IODP Proposal Cover Sheet

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Title: **697-Full3: The rear arc: the missing half of the subduction factory**

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Keywords: *(5 or less)* Intra-oceanic arc; continental crust; crustal evolution; arc rifting; across-arc variation

Area: Izu-Bonin Arc

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Permission to post abstract on IODP Web site: ■ Yes   ☐ No

Abstract: *(400 words or less)*

The spatial and temporal evolution of arc magmas within a single oceanic arc is fundamental to understanding the initiation and evolution of oceanic arcs and the genesis of continental crust, which is one key objective of the IODP ISP. The Izu-Bonin-Mariana arc has been a target for this task for many years, but previous drilling efforts have focused mainly on the IBM forearc, and thus the magmatic evolution of the volcanic front through 50 million years. Rear-arc IBM magmatic history has not been similarly well studied in spite of its importance in mass balance and flux calculations for crustal evolution, in establishing whether and why arc-related crust has inherent chemical asymmetry, in testing models of mantle flow and the history of mantle depletions and enrichments during arc evolution, and in testing models of intra-crustal differentiation. Especially, (1) crust develops that is "continental" in velocity structure and seismically similar beneath both the volcanic front and rear arc but is heterogeneous in chemical composition. (2) Magmas at the volcanic front are rich in fluid-mobile recycled slab components that swamp the mantle yet these magmas are so depleted in mantle-derived fluid-immobile elements that they are dissimilar to "average continental crust" in detail. This is less true in the rear arc where the diminished slab signature and lower degrees of mantle melting create crust that is more typical of the continents and allow the temporal history of the mantle source to be tracked more easily. Furthermore, (3) the crust beneath the rear arc is volumetrically more abundant than beneath the volcanic front. In order to understand the evolution of the whole IBM crust, therefore, we propose to drill the Izu rear-arc region in the west of the modern volcanic front to recover a complete record of rear-arc volcanism from the present back to its likely inception in Early Oligocene or Eocene times. Rear arc drilling is the necessary "Other Half" of subduction factory output and essential to the IBM drilling strategy.

Scientific Objectives: (*250 words or less*)

The primary objective of IBM-3C is to test three pairs of alternative hypotheses about crustal genesis and mantle evolution:

1. Geochemically asymmetric crust, which is most like "average continent" in the rear arc, is either (i) a fundamental trait of crust in oceanic arcs that is produced in the steady state throughout arc history from Paleogene inception, or (ii) a secondary trait that develops only after backarc spreading;

2. Intra-crustal differentiation amplifies this asymmetry (i) continuously as a steady state process, or (ii) mostly during non-steady state events such as arc rifting.

3. After or near the cessation of the Shikoku Backarc Basin opening, rear-arc magmatism either (i) started from the western end of the rear arc seamount chains and migrated east, or (ii) started at the same time along the length of the rear arc seamount chains, but ended from west to east.

Testing these hypotheses requires obtaining a temporal record of across-arc variation in magma composition from Eocene to Neogene time. This information is in hand for the volcanic front but missing for the rear arc which overlies the majority of "continent-type" crust. Specifically, our objectives are to establish the temporal history of across-arc variations during five time periods that stand out in the rear-arc evolution: 3 Ma to the present, 9 to 3 Ma, 17 to 9 Ma, 25 to 17 Ma, and >25 Ma. We will determine whether there were across arc variations in even at the initial stage of arc development.

Please describe below any non-standard measurements technology needed to achieve the proposed scientific objectives.

Proposed Sites:

Site Name	Position	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
IBM-3C	31°47.3874'N 139°01.5786'E	2114	1,200	700	1,900	Recovery of sediments and upper most Oligocene-Eocene basement

The Rear Arc: the Missing Half of the Subduction Factory

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1. INTRODUCTION

The IODP Science Plan states that; '*The creation and growth of continental crust remains one of the fundamental, unsolved problems in Earth science.*' The formation and evolution of the continental crust is a first order problem of terrestrial geochemistry because for many trace and minor elements, this reservoir is quantitatively important despite its volumetric insignificance on a planetary scale. In the latter part of the 1960s, Ross Taylor (1967) proposed the "andesite model" for the origins of continental crust on the basis of similarities between "calc-alkaline" or orogenic andesite formed in island arcs and the "intermediate" bulk composition (~60 wt% SiO_2) of this crustal type. For many arc enthusiasts, this observation has been a prime motivation for studies of island and continental arc systems. Subsequent studies have substantiated Taylor's estimate of continental crust bulk composition, and have noted that distinctive continental trace element fractionations (e.g., high U/Nb and Pb/Ce) are only found in supra-subduction zone magma types (Hofmann, 1988).

The andesites of most young oceanic arcs, however, have been found to be more depleted elementally and isotopically than average continental crust, at least at the volcanic front. An old idea, still generally valid, that may explain part of this problem is the Kuno-Dickinson-Hatherton K-h relationship (Kuno, 1959; Dickinson & Hatherton, 1967): at a given SiO_2 content, the K_2O of related volcanic series is positively correlated with depth (h) to the Wadati-Benioff Zone. Thus geochemical asymmetry in arcs was known prior to the advent of plate tectonics and may be what makes juvenile arc crust "continental" in key elements like Th and LREE as well as intermediate in silica content. Potential processes to produce this asymmetry might be that: (1) magma is first extracted from the mantle in the rear arc and is then extracted a second time as the depleted mantle moves toward volcanic front where it is fluxed by fluid from the slab (Hochstaedter *et al.,* 2000, 2001); (2) there is more slab-derived sediment melt in the rear-arc magma source (Ishizuka *et al.,* 2003a, 2006; Tamura *et al.,* 2007); (3) the degree of melting is smaller beneath the rear arc (e.g. Tatsumi *et al.,* 1983, Sakuyama & Nesbitt, 1986; Kushiro, 1994); or (4) there is more recycling of old crust at the magmatic front (Kimura & Yoshida, 2006).

In addition to these petrological considerations, paleo-arcs are an essential part of most mountain belts from the Archean to Tertiary. Their geological architecture is, therefore, a fundamental aspect of the formation of continental crust. Most rocks in the upper crust of arcs are volcaniclastic, highly vesicular, and vitric. Models for their facies architecture have relatively

good constraints for the subaerial arc-front and for some aspects of submerged arc front volcanoes, but knowledge of the rear-arc facies architecture is limited by the paucity of mapping, drilling and sampling from modern rear arc settings. Facies models depend largely on ancient successions now uplifted and dissected (e.g. McPhie & Allen, 1992), but incomplete preservation and exposure limit the value of such models. Nevertheless, they underpin a great deal of foldbelt research worldwide, particularly tectonic interpretations, structural analyses, palaeogeography reconstructions, and resource assessments. For example, in ancient successions, aligned volcanic centres and proximal associations are commonly the basis for reconstructing the arc trend and polarity. The presence of almost orthogonal rear-arc seamount chains in arcs like Izu has serious implications for such reconstructions. If the rear arc affinities of volcaniclastic sediments can be better defined through this proposal, then there is hope that similar features can be recognized in ancient foldbelt successions. Likewise, knowledge of the eruption and depositional processes at submarine arc volcanoes depends largely on these same ancient successions (Fisher & Schmincke, 1984) and are weighted toward shallow water volcanic front edifices. The effects of voluminous vesicular glass on water chemistry and microbiology are potentially enormous but largely unknown. Drilling is the only way to obtain information about volcanic eruption, sedimentation, and stratigraphy in oceanic arcs without looking through the effects of collision and accretion (e.g. Haeckel, *et al.,* 2001; Wiesner *et al.,* 2004).
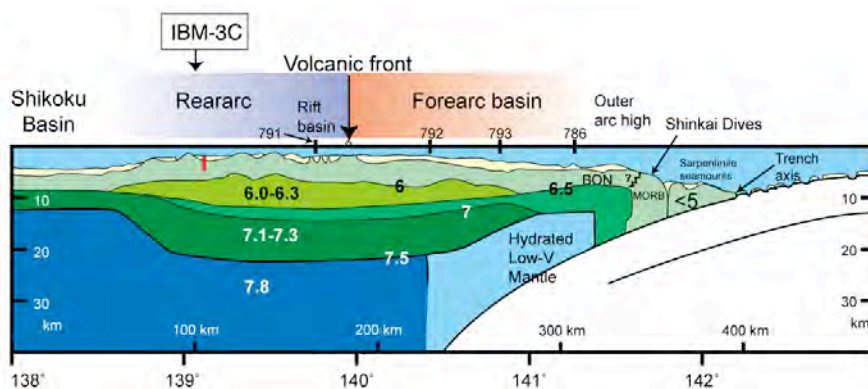
Figure 1. Izu-Bonin arc seismic stratigraphy (P-wave velocity, km/s) after Suyehiro *et al.* (1996). Proposed drilling site IBM-3C (697Full3) is designated as a red bar. Black bars suggest previous sites (ODP 786, 791, 792 and 793).

