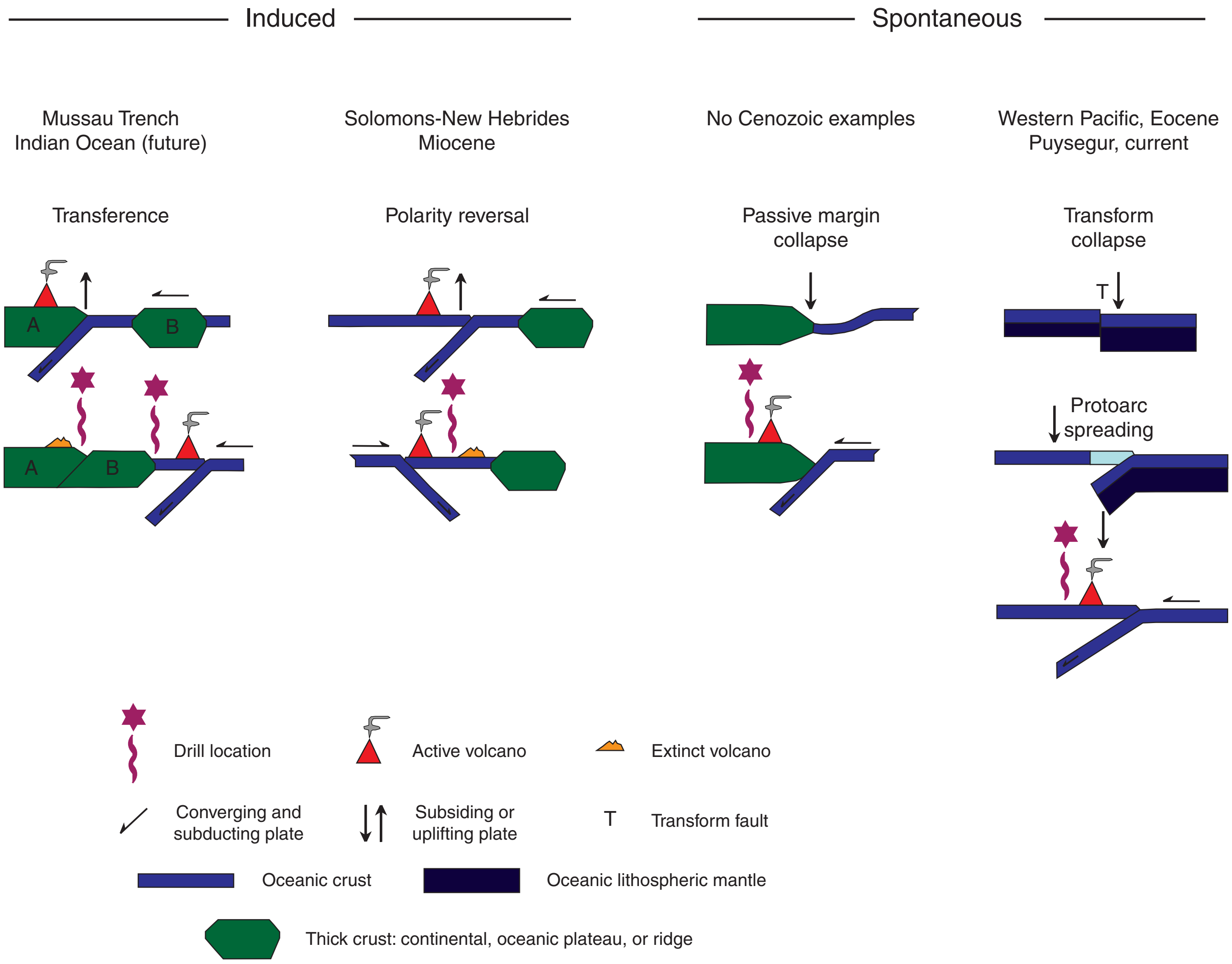


Figure F2. Location map of Philippine Sea region. The Izu-Bonin-Mariana (IBM) arc trench system forms the convergent boundary between the Pacific and Philippine Sea plates. Back-arc basins such as Shikoku Basin, Parece Vela Basin, and Mariana Trough were created by seafloor spreading between the formerly contiguous remnant arc (Kyushu-Palau and West Mariana Ridges).