Full crustal velocity profiles for the IBM arc obtained in the last decade show a velocity structure with continuous layers extending ~200 km across the arc (Fig. 1). We do not yet know how these layers developed but testable ideas are being developed (Kodaira *et al.,* 2007a,b; Tatsumi *et al.,* 2008). Given the relatively large volume of crust now in a rear arc position (Fig. 1) and its present day geochemical contrast with the magmas erupted at the volcanic front (see below), it is clearly vital that we understand the structure and compositional variations of the rear arc through time in the same way that we have unraveled the

temporal evolution of the fore- and volcanic front magmas.

A basic premise of this proposal is that time series geochemical information about igneous rocks can be obtained from volcaniclastic sediments, mostly turbidites. This potential was realized during earlier ODP drilling in the Izu forearc (e.g., Gill *et al.,* 1994), and subsequent advances in micro-analytical methods (e.g., analysis of clinopyroxene and zircons to obtain igneous geochemical information) make this even more likely now. The forearc turbidites preserve a faithful record of arc evolution, which parallels that seen in tephra (e,g., Straub, 2003; Bryant *et al.,* 2003). The mass wasting of submarine edifices guarantees lots of volcaniclastic sediment. Even though mixing makes the signal more of a running average than in tephra, first order changes (say on a few hundreds of thousand year scale) are well resolved. Therefore, although many of our ends are igneous in nature, our means are sediments.

This revision of our proposal has been substantially rewritten (again) to address the SSEP's November 2007 Comments. We have strengthened discussion of models about the formation of crust and across-arc asymmetry, the geologic and geochemical background of the Izu arc, how drilling results will test hypotheses, and site selection. We re-interpreted the seismic stratigraphy. We have added a specialist in paleontology as PI, clarified the geochemical criteria for distinguishing between source areas, and consulted with microbiologist, and TAMU staff. We hope that the proposal is now ready for external review.

2. GEOLOGIC AND GEOCHEMICAL BACKGROUND

The IBM subduction zone began as part of a hemispheric-scale foundering of old, dense lithosphere in the Western Pacific about 50 Ma (Bloomer *et al.,* 1995; Cosca *et al.,* 1998; Stern, 2004), perhaps aided by reorganization of plate boundaries throughout the western Pacific (Okino et al., 2004; Hall et al., 2003; Whittaker et al., 2007). The latter is consistent with the initiation of the Hawaiian-Emperor bend near Kimmei seamount, suggesting a major change in the Pacific Plate motion at 50 Ma (Sharp & Clague, 2006). During this stage, the fore-arc was the site of prodigious igneous activity (Fig. 2). Magmatic products consist of boninite, low-K tholeiite, and subordinate low-K rhyodacite everywhere the fore-arc has been sampled, implying a dramatic episode of asthenospheric upwelling and melting associated with seafloor spreading over a zone that was hundreds of km broad and thousands of km long.

After ~ 5 million years, magmatic activity front localized ~20 km east of the present front, building the first mature arc from 42 to 25 Ma. (Taylor, 1992; Ishizuka et al., 2006). The rear arc

crust of this age is one of our targets. This retreat of magmatism allowed fore-arc lithosphere to cool. Arc volcanism was accompanied until at least 33 Ma by spreading along the WNW-ESE (present co-ordinates) trending Central Basin Fault in the W. Philippine Sea (Deschamps et al., 2002; Deschamps & Lallemand, 2002; Taylor & Goodliffe, 2004). Eocene-Oligocene arc rocks have been found both at the frontal arc highs (Taylor, 1992), one of which was drilled as ODP Site 792 and is the target for drilling to the middle crust at IBM-4 (698 Full2), and at the Kyushu-Palau ridge (Malyarenko & Lelikov, 1995; Mizuno et al., 1977; Shibata & Okuda, 1975; Ishizuka et al., unpublished data). In addition, Yamazaki & Yuasa (1998) reported three conspicuous north-south rows of long-wavelength magnetic anomalies in the Izu-Bonin arc, which are slightly oblique to the present volcanic front. The eastern row correlates with the frontal arc highs, the western row coincides with the Kyushu-Palau Ridge (the remnant arc), and the middle row lies at 139°E at our proposed site. Yamazaki & Yuasa (1998) attributed all three to loci of Oligocene magmatic centers.
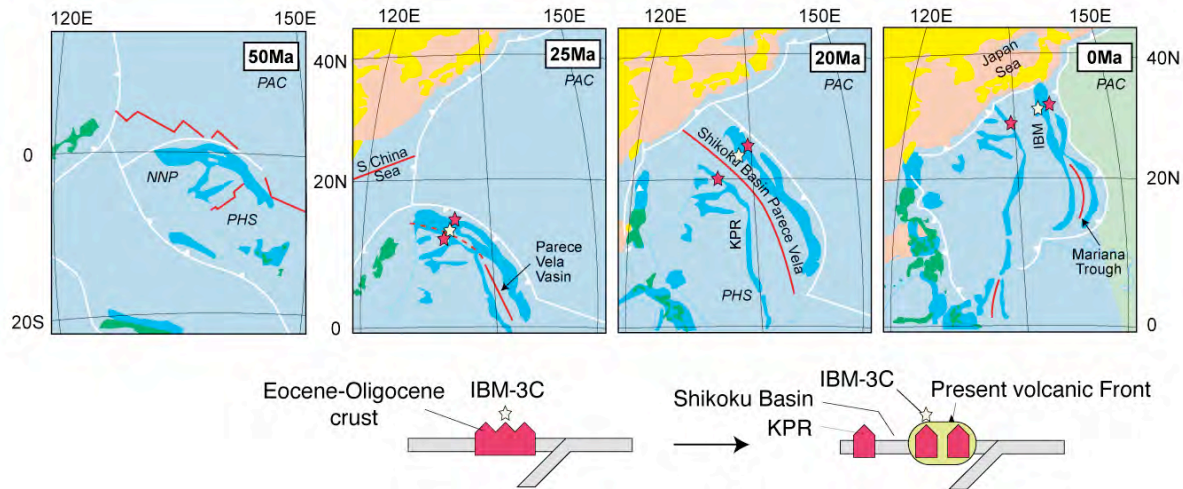

Figure 2. A model for tectonic evolution of the Philippine Sea region after Hall (2002). NNP, North New Guinea plate: PHS, Philippine Sea plate; PAC, Pacific plate; IBM, Izu-Bonin-Mariana arc; KPR, Kyushu-Palau Ridge. Paleo- and present positions of the proposed drilling site (IBM-3C) are shown by yellow stars. Red and yellow stars show Eocene-Oligocene crust, which formed an across-arc section until the time of 25 Ma.