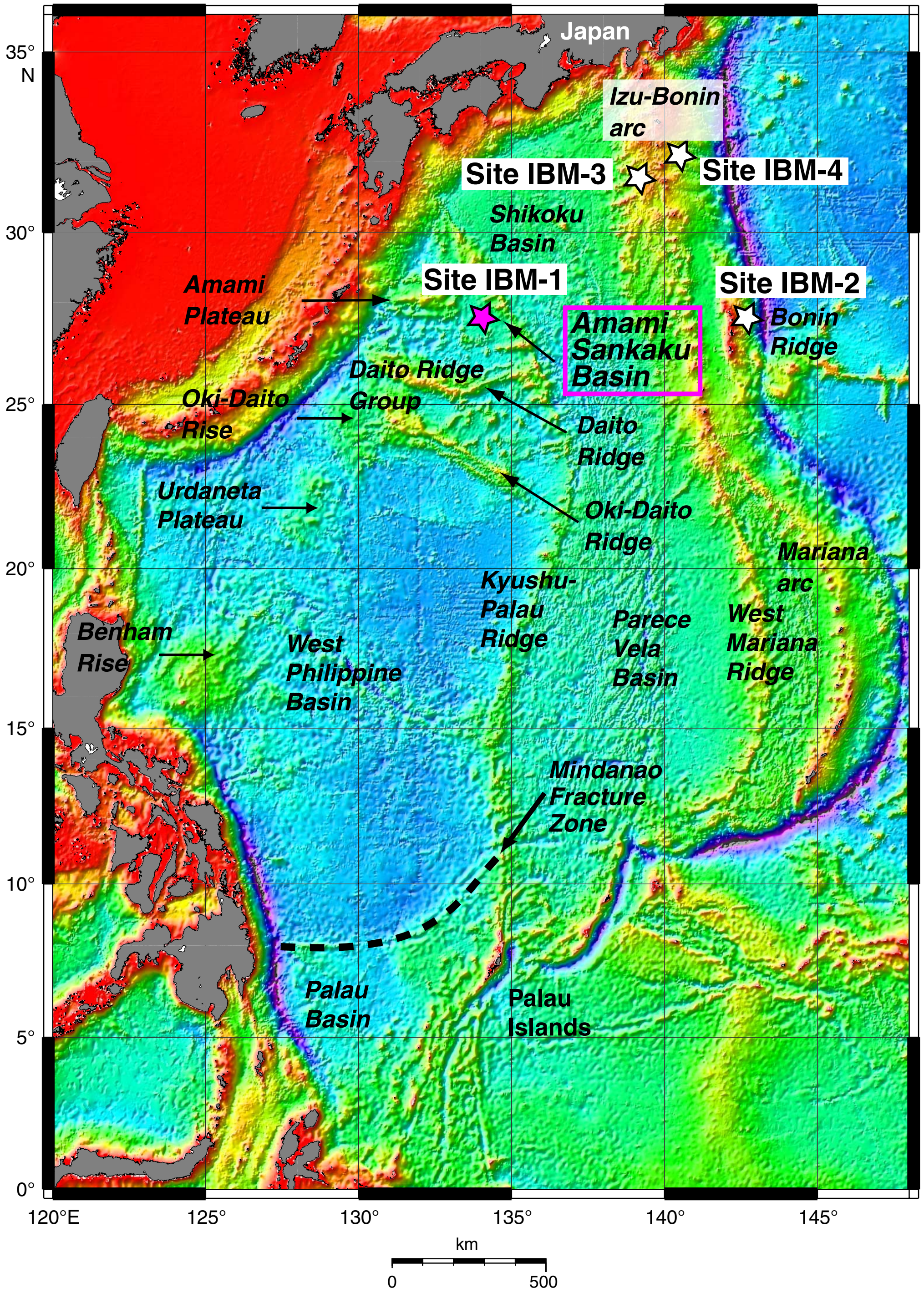


Figure F3. **A.** Interpretation of magnetic anomalies of the West Philippine Basin (Hilde and Lee, 1984); figure is modified after Deschamps et al. (2002). **B.** Schematic of the evolution of the spreading mode of the West Philippine Basin (after Okino and Fujioka, 2003). BR = Benham Rise, FR = failed rift, FZ = fracture zone, PF = pseudofaults, UP = Urdaneta Plateau, VS = Vinogradov Seamount. **C.** Evolutionary model of the West Philippine Basin at 50 Ma (Deschamps and Lallemand, 2003). BABB = back-arc basin basalt, N-MORB = normal mid-ocean-ridge basalt, OIB = ocean-island basalt, PAC = Pacific plate. Blue triangles = MORB or OIB volcanoes, green triangles = arc volcanoes, red triangles = boninitic volcanoes. **D.** Paleogeodynamic reconstruction of the western Pacific after Jolivet et al. (1989), based on the "trapped basin model" for the generation of the West Philippine Basin. ANT = Antarctic plate, AUS = Australian plate.

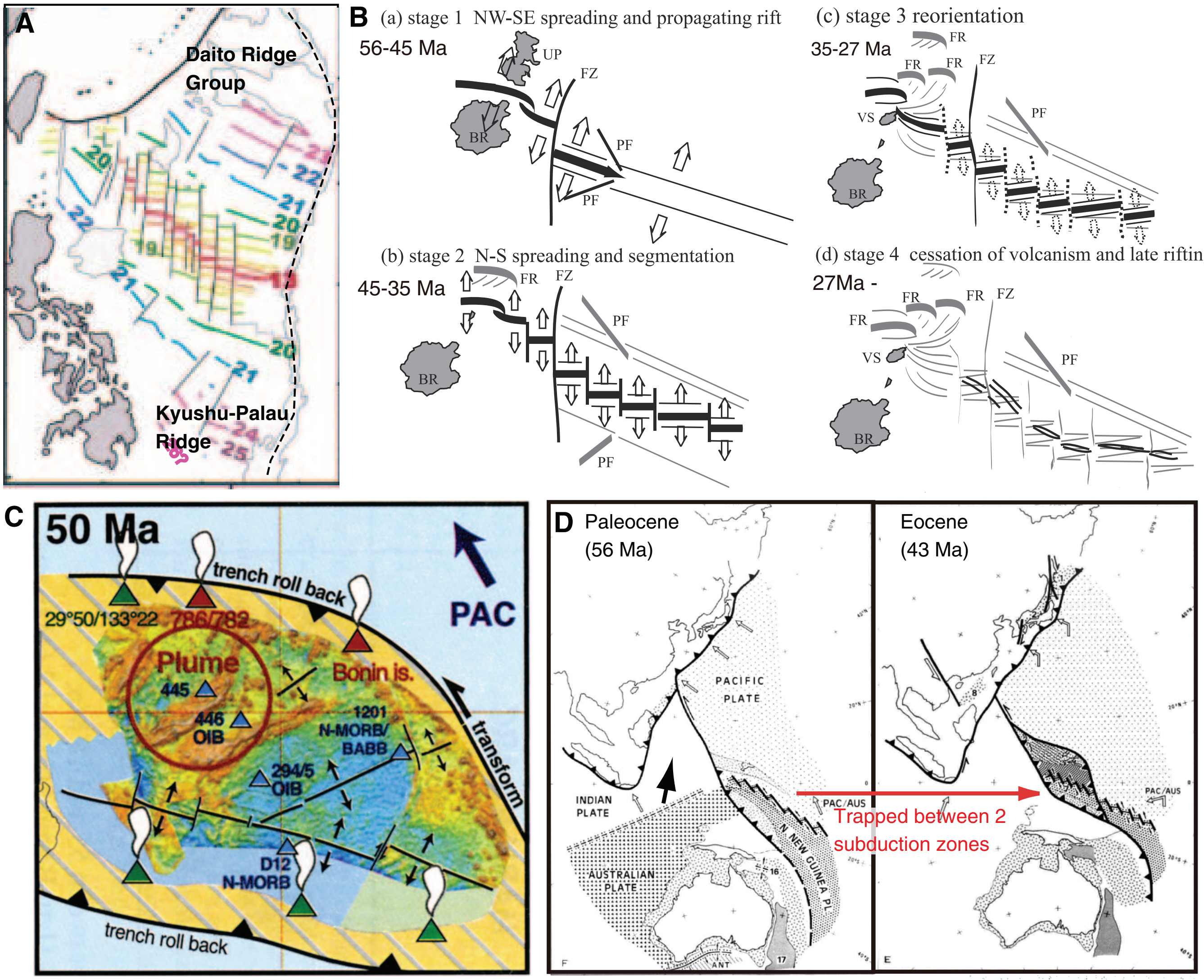


Figure F4. Distribution of $^{40}Ar/^{39}Ar$ ages obtained for volcanic rocks from the Kyushu-Palau Ridge area (Ishizuka et al., 2011b).

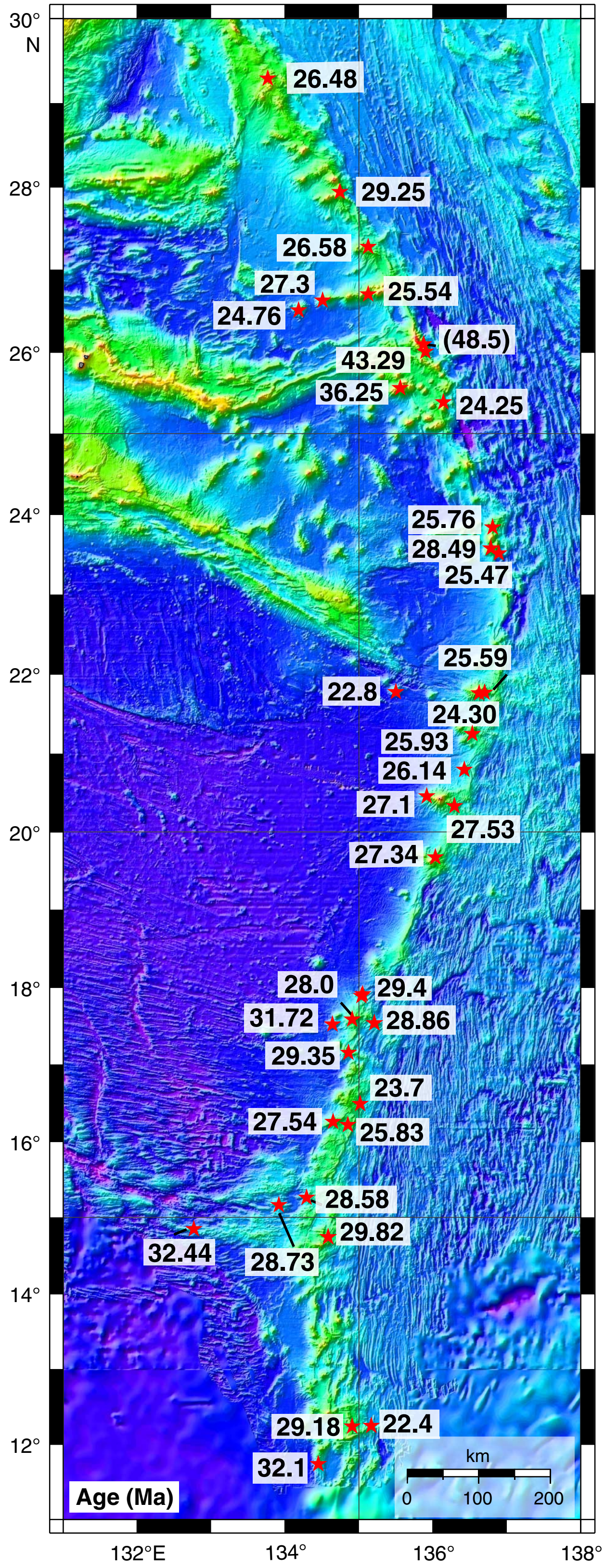


Figure F5. Along-arc isotopic variation of volcanic rocks of the Izu-Bonin-Mariana arc and Kyushu-Palau Ridge (Ishizuka et al., 2007, 2011b).