About 30 Ma, the IBM arc began to form its back-arc basins, the Shikoku Basin and Parece Vela Basin spreading systems, which met about 20 Ma, stranding the KPR as a remnant arc. This back-arc basin spreading stopped ~15 Ma, simultaneous with opening of the Sea of Japan. This also caused the northernmost IBM to collide with Honshu beginning about 15 Ma. Izu arc magmatism was minimal or even absent from 25 to 15 Ma during opening of the Shikoku Basin, and when it resumed the volcanic front was about 20 km west of its Oligocene position and has

remained there ever since (Taylor, 1992).
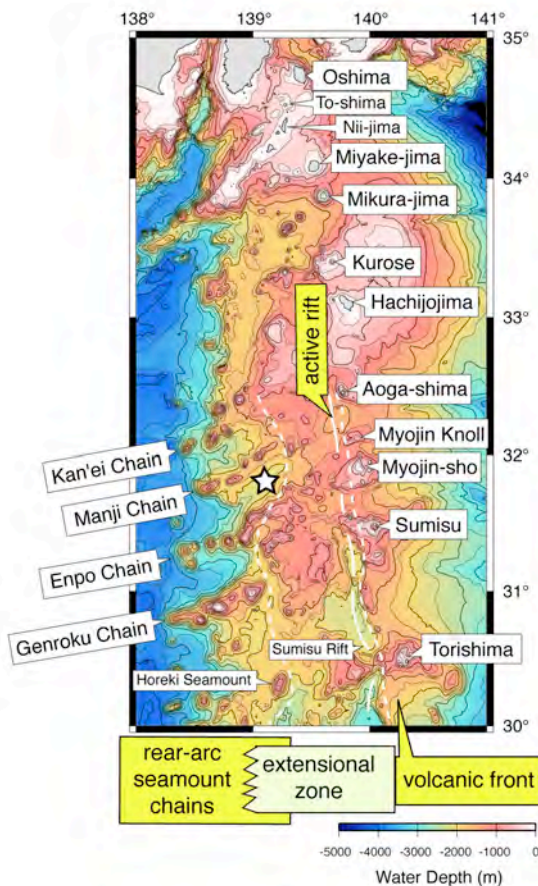
Figure 3. Location map. Primary proposed drill site (IBM-3C) is designated as a white star. We will refer to four tectonic settings of magmatism in this proposal: the <u>volcanic front</u> which includes the named volcanoes in Figure 2; <u>active rifts</u>, which are located just behind and between the volcanic front volcanoes; a 100 km-wide <u>extensional zone</u> that extends westward from the active rifts; and <u>rear arc seamount chains</u> including Enpo and Manji that start in the Shikoku (backarc) Basin west of the arc and continue into the extensional zone. We refer to magmatism in the active rifts and extensional zone as "rift-type", and magmatism in the rear arc seamount chains as "rear-arc type".

Neogene volcanism along the rear arc seamount chains and at adjacent isolated seamounts began at ca. 17 Ma, slightly before the Shikoku Basin ceased spreading, and continued until ca. 3 Ma (Fig. 4, Ishizuka *et al.* 1998; 2003b). The most obvious features of the Izu rear arc are the several ~50-km long en echelon chains of large seamounts striking N60°E. Basalts to dacites from 17 to 3 Ma have been dredged from many of the seamounts. Volcanism along these chains occurred sporadically along their total length, but lavas dredged from the top of seamounts in the western part of the chains are generally older than those to the east (Fig. 4). Rear-arc type volcanism ceased altogether at the initiation of rifting behind the volcanic front at ca. 2.8 Ma (Ishizuka *et al.* 2002). The eastern end of the chains lies above the middle row of Yamazaki and Yuasa's magnetic anomalies; the western end lies on Shikoku Basin crust. In some cases (e.g., Manji and Genroku), the seamount chains seem aligned with large volcanoes on the volcanic front (e.g., Aoga-shima and Sumisu, respectively) and with areas of thickened middle and total crust, but the association is imperfect. Consequently, it is not yet known whether similar features pre-date the Shikoku Basin or how the modern day along-strike variations in thickness and velocity structure of Izu arc crust (Kodaira *et al.*, 2007a,b) relate to the rear arc.

Several explanations of the seamount chains have been proposed. They might be related to compression caused by collision between the SW Japan and Izu arcs associated with the Japan Sea opening (Karig & Moore, 1975; Bandy & Hilde, 1983). Or they might overlie Shikoku Basin transform faults (Yamazaki & Yuasa, 1998). Or they may overlie diapirs in the mantle wedge such as the "hot fingers" proposed for NE Japan (Tamura *et al.,* 2002, Honda *et al.,* 2007).
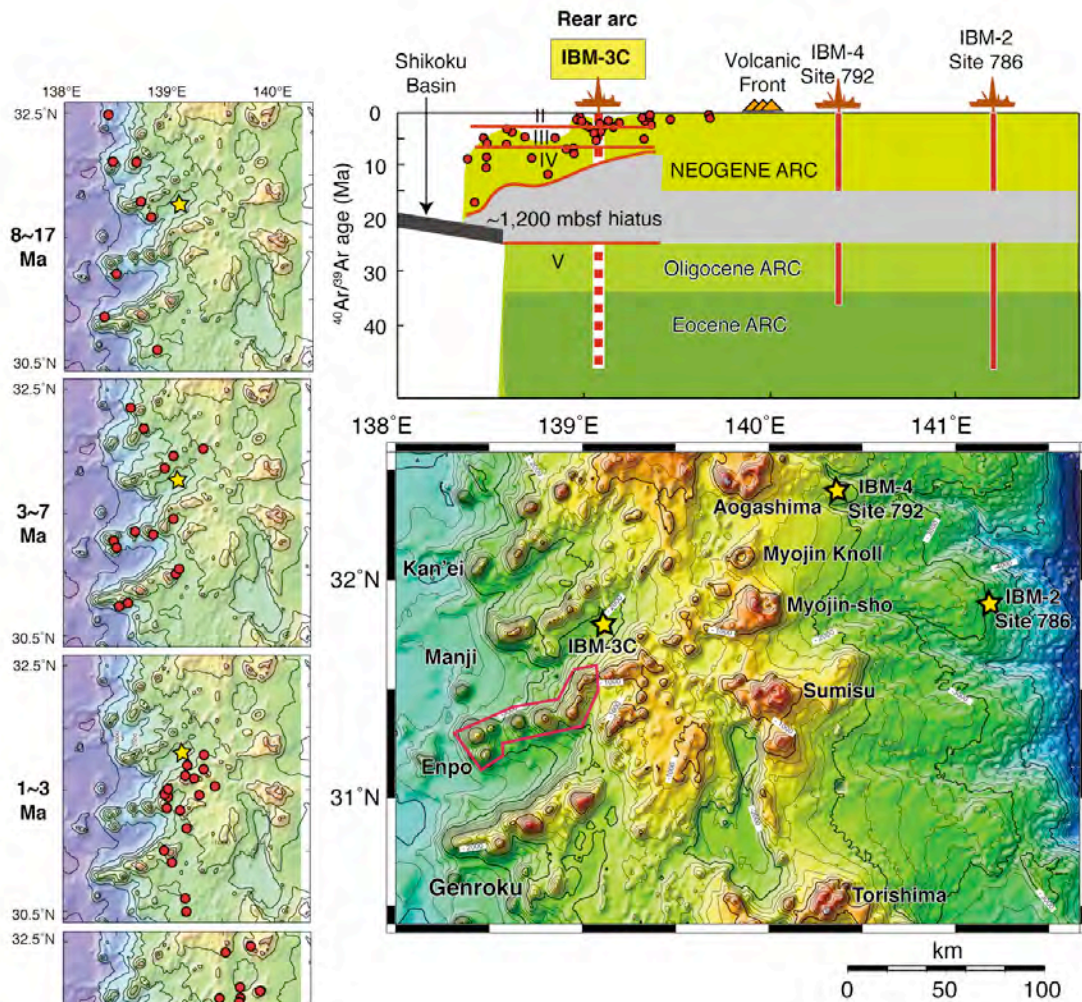
Figure 4. Temporal variation of locations of volcanism in the Izu-Bonin arc (left figures) and location vs. ^{40}Ar/^{39}Ar age plot for the rear-arc volcanics (upper right figure) (after Ishizuka *et al.,* 2003b). Sites 786 and 792 already have been drilled about 1000 m through volcaniclastic sediment into Eocene basement. The samples shown by red dots in the <1 to 3 Ma boxes have "rift-type" compositions; those in the 3-17 Ma boxes have "rear-arc type" compositions shown in Figures 5-8. Dating of dredged lavas provides only a minimum age for the edifice, and cannot constrain relative eruption rates which can be estimated from sedimentation rates. The data from Enpo chain, just south of the proposed drill site and enclosed by red lines, are shown in the geochemical figures with other rear arc chains. They show the essential differences between the volcanic front, rift-type, and rear-arc type magma compositions. Proposed drill sites are shown by yellow stars. Roman numerals show seismic units (Section 7.1). The estimated depths of Neogene/Paleogene boundary at IBM-3C is ~1,200 mbsf (Section 7.3, Table 1).