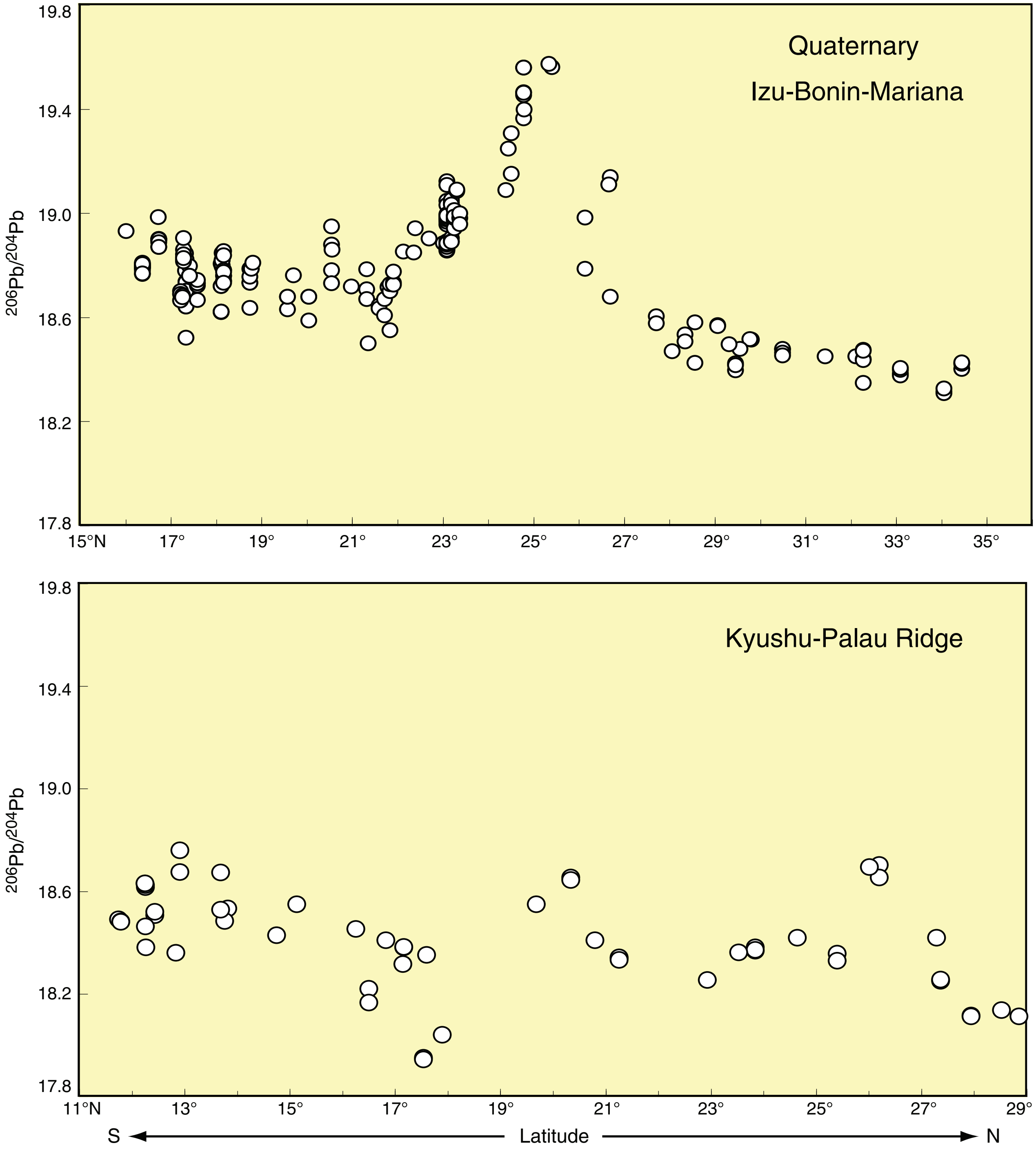


Figure F6. Distinct geochemical characteristics of volcanic rocks from the Kyushu-Palau Ridge (KPR)/Daito Ridge intersection (after Ishizuka et al., 2011b). Pb isotopes clearly discriminate volcanic rocks of this area from other KPR volcanics. EM = enriched mantle, HIMU = high μ, MORB = mid-ocean-ridge basalt, OIB = ocean-island basalt, PSP = Philippine Sea plate.

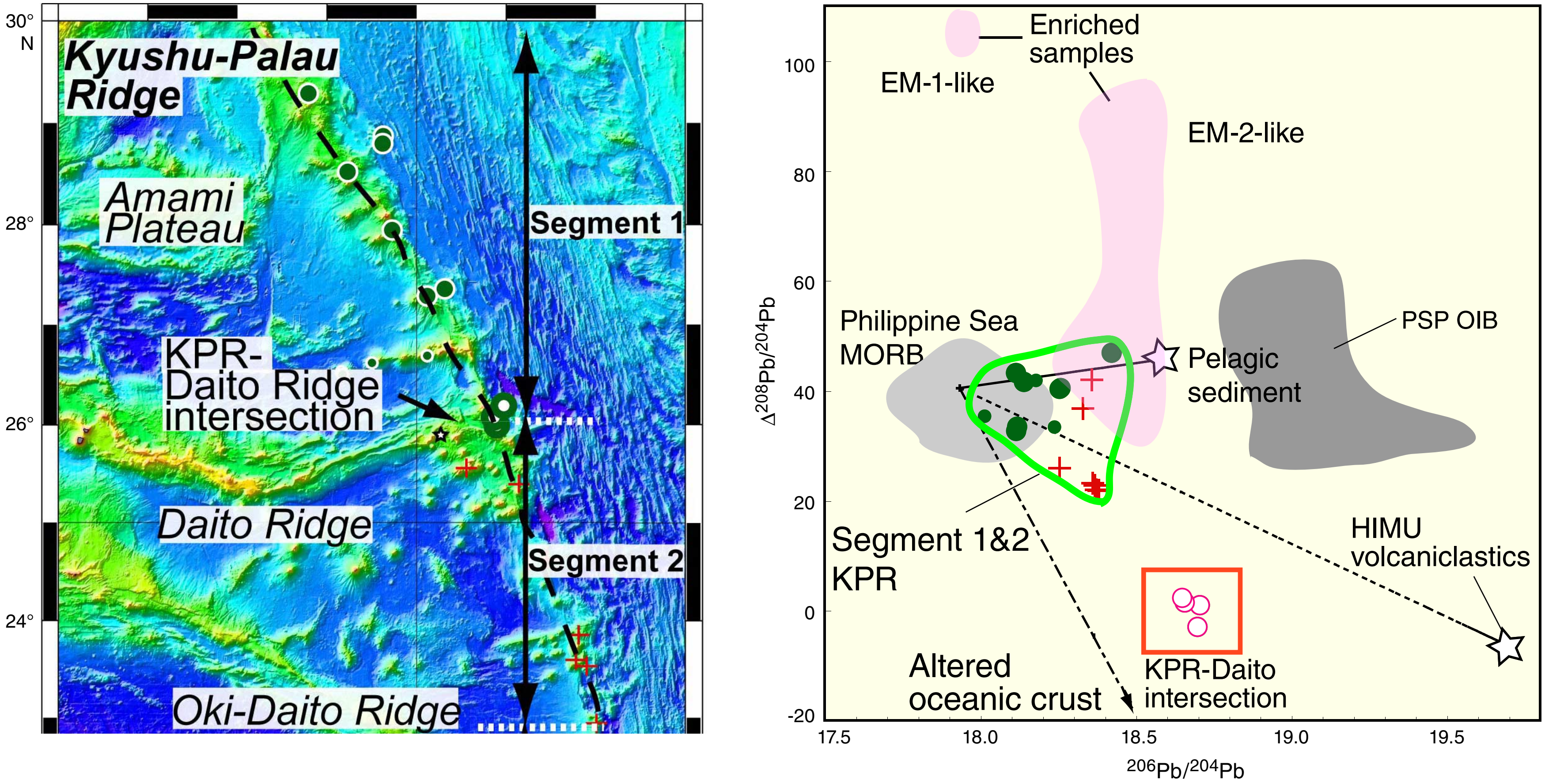


Figure F7. Location of previous DSDP and ODP sites in the region of the Amami Sankaku Basin as well as Shinkai 6500 Dive 337 and the primary Site IBM-1. KPR = Kyushu-Palau Ridge.

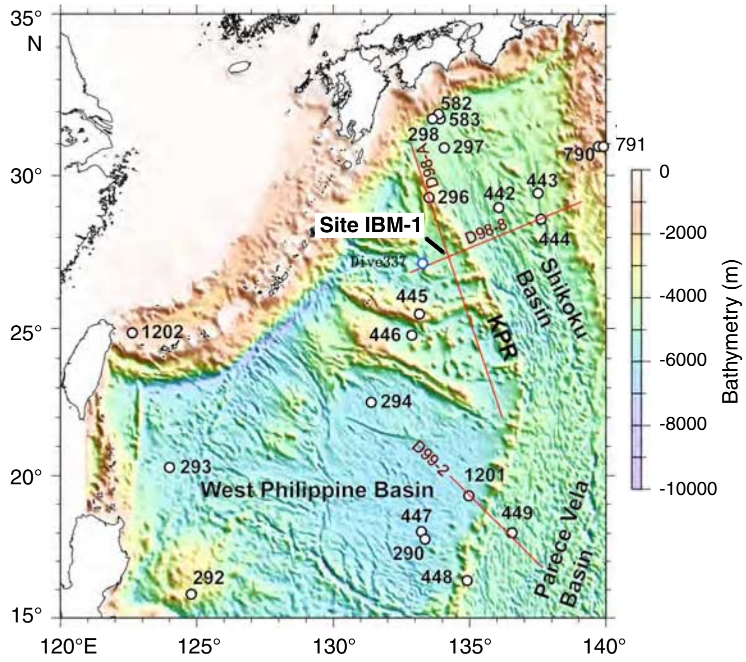
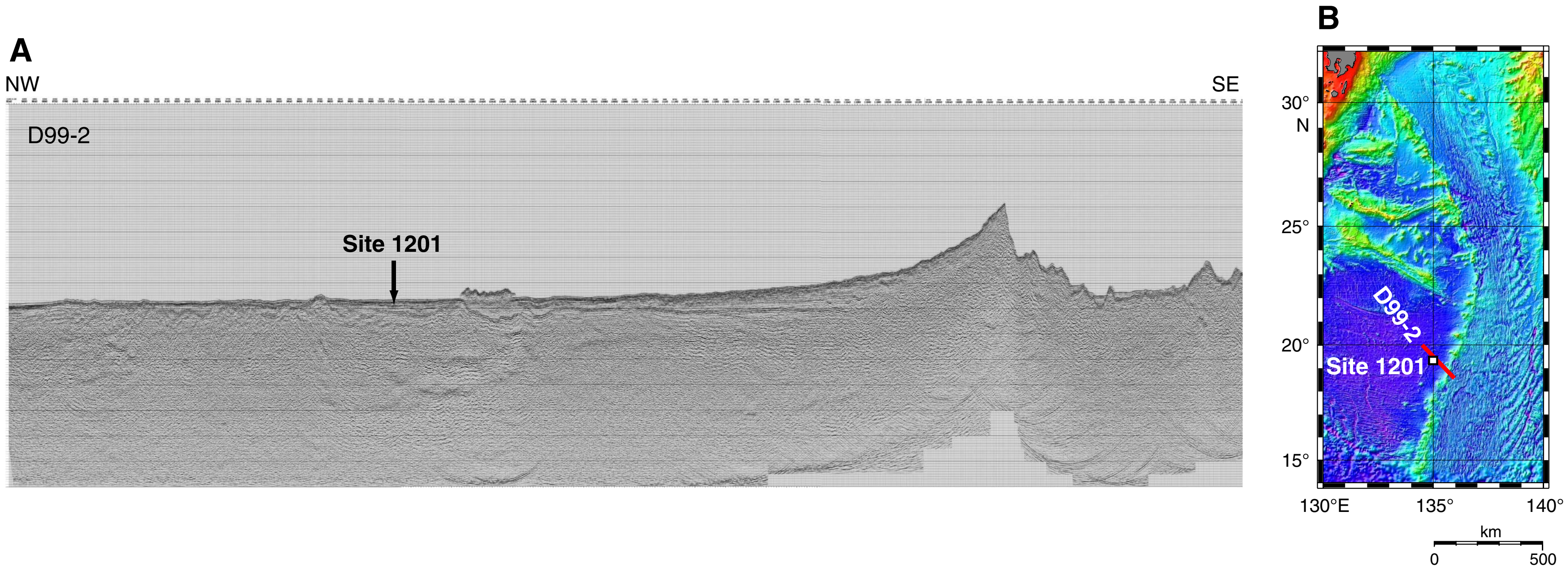


Figure F8. A. Multichannel seismic Line D99-2. The prominent topographic high is the Kyushu-Palau Ridge. ODP Site 1201 has been projected onto the cross section. **B.** Location of ODP Site 1201 on Line D99-2.



Site summaries

Site IBM-1

Priority:	Primary
Position:	27.383518°N, 134.31837°E
Water depth (m):	4720
Target drilling depth (mbsf):	1600
Approved maximum penetration (mbsf):	1600
Survey coverage (track map; seismic profile):	• Location map (Fig. **AF1**) • Site track map (Fig. **AF2**) • Multichannel seismic profiles (Fig. **AF3**)
Objective(s):	Recover hemipelagic sediment, volcanic ash, and volcaniclastic turbidite filling the basin and penetrate into oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics.
Drilling program:	APC/XCB to refusal; RCB to 1600 mbsf
Logging program:	Triple combo, FMS-sonic, VSI; potential third-party tool, such as UBI, MMM, or GBM (see **"Logging/Downhole measurements strategy"** for details)
Nature of rock anticipated:	Mixed hemipelagic and volcaniclastic sediments, then igneous basement

Site summaries (continued)

Site IBM-1A

Priority:	Alternate
Position:	27.469769°N, 134.31837°E
Water depth (m):	4660
Target drilling depth (mbsf):	1600
Approved maximum penetration (mbsf):	1600
Survey coverage (track map; seismic profile):	• Location map (Fig. **AF1**) • Site track map (Fig. **AF2**) • Multichannel seismic profiles (Fig. **AF3**)
Objective(s):	Recover hemipelagic sediment, volcanic ash, and volcaniclastic turbidite filling the basin and penetrate into oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics.
Drilling program:	APC/XCB to refusal; RCB to 1600 mbsf
Logging program:	Triple combo, FMS-sonic, VSI; potential third-party tool, such as UBI, MMM, or GBM (see **"Logging/Downhole measurements strategy"** for details)
Nature of rock anticipated:	Mixed hemipelagic and volcaniclastic sediments, then igneous basement

Site summaries (continued)