A less obvious aspect of the Izu rear arc is the 100-km wide extensional zone that lies between the Quaternary volcanic front and the eastern end of the seamount chains (Fig. 3). This is where all <3 Ma rear arc volcanism has occurred, mostly in small cones or ridges including several km-deep rift grabens just behind large volcanoes on the volcanic front. These volcanic rocks differ in composition from those of the rear arc seamount chains which predate them. Post 3 Ma volcanism behind the volcanic front has been "rift-type" which is bimodal in silica and

distinguishable in trace element and isotope ratios from both the volcanic front and across-arc chains (Figs. 7 and 8). It is not simply intermediate in composition as it is in location (Hochstaedter *et al.*, 2001; Ishizuka *et al.,* 2003a). The differences have been attributed to some combination of a transition from flux to decompression mantle melting as arc rifting commences, a change in the character of the slab-derived flux, or a change in the mantle (Hochstaedter *et al.,* 1990a,b; 2001; Ishizuka *et al.,* 2003, 2006). Thus two different magmatic suites occur in the Izu rear arc: 'rear-arc type' from 17 to 3 Ma, and 'rift-type' from 3 to 0 Ma. Neither one formed in a backarc basin.

Large basalt-dominated volcanoes are spaced at ~100 km intervals along the Quaternary volcanic front, and correlate with thickened portions of arc middle crust and perhaps total crust (Kodaira *et al.,* 2007a, b). Rhyolite-dominated calderas lie between the large volcanoes of the volcanic front north of 31°N, and there are gaps of 50-75 km with no volcanic edifices. Similar wavelength along-strike variations in the thickness of middle and total crust also have been imaged in the rear arc from 28 to 32°N (Kodaira, in preparation). Crustal development in the rear arc appears similar to the volcanic front, although no Quaternary volcanoes exist in the rear arc and Neogene chemical compositions show clear across-arc variations. Thus the magmatic evolution of the rear arc is vital to understanding the history and composition of Izu arc crust.

Site 697 lies directly above the middle row of N-S magnetic anomalies, and near two large seamounts of the Manji Chain. Therefore it may coincide with an area of thickened crust behind Aogashima. It is also within 10-15 km of several <3 Ma cones east of the Enpo Chain. Therefore, it should have received volcaniclastic sediment both from the small rift-type cones that were active in the Plio-Pleistocene and the rear-arc type seamounts that were active in the Miocene. Finally, it should overlie igneous basement of the Oligocene arc.

SSEP asked whether Izu backarc basement rocks might be exposed in the Mineoka-Setogawa Complex (MSC) on Honshu (*e.g.* Hirano *et al.,* 2003; Taniguchi & Ogawa, 1990; Arai, 1991; Ishiwatari, 1991; Shiraki *et al.,* 2005). They might be but the provenance of the MSC is quite unclear. It would be unreliable to assume that they belong to the Izu rear arc and another plate might be required to explain them (*e.g.* Ogawa & Taniguchi, 1987, 1988; Sato *et al.,* 1999; Ogawa & Takahashi, 2004). The MSC contains picrite, tholeiite, meimechite, and boninite-like rocks and their diversity and origin are one of scientific targets of IFREE groups (Sato *et al.,* Japan Geoscience Union 2007, abstract). Thus, if drilling discovers similar lithologies in the Izu

rear arc, then that would motivate the petrological studies and would explain the origin of the MSC. Saying more is beyond the scope of this proposal, but we have addressed the topic in an accompanying reply to SSEP.

3. THE TECTONIC SETTING OF DIFFERENT MAGMAS; ARC-FRONT (ENRICHED AND DEPLETED), REAR-ARC AND RIFT TYPE

Basalts and andesites of the rear arc seamount chains are enriched in alkalis, high-field-strength elements (HFSE: e.g. Nb, Zr) and other incompatible elements, but have less enriched Sr, Nd, Hf, and Pb isotopes compared to the volcanic front (Hochstaedter *et al.,* 2000; Ishizuka *et al.* 2003a; see Figs. 5-8). Thus, we can clearly identify different magmatic sources (front vs. rear-arc vs. rift-type) using geochemical criteria such as these.
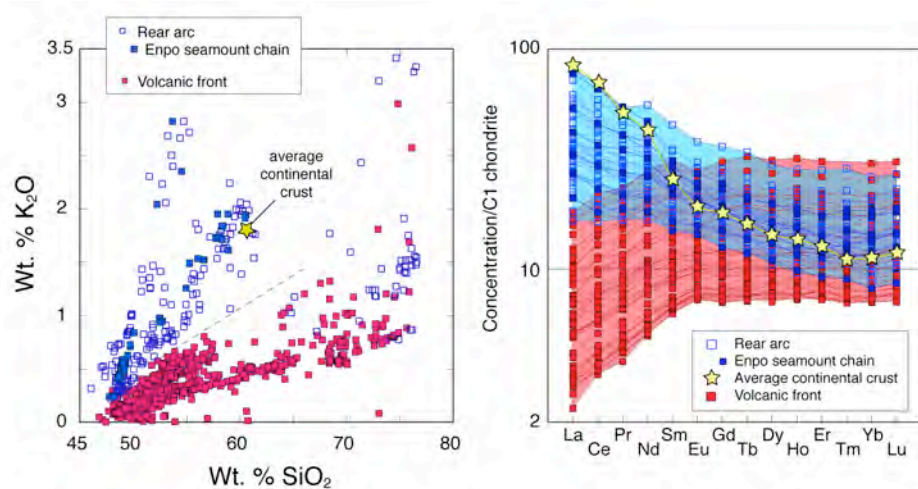
Figure 5 (left). K_2O vs SiO_2 (wt %) of lavas of the volcanic front (Oshima, Miyake-jima, Mikura-jima, Hachijojima, Aoga-shima, Myojin Knoll, Sumisu and Torishima), the rear arc (Kan'ei, Manji, Enpo, Genroku, Horeki) and average continental crust (Rudnick & Gao, 2003). Data from Tamura & Tatsumi (2002) and references therein, Machida & Ishii (2003), Tamura *et al.* (2005, 2007), Machida (unpublished data). Data for the Enpo chain, just south of IBM-3, are shown in solid blue color and are similar to other rear-arc type magmas. No field is shown for rift-type magmas (< 3Ma) in Figs. 5-6 for reasons of clarity. Discriminant diagrams are shown in Figs. 7-8.

Figure 6 (right). Chondrite-normalized rare earth element (REE) abundances in the volcanic front and the rear-arc basalts and andesites and average continental crust (Rudnick & Gao, 2003). Data of the volcanic front (Oshima, Miyake-jima, Hachijojima, Aoga-shima, Sumisu, Torishima) from Taylor & Nesbitt (1998) and Tamura *et al.* (2005, 2007). Rear arc data (Kan'ei, Manji, Enpo, Genroku, Horeki) from Ishizuka *et al.* (2003), Hochstaedter *et al* (2001), Machida & Ishii (2003), Ishizuka (unpublished data). Data for the Enpo chain, just south of IBM-3, are shown in solid blue color and are similar to other rear-arc type magmas. Rear-arc patterns are similar to average continental crust in heavy REE.

Figures 5 and 6 show K_2O and REE differences between the arc-front and rear arc areas. A striking characteristic of orogenic andesites and associated rocks within many volcanic arcs of modest width is the consistent increase of their incompatible element concentrations, notably K_2O, away from the arc front (Gill, 1981). Basalts and andesites along the Izu-Bonin volcanic front have significantly less K, U, Th, and lower Th/U than those from the rear of the arc (Fig. 5), which can be monitored using the gamma logging tool. Rocks from the frontal volcanoes are

low-K as defined by Gill (1981), but the rear-arc type lavas are medium- and high-K. Basalt and andesite magmas at the front of the Izu-Bonin are so depleted in K_2O and other incompatible elements that they are dissimilar to the "average continental crust" of Rudnick & Gao (2003).