Site IBM-1B

Priority:	Alternate
Position:	27.459276°N, 134.508459°E
Water depth (m):	4650
Target drilling depth (mbsf):	1600
Approved maximum penetration (mbsf):	1600
Survey coverage (track map; seismic profile):	• Location map (Fig. **AF1**) • Site track map (Fig. **AF2**) • Multichannel seismic profiles (Fig. **AF3**)
Objective(s):	Recover hemipelagic sediment, volcanic ash, and volcaniclastic turbidite filling the basin and penetrate into oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics.
Drilling program:	APC/XCB to refusal; RCB to 1600 mbsf
Logging program:	Triple combo, FMS-sonic, VSI; potential third-party tool, such as UBI, MMM, or GBM (see **"Logging/Downhole measurements strategy"** for details)
Nature of rock anticipated:	Mixed hemipelagic and volcaniclastic sediments, then igneous basement

Site summaries (continued)

Site IBM-1C

Priority:	Alternate
Position:	27.318412°N, 134.341389°E
Water depth (m):	4730
Target drilling depth (mbsf):	1600
Approved maximum penetration (mbsf):	Pending EPSP approval.
Survey coverage (track map; seismic profile):	• Location map (Fig. **AF1**) • Site track map (Fig. **AF2**) • Multichannel seismic profiles (Fig. **AF3**)
Objective(s):	Recover hemipelagic sediment, volcanic ash, and volcaniclastic turbidite filling the basin and penetrate into oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics.
Drilling program:	RCB to 150 m into basement; upper sedimentary section drilled without coring pending EPSP approval
Logging program:	Triple combo, FMS-sonic, VSI; potential third-party tool, such as UBI, MMM, or GBM (see **"Logging/Downhole measurements strategy"** for details)
Nature of rock anticipated:	Mixed hemipelagic and volcaniclastic sediments, then igneous basement

Site summaries (continued)

Site IBM-4GT

Priority:	Alternate
Position:	32°23.8854′N, 140°21.9288′E
Water depth (m):	1776.6
Target drilling depth (mbsf):	150
Approved maximum penetration (mbsf):	200
Survey coverage (track map; seismic profile):	• Site track map (Fig. **AF4A**) • Multichannel seismic profiles (Fig. **AF4B**)
Objective(s):	Obtain adequate shear strength data to aid riser operations planning for a future riser expedition on the D/V *Chikyu*
Drilling program:	APC to 150 mbsf
Logging program:	None
Nature of rock anticipated:	Silty clay

Figure AF1. Location of primary Site IBM-1 and alternate Sites IBM-1A, IBM-1B, and IBM-1C for Expedition 351 in the Amami Sankaku Basin.

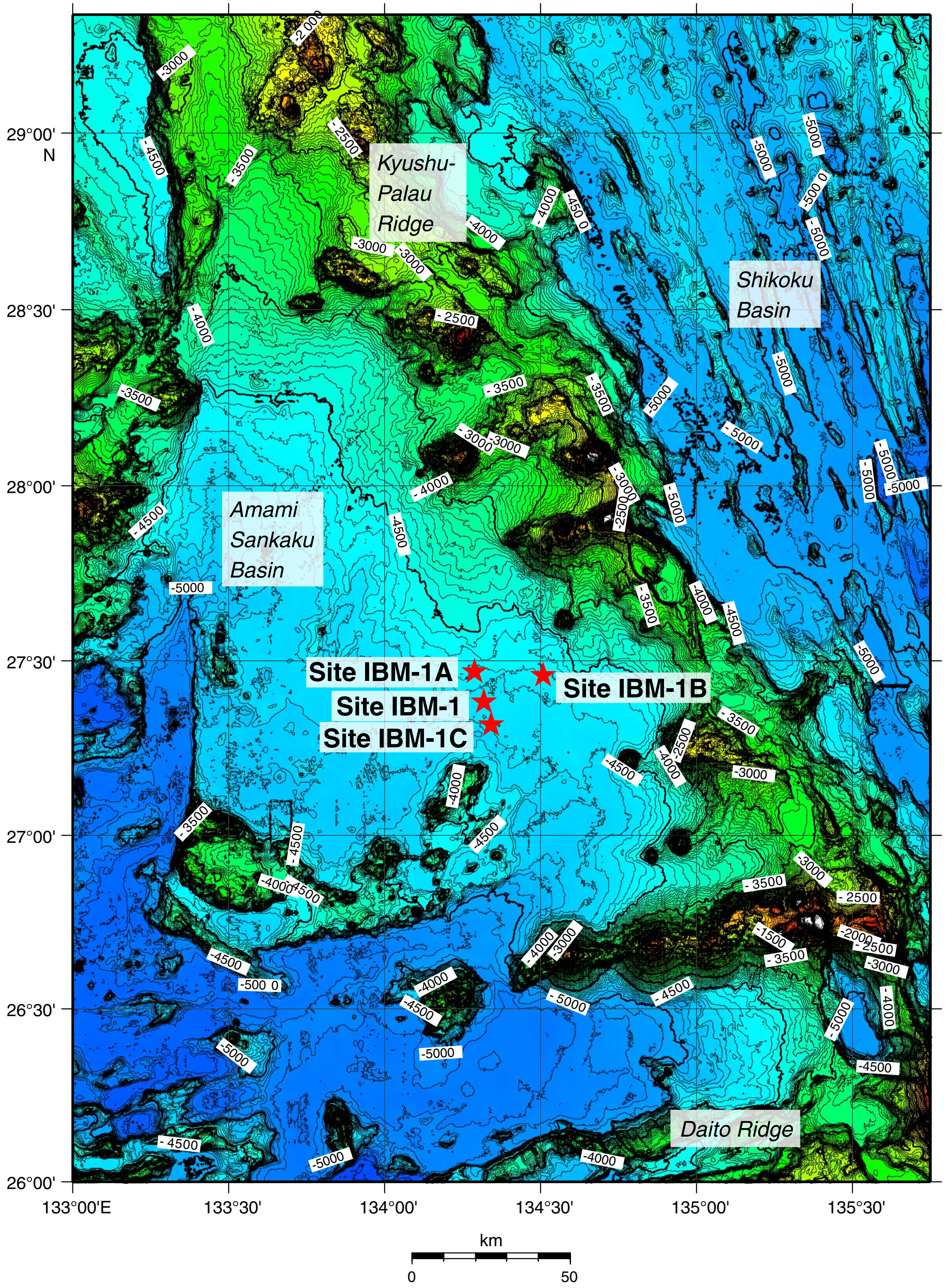


Figure AF2. Track map of multichannel seismic survey Lines D98-A and D98-8. Primary Site IBM-1 is located at the intersection of the two lines, whereas alternate Sites IBM-1A and IBM-1C are along Line D98-A and alternate Site IBM-1B is on Line D98-8.