Figure 6 shows a chondrite-normalized REE plot for the Izu-Bonin basalts and andesites. All basalts from arc-front volcanoes are strongly depleted in the more incompatible light rare earth elements (LREE) compared with the middle and heavy REE (MREE and HREE). In contrast, basalts and andesites from rear arc sites are enriched in the LREE and MREE compared with the HREE (Fig. 6). Thus, rear arc compositions are closer approximations to the average continental crust of Rudnick & Gao (2003). Although similarly enriched magmas also erupt at the volcanic front in the vicinity of Io Jima, the large isotopic differences between the two allows them to be easily distinguished (Figs 7 and 8).
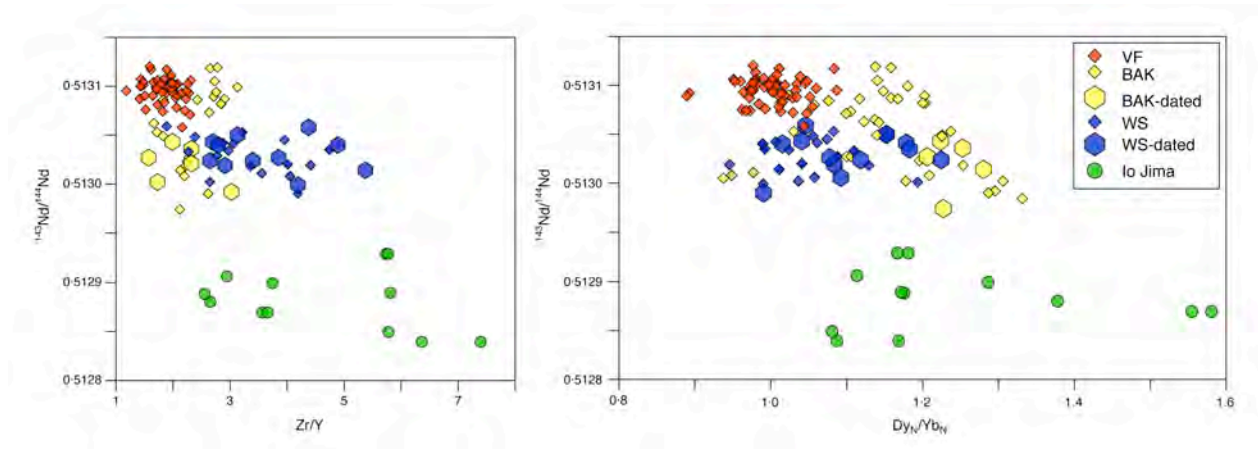
Figures 7 (left), **Figure** 8 (right) Discrimination diagrams between proximal arc front (VF), enriched arc front (Io Jima), rear-arc type (WS) and rift type (BAK). Dated symbols are enlarged. Some overlap between undated WS and BAK may reflect the somewhat subjective distinction between "seamounts" and "knolls". The latter are smaller, farther east, and more mafic.

Because the primary objective of the proposed site is to document and interpret temporal changes in Izu rear arc magmatism, it is important to demonstrate that locally-derived rear arc volcaniclastic rocks can be distinguished from those sourced at the volcanic front but deposited in the rear arc, and that rear arc magmas have temporal diversity. Figure 7 is one example of how this can be done. Nd (and Hf) isotopes cleanly separate rocks from the adjacent volcanic front, distal volcanic front (near Io Jima), and "rear-arc" (Western Seamount Chains, 3-17 Ma). Although basalts from the "rift-type" Backarc Knolls (0-3 Ma) overlap both the volcanic front and western seamounts in Nd isotopes, most of them can be separated by combining these isotopes with Zr/Y ratios or the shape of REE patterns (Figs. 7, 8). None of these geochemical criteria are much affected by the kind of alteration expected at the site and could be obtained

from pyroxenes in the worst case. In addition, sedimentological criteria also will help to distinguish proximally-derived from distally-derived units.

Note that complete geochemical distinction between "rear-arc" and "rift" type basalts is less a requirement for successful drilling than part of the hypotheses to be tested. What caused the change? Was it uniform in space and time? How does the change relate to the evolution of mantle melting styles that eventually leads to backarc basin basalts (BABB) such as in the Mariana Trough? The figures demonstrate diversity behind the front, but only drilling can reveal the interplay of these magma types with time.

The kind of across-arc asymmetry shown in Figs. 5-8 can remain for millions of years (e.g., Tamura *et al.,* 2002; Hasegawa & Nakajima, 2004; Honda & Yoshida, 2005). Data from ODP Legs 125 and 126 show a temporal variation in volcanic front magmas (Gill *et al.,* 1994; Bryant *et al.,* 2003; Straub, 2003) but the temporal variation within rear-arc type magma chemistry from 17 to 3 Ma, and within rift-type chemistry during the last 3 m.y. is unknown. Nothing at all is known about rear arc volcanism in the Paleogene (Fig. 4). Were the differences between the volcanic front and rear arc in the Neogene presaged by differences in the Oligocene? And what are the relative effects of steady-state subduction versus episodic events such as arc rifting?

Because the across-arc variation in Figs 5-8 is based on dredge samples (Fig. 4), it is unclear whether it is purely spatial (across-arc variation in a strict sense), just temporal, or a combination of the two. The drilling record will clarify whether or not temporal variation occurred in a specific location, and constrain the origin of the observed variation. Drilling at our proposed site will test whether the change from rear-arc type to rift-type was abrupt or gradual, whether rift-related magmas changed with time (as observed for rifted continental margins), whether there is a fundamental change in mantle sources at about this time, and whether the composition of felsic magmas (potential crustal melts) changed at this time across the arc. We hypothesize that intra-crustal differentiation (formation of felsic volcanics and tonalite) occurs especially during rifting prior to spreading in both the volcanic front and rear arc, and that the eventual sub-arc mantle is depleted during spreading. Only by drilling the rear arc can we test these hypotheses by comparing magmatic records for both places.

In summary, a major effort has been made in the forearc region of the IBM system where studies of tephra, volcaniclastic turbidites, and basement rocks have established a history that shows the major influence of tectonic events such as backarc basin formation. However, this is

solely the history of the volcanic front, not the entire arc. Figure 1 shows that the rear IBM arc overlies seismically "typical" middle crust, and that the crust beneath the rear arc is volumetrically equal to that beneath the volcanic front alone. While ODP Legs 125 and 126 gathered an enormous amount of data relating to the forearc and volcanic front, we remain ignorant of the volumetrically significant portion of the arc represented by rear arc activity. IBM-3C targets this rear arc region. The rear arc magmatic history is essential in mass balance and flux calculations for crustal evolution, in establishing whether and why arc-related crust has inherent chemical asymmetry, in testing models of mantle flow and the history of mantle depletions and enrichments during arc evolution, and in testing models of intra-crustal differentiation.

4. PRIMARY HYPOTHESES TO BE TESTED

The primary objective of IBM-3C is to test three pairs of alternative hypotheses about crustal genesis and mantle evolution:

1. Geochemically asymmetric crust, which is most like "average continent" in the rear arc, is either (i) a fundamental trait of crust in oceanic arcs that is produced in the steady state throughout arc history from Paleogene inception, or (ii) a secondary trait that develops only after backarc spreading (Fig. 9);

2. Intra-crustal differentiation amplifies this asymmetry (i) continuously as a steady state process, or (ii) mostly during non-steady state events such as arc rifting.

3. After or near the cessation of the Shikoku Backarc Basin opening, rear-arc magmatism either (i) started from the western end of the rear arc seamount chains and migrated east, or (ii) started at the same time along the length of the rear arc seamount chains, but ended from west to east (Fig. 4).

Figure 9 illustrates the alternatives for hypothesis 1 that can be tested by drilling. We call them the "From-the-Beginning" and "From-the-Middle" alternatives. Colors in Fig. 9 simplify chemical differences between the volcanic front and rear arc that are predicted by these two hypotheses. During steady-state arc growth, crust develops that is "continental" in velocity structure and seismically similar beneath both the volcanic front and rear arc but is heterogeneous in chemical composition. Magmas at the volcanic front are rich in fluid-mobile recycled slab components (e.g., Sr, Pb, U) that swamp the mantle yet these magmas are so depleted in mantle-derived fluid-immobile elements (e.g., Nd, Hf, Nb) that they are dissimilar to "average continental crust" in detail. This is less true in the rear arc where the less depleted mantle,

diminished slab fluid signature, possible addition of melt from subducted sediment, and lower degrees of mantle melting create crust that is more typical of the continents and allow the temporal history of the mantle source to be tracked more easily. Although the asymmetry is known in general in Izu from Neogene volcanic rocks obtained by dredging, the best way to assess its variability during the Neogene, and to learn how far back in arc history it extends, is to obtain a temporal record by drilling the volcaniclastic sediments in the rear arc. The alternative hypothesis is that the asymmetry is only true in the Neogene Izu arc and that magmatism was uniformly less depleted and/or uniformly rich in fluid-mobile recycled slab components (e.g., Sr, Pb, U) during the Oligocene and Eocene. The latter would indicate that the subduction parameters that cause geochemical asymmetry differed in early arc history. These two hypotheses, "From-the-Beginning" and "From-the-Middle", and others, can be tested only by recovery of the Eocene-Oligocene tephra and turbidites in the rear arc.
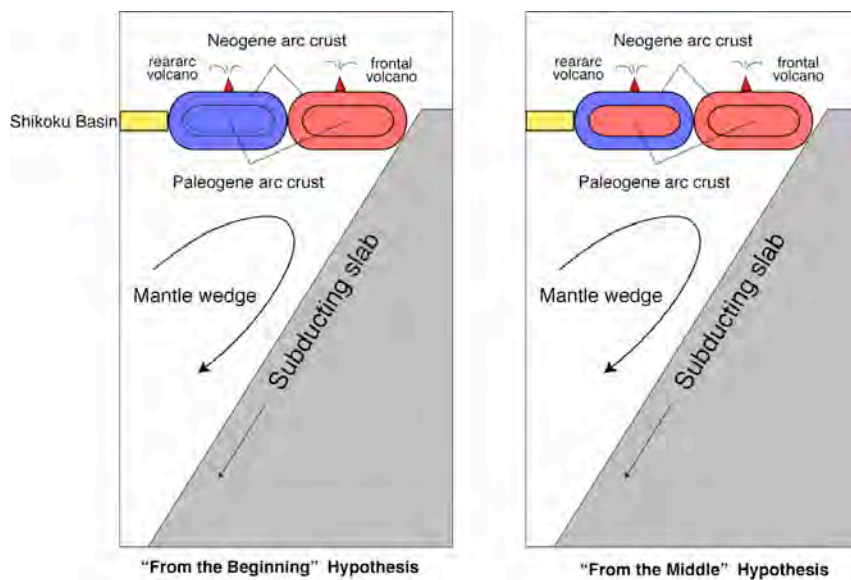
Figure 9. Crust develops that is "continental" in velocity structure and seismically similar beneath both the volcanic front and rear arc but is heterogeneous in chemical composition, schematically shown in blue and red. Red shows crust and mantle that are rich in fluid-mobile, recycled slab components but also strongly depleted in mantle-derived fluid-immobile elements. Blue shows those areas where the diminished slab signature and lower degrees of mantle melting, create crust that is more typical of the present-day overall continent composition. The "From-the-Beginning" hypothesis shows this heterogeneity established from the Eocene Arc inception through to the Neogene. The "From-the-Middle" hypothesis shows this heterogeneity only developed after the cessation of the Shikoku basin (i.e., only in the Neogene).

The second hypothesis is that non-steady-state events play a major role in the evolution of arc crust. One alternative is that the intra-crustal recycling which creates felsic magmas, possibly forming the distinctive 6.0 km/sec "tonalitic" middle crust, is heightened during periods of rifting preceding backarc spreading (e.g., since 3 Ma), and that this recycling amplifies the across-arc chemical asymmetry. We know from ODP Legs 125 and 126 that the current phase of arc rifting produced a marked increase in felsic magmatism at the arc front, and we know from dredging

that there are along-arc and across-arc differences in the chemical composition of tonalites and rhyolites, but only 697 drilling can test this hypothesis by providing a stratigraphic record of felsic magmas across the arc, especially in the rear arc. The 7 Ma tonalities from Manji Seamount provide a comparison between extrusive and intrusive rear-arc felsic rocks.

The third hypothesis is that the origin of the Izu rear arc seamount chains can be related to mantle convection patterns (hot fingers) (*e.g.* Tamura *et al.,* 2002; Honda *et al.,* 2007). Numerical simulations of small-scale convection under island-arcs (Honda & Yoshida, 2005) suggest that a roll (finger)-like pattern of hot and cold anomalies emerges in the mantle wedge starting from the back-arc side of the rolls. Thus the small-scale convection hypothesis predicts that the rear-arc magmatism migrated from west to east.

5. ROAD MAP FOR TESTING HYPOTHESES

Testing these hypotheses requires obtaining a temporal record of across-arc variation in magma composition from Eocene to Neogene time. This should enable (a) identification of temporal changes of basaltic magma chemistry and interpretation of the source processes, and (b) identification of temporal variation of intermediate and felsic magmas and interpretation of crust-level differentiation processes. This information is in hand for the volcanic front but missing for the rear arc, which overlies the majority of crust that is "continent-type" in composition. It is also needed in order to compare these characteristics to what is already known about these parameters for the volcanic front. Specifically, our objectives are to establish the temporal history of across-arc variations during five time periods that stand out in the rear arc evolution:

1. 3 Ma to the present. We will determine whether rear-arc and rift-type magmatism have overlapped since the onset of rifting at 3 Ma, and whether rift-type mafic and felsic magmatism changes during that time (see Fig. 4);

 2. 9 to 3 Ma. We will also establish whether rear arc magmatism changed with time and how felsic rear arc magmatism is distributed through time and compares in composition between the rear arc and volcanic front;

3. 17 to 9 Ma. We will determine whether rear arc magmatism migrates from west to east and the rocks of this age are missing in the proposed site (see Fig. 4);

4. 25 to 17 Ma. We will determine whether volcanism stopped in the rear arc during opening of the nearby Shikoku Basin as it did at the volcanic front;

5. <u>>25 Ma.</u> We will determine whether rear arc magmatism changed with time, whether Oligocene rear arc and frontal arc magmas differed in the Oligocene, whether there were across arc variations in even at the initial stage of arc development, and especially whether felsic materials differ in their abundance, character, and mode of origin during arc evolution.

These determinations will be made using standard igneous geochemical tools applied to volcaniclastic materials (and any lavas encountered). These tools include bulk rock major, trace element, and Sr-Nd-Hf-Pb isotope chemistry, and the same applied to glass shards, minerals, and their melt inclusions. Some of these tools (e.g., REE+HFSE trace elements and Nd-Hf isotopes, especially in minerals likes pyroxenes) are not much affected by the level of alteration expected (see Section 7.5). Geochronology is essential and will be established using paleontology, paleomagnetism, Ar-Ar, and U/Pb dating of zircon in felsic materials. The provenance and mode of deposition of volcaniclastic sediments also is essential and will be established by examining the morphology of grains and the overall character of sedimentary units (e.g. Bednarz & Schmincke, 1994; McPhie & Allen, 2003).

These five objectives will establish the effects of a fundamental characteristic of island arc magmatism (across-arc geochemical variations) on crustal production in that environment, and will constrain the fundamental reasons for the variations themselves. This temporal record is also necessary to assess the evolution of the mantle wedge and slab, to evaluate processes of intra-crustal differentiation, and to calculate mass balance and flux models of crustal growth.
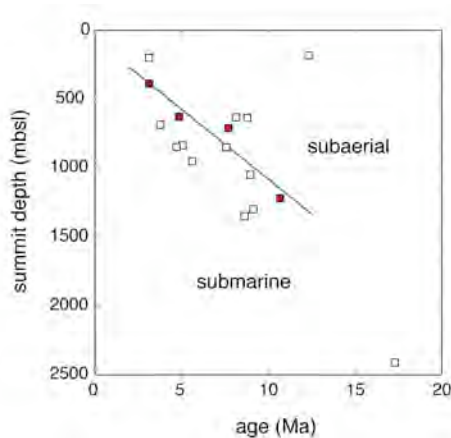
6. ADDITIONAL DRILLING DISCOVERY OPPORTUNITIES

6.1. Physical volcanology

As noted in the Introduction, most rocks in the upper crust of arcs are submarine volcaniclastics. Previous studies of the IBM have revealed the importance of thick pumice-rich pyroclastic units as a component of rift basins and arc-front volcano aprons (e.g. Nishimura *et al.* 1992, Tani *et al.,* 2007). Their ultimate origin as the products of explosive eruptions is widely accepted. However, it is less clear how to distinguish eruption-fed products, strictly contemporaneous with an eruption, from those generated by re-sedimentation of temporarily stored pumiceous facies. A further source is the collapse of volcaniclastic aprons, recently recognized as a major sediment source in the Miocene arcs of the North Island of New Zealand (Allen, 2004). Also unclear is how to distinguish the products of totally submerged explosive eruption plumes, versus plumes that break the water-air interface, versus plumes that are totally subaerial (e.g. McPhie & Allen

2003). Data from well preserved examples where the context is well constrained, such as Izu, have the potential to greatly refine our currently primitive criteria, and test some inferences based on older foldbelt examples. We will attempt to distinguish not simply the compositions of source volcanoes for rear arc pyroclastic components but also their proximity, vent setting, and whether they were eruption-fed or re-sedimented. We note that these methods led to the serendipitous discovery of a new type of deep seafloor pyroclastic eruption during ODP 126 (Gill *et al.,* 1990), and we believe that more rear arc drilling will lead to more such discovery.