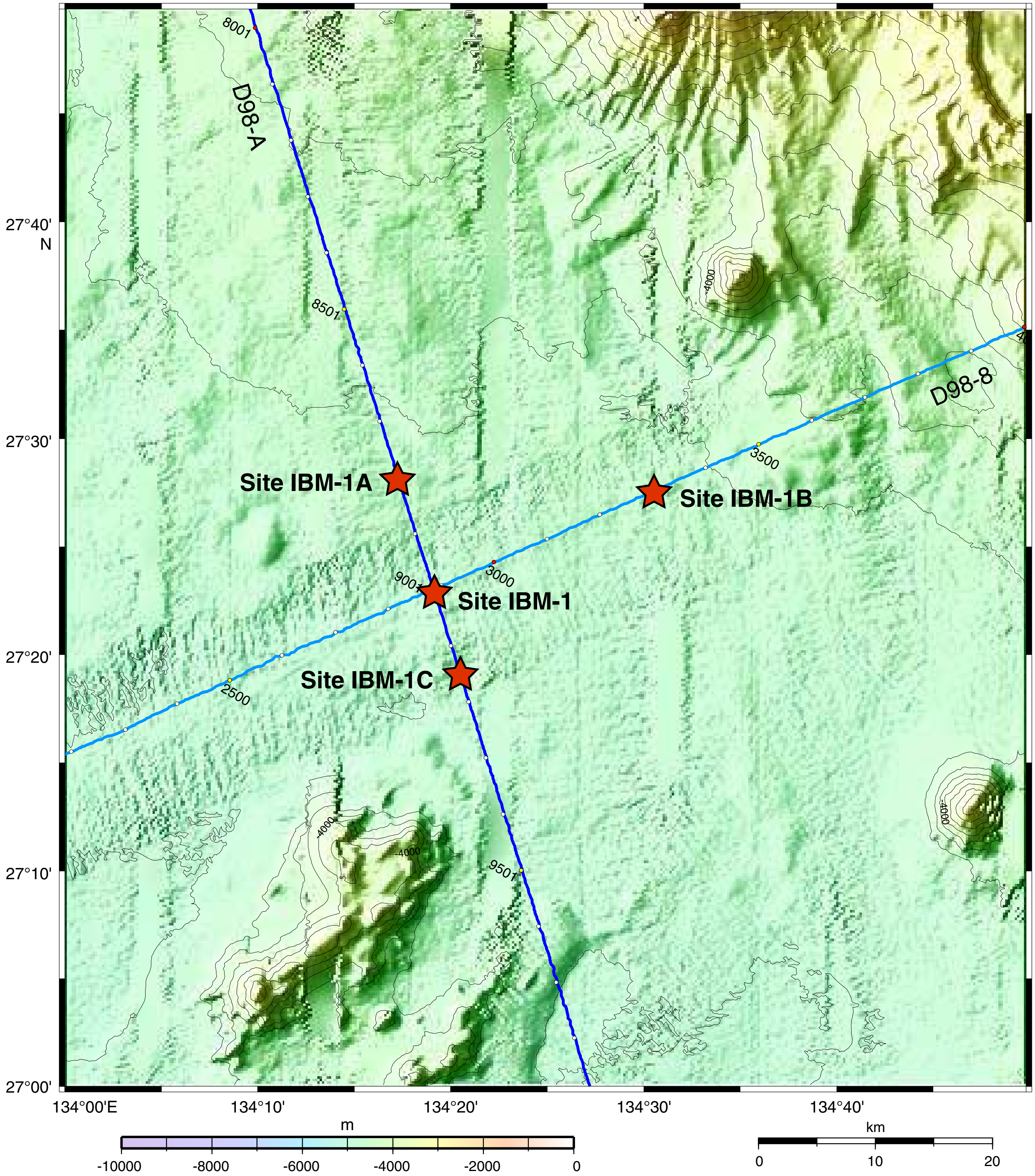


Figure AF3. Seismic reflection images of Expedition 351 sites. **A.** Top: multichannel seismic (MCS) Line D98-8; bottom: with major reflectors and Sites IBM-1 and IBM-1B (alternate). **B.** Top: MCS Line D98-A; bottom: with major reflectors and Sites IBM-1 and IBM-1A and IBM-1C (alternates).