Drilling IBM-3C will test whether or not there is asymmetry in the physical volcanology of arcs as well as in magma compositions, how the differences evolve temporally, and how the differences can be applied to studies of paleo-arcs worldwide. Plausible cross-arc influences on the physical volcanology of arc volcanoes include:

(1) Magma composition: spatial and temporal gradients in magma compositions, especially SiO_2 and volatiles, ought to be accompanied by variations in eruption styles and volcano types. Higher SiO_2- and volatile-magmas favour powerful explosive eruptions and the production of diverse, widely dispersed pyroclastic facies, as well as lavas and domes. On the other hand, lower SiO_2- and volatile-poor magmas favour lavas or domes and subordinate, weakly explosive eruptions.

(2) Vent environment: vents for rear arc volcanoes are likely to be submerged (Fig. 10). In contrast, vents for arc front volcanoes can be either submerged (particularly in the early stages of arc evolution) or subaerial. The presence of water greatly alters the dynamics of eruptions, and hence also the products. Deep water may suppress explosive activity whereas shallow water may introduce the possibility of magma-water interaction and any water promotes quench fragmentation.


Figure 10. Summit depth (mbsl) vs. age (Ma) of rear-arc type volcanoes. The red symbols show flat-topped rear arc volcanoes, suggesting that their summits reached sea level. There is a positive and linear correlation between the age and depth of flat-topped volcanoes, suggesting that rear arc volcanoes submerge at a constant rate (~100m/Ma) (Ishizuka in press). Thus rear arc volcanoes deeper than the flat-topped volcanoes probably always were submarine (<500 mbsl), and we can expect volcaniclastic sediments from both subaerial and submarine eruptions.

(3) Presence or absence of wet sediment: ancient successions show that magmas intrude, rather than erupt, in submerged settings where wet sediment has accumulated (e.g. Skilling *et al.*, 2002). The products are sill-sediment complexes and/or cryptodome complexes. In some cases, these intrusive complexes evolve into volcanoes, and in other cases, there is no such evolution. The

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formation of sill-sediment and/or cryptodome complexes is predicted to be a common feature of the rear arc in contrast to the arc front, where they may be present but largely limited to the earliest stages of arc evolution.

6.2. Microbiology

This site represents a potentially exciting opportunity to study the microbiology of the deep subseafloor in the opinion of microbiologists including K. Edwards (USC) and M. Schrenk (CIW) with whom we have consulted. Of all IODP sites on the horizon, this one should have the most abundant vesicular, basaltic glass. Such glass has extremely large amounts of reactive surface area and, based on what is known from dredged lavas, should have high levels of the oxidant Fe^{3+} and the nutrient P (certainly relative to MORB lava). The site would also provide new P,T,X conditions in which to explore for subseafloor microbial ecology and biogeochemistry (20-50 MPa, $\leq 100^{\circ}$C, high Ca-Cl_2 pore water). We predict relatively unaltered glass in at least the top 600 m, quite altered glass below 1500 m, and increasing alteration in between, based on what was found at ODP Sites 792 and 793 in the Izu forearc. There, the lower depth corresponded to a
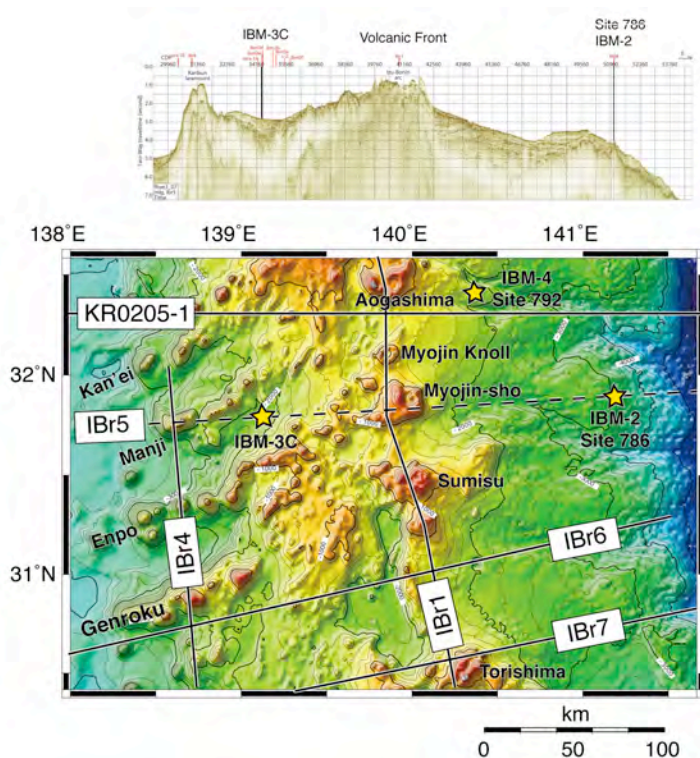

marked change in pore water chemistry (increased Ca and inorganic C; decreased Si, SO_4, and Mg) and decrease in porosity (Egeberg, 1992). At this stage, no microbiologist has joined this proposal as Co-Proponent, and it is uncertain whether the level of microbiological activity would be abnormally high (because of bio-availability of oxidants and nutrients) or low (because of decreased permeability and increased rock/water equilibration). However, we feel that this drilling objective should continue to be explored at this site.

Figure 11. MCS profile IBr5 (JAMSTEC, 2007), uninterpreted time-section (upper). CDP interval = 12.5m. Vertical exaggeration ~10. Locations of multi-channel seismic reflection (MCS) data (lower).

6.3. Tonalite emplacement, mineralization, and exhumation

The proposed site lies below the only known submarine example of porphyry copper mineralization in a rear arc – at Manji Seamount (Ishizuka *et al.,* 2002). Rounded cobbles of chalcopyrite-bearing quartz-magnetite stockwork and 7 Ma gabrroic to tonalitic plutoninc rocks have been dredged from its flat-topped, subaerially-eroded summit. Shinkai 2000 diving survey discovered exposures of classic potassic and propylitic alteration indicative of activity of hyper-saline fluids, and closely-associated plutonic rocks. The plutonic rocks plot within the WS fields of Figs. 5-8 and are examples of the rear-arc type of tonalitic middle crust referred to above. Because rounded cobbles occur on the seamount's flanks, clasts and heavy minerals (sulfides) also may be found at our proposed site. If so, then we might discover a history of rear-arc tonalite intrusion, mineralization, exhumation and submergence.

7. PLANNING AND LOCATION OF SITE IBM-3C
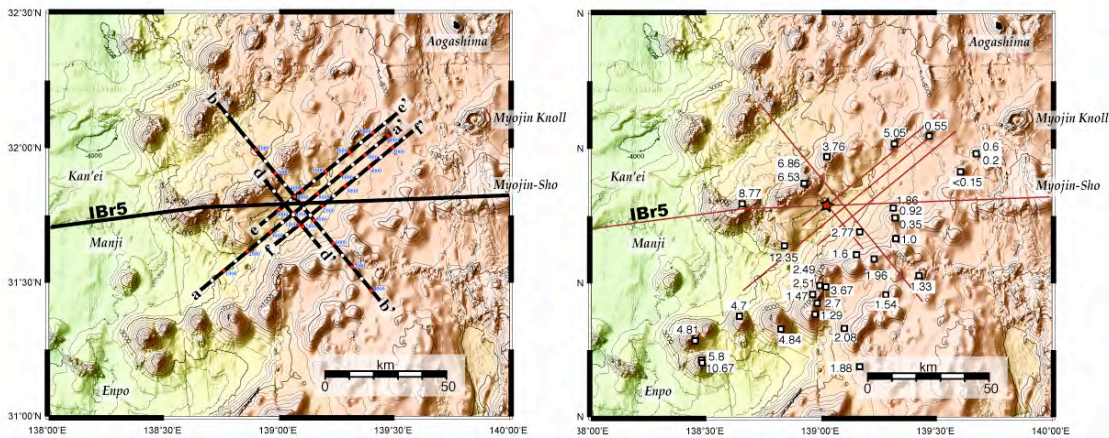
Figure 12. (Left) Locations of the new six MCS (multi-channel seismic) profiles near IBM-3C. The intersection of d-d' with e-e' is thought to be the best site for drilling. **(Right)** Ar-Ar and K-Ar ages (Ma) of dredged samples near IBM-3C (Ishizuka *et al.*, 2003). Rear-arc seamounts northeast-west of the drilling area are older than the seamounts on the southwest-east side, and thus the drilling point is chosen as the intersecting point closest to the older volcanoes, having lower heat flow and cooler temperatures.