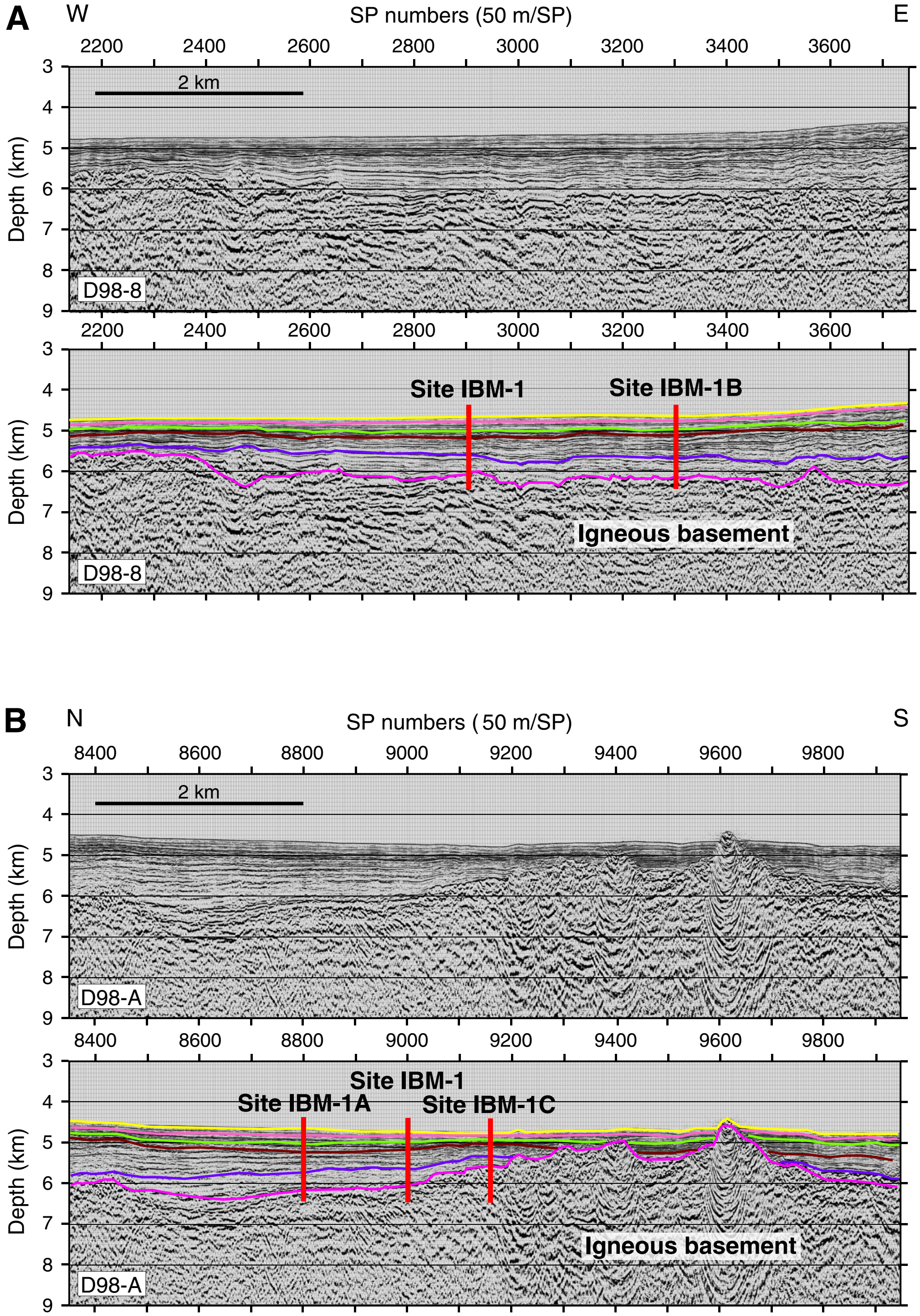
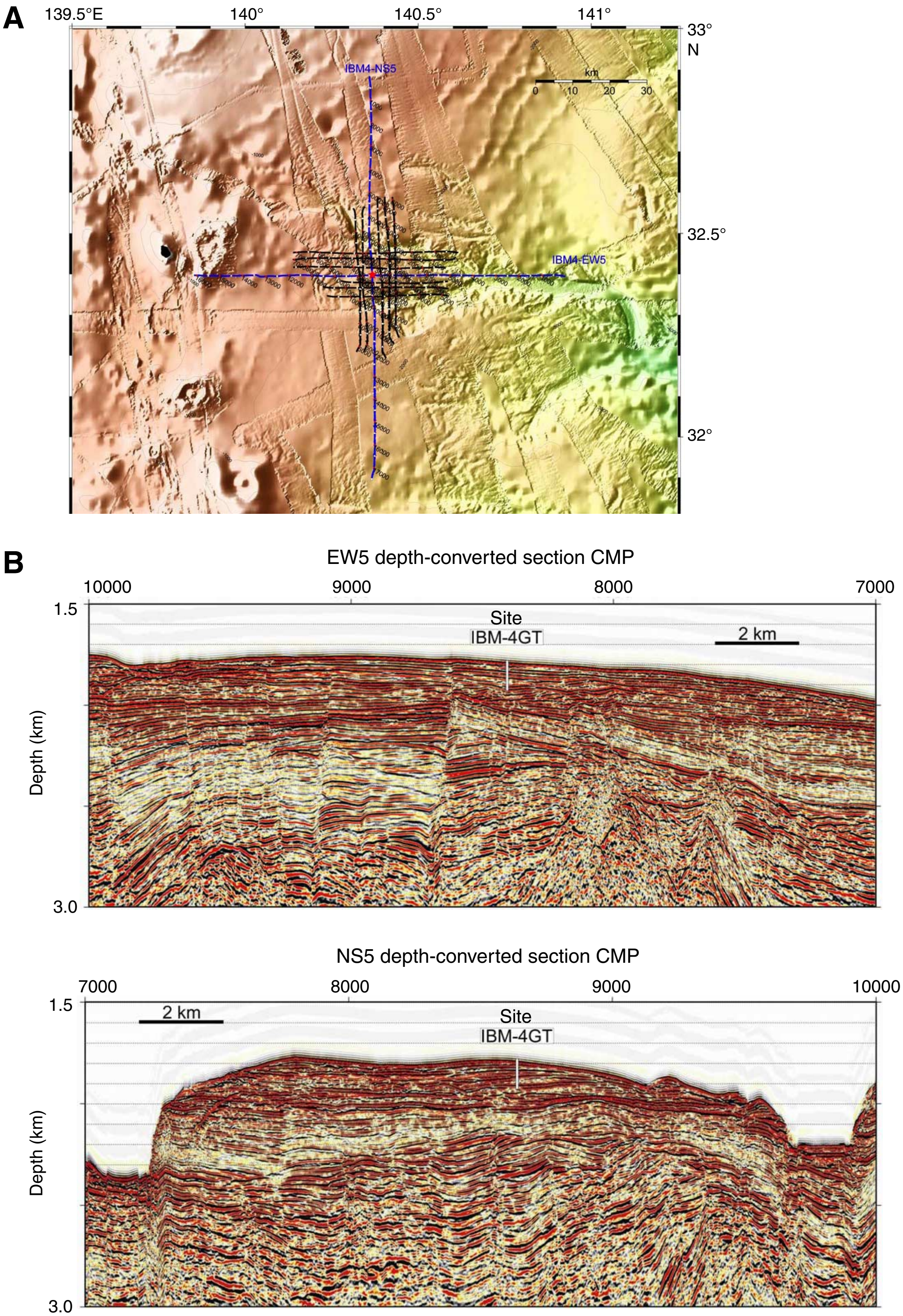


Figure AF4. **A.** Location and track map showing alternate Site IBM-4GT (red star) at the intersection of multichannel seismic survey Lines IBM4-EW5 and IBM4-NS5. **B.** Seismic reflection images along (top) Line IBM4-EW5 and (bottom) IBM4-NS5 with Site IBM-4GT projected onto the images. CMP = common midpoint.



Expedition scientists and scientific participants

The current list of participants for Expedition 351 can be found at: **iodp.tamu.edu/scienceops/precruise/izuboninarc/participants.html.**