Based on site-survey multi-channel seismic (MCS) reflection data, the site location has been adjusted to be largely isolated from the volcanic front (VF) topographically by having a large edifice or trough or both in between. Because complete isolation from the VF is not possible, we will use a combination of rock and mineral chemistry (Figs. 5 to 8), clast morphology, FMS (formation microscanner) logging, and general sediment character to identify and exclude VF-sourced material. We have chosen the single best site based on (i) existing information from dredges and bathymetry (Fig. 4); (ii) maximum protection from VF mass wasting, (iii) likelihood

of receiving sediment from as much rear arc diversity as possible (rear-arc seamount chains and rift-type knolls), (iv) clearly located east of the eastern extent of the Shikoku Basin as defined by magnetic lineations (Okino, personal communication), (v) overlying seismically "typical" middle crust with a low velocity gradient (Fig. 1), and (vi) potentially accessible Oligocene basement.

7.1 Detailed descriptions of the stratigraphy of the sedimentary deposits and basement from multi-channel seismic profiles

Since the last submission of this proposal, Kodaira, Yamashita, Tamura, and Gill have revisited our interpretation of six low-fold multi-channel seismic reflection (MCS) profiles intersecting in the area of the possible drilling target (IBM-3C). They were obtained during JAMSTEC cruise KY06-14 in December 2006 and JAMSTEC cruise KR07-09 in June and July 2007 (Figs. 11 & 12). Our proposed site is at the intersection of lines IBM3d (Fig. 13), IBr5 (Fig. 14), and IBM3e (Fig. 16); see composite in Fig. 17. These profiles between Manji and Enpo seamount chains enabled us to determine 3D structural images of sedimentary deposits in the targeted area. This seismic information and ages of the rear arc seamounts allow us to determine the age and thickness of each layer, and the best drilling site. Many sediment layers are laterally discontinuous. This lateral heterogeneity suggests the proximal nature of these deposits which are similar to those of the uplifted Izu rear-arc, i.e., in the Mio-Pliocene Shirahama Group of the Izu Peninsula (e.g., Tamura *et al.,* 1991; Cashman & Fiske, 1990).
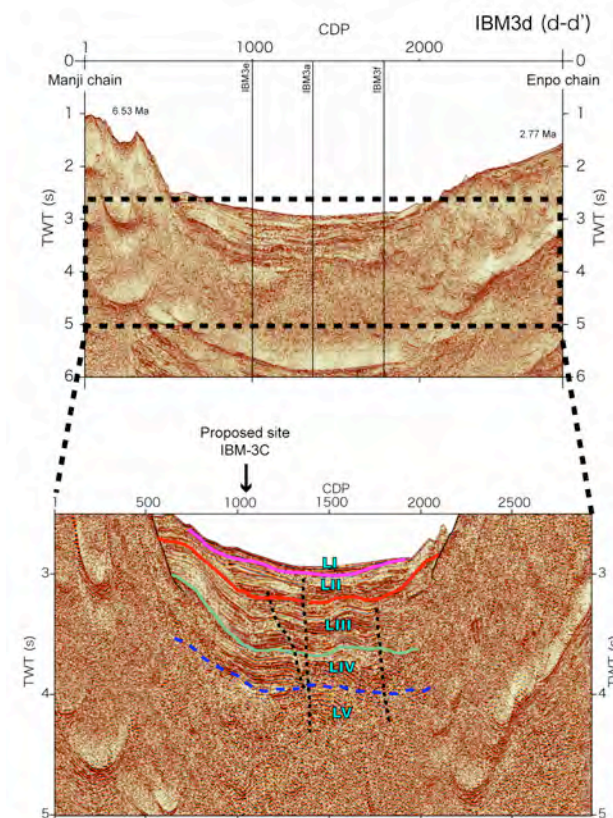
Figure 13. Upper: seismic profile in line IBM3d (d-d'). Lower: interpretation of expanded profile around site IBM-3C. Pink line shows the boundary between seismic unit LI and LII. Red line indicates the boundary between seismic unit LII and LIII. Green line indicates the boundary between seismic unit LIII and LIV. Blue dotted line shows the boundary between seismic unit LIV and LV. Black dotted lines indicate faults. Black solid lines show the edge of the seamounts around site IBM-3C.

The reflector sequence can be divided into four sedimentary units (LI, LII, LIII, and LIV) and acoustic basement (LV). Ishizuka *et al.* (2003) reported Ar-Ar ages of dredge samples

from nearby seamounts (Fig. 12). We can estimate the age of the units by combining onlapping relationships and Ar-Ar ages. We describe these characteristics from top to bottom as follows.

Uppermost seismic unit LI is parallels the seafloor and is estimated to be channel deposits of recent age. It is extremely thin and onlaps seismic unit LII. It is the unit most likely to be derived extensively from the volcanic front, especially Myojin Knoll. The top of seismic unit LII has strong amplitude and is subparallel to LI. Unit LII dips southwestward and crops out in line IBM-3a. The lower part of this layer is often interrupted and deformed by faulting. It is well-bedded with high-amplitude reflectors and a transparent portion. Its thickness is almost constant (> 0.5 s) along each MCS line. It onlaps Manji seamount (6.5-6.9 Ma) to the north, but sediments from a 1.96 Ma seamount overlie the top of LII in line IBM-3b to the south. In line IBM-3d (Fig. 13) the boundary between LI and LII lies on the basement of a 2.77 Ma seamount. Consequently, seismic unit LII accumulated after ~3 Ma and coincides with backarc extension and eruption of rift-type magmas to the east and south of the proposed site. Like unit II, unit III is well-bedded and laps onto seamounts of the Manji Chain (Fig. 13). The interface between seismic units LII and LIII crops out on lines IBM-3a and IBr5 (Fig. 14). Thus unit LIII seems to be 3-6.5 Ma and to coincide with development of the Manji and Enpo Chain seamounts in the vicinity of the proposed site

Seismic unit LIV also is well-bedded and almost subparallel to LIII. Its upper part laps onto nearby Manji Chain seamounts in lines d, e, and IBr5. Its lower part is less clear: it may onlap or be intruded by the seamounts. Overall it is more strongly faulted than the overlying units, and is characterized by inhomogeneous, discontinuous reflectors of low frequency. From the seismic profile of IBr3 (Fig. 14), the boundary between LIV and LV could be as young as 9 Ma.

The age of unit V is important but uncertain. The boundary between LIV and LV has high relief that we attribute in part to erosional relief. Unit V uniformly lacks the well-bedded character of the overlying units, and its chaotic, discontinuous reflectors have low to medium amplitude. We attribute these features to greater lithification or the presence of lava. The simplest interpretation of all these features is that unit V is the Oligocene basement, and the boundary above it represents the unconformity developed during the Shikoku backarc basin formation.

The on-lapping relationships of Unit V are uncertain. It appears intruded by seamounts of both chains on lines d and e. Because western seamount volcanisms become younger toward the east, we hypothesize that the unconformity does too (Fig. 4). If so, unit V at the proposed site would

be Oligocene basement. However, this is a hypothesis to be tested by drilling and, therefore, it is uncertain from seismic profiles whether the deep objectives of our proposal can be achieved in one site. However, the relationships between volcanoes and their basements discussed in 7.2 suggest that Oligocene basement may be uplifted beneath these Miocene volcanoes.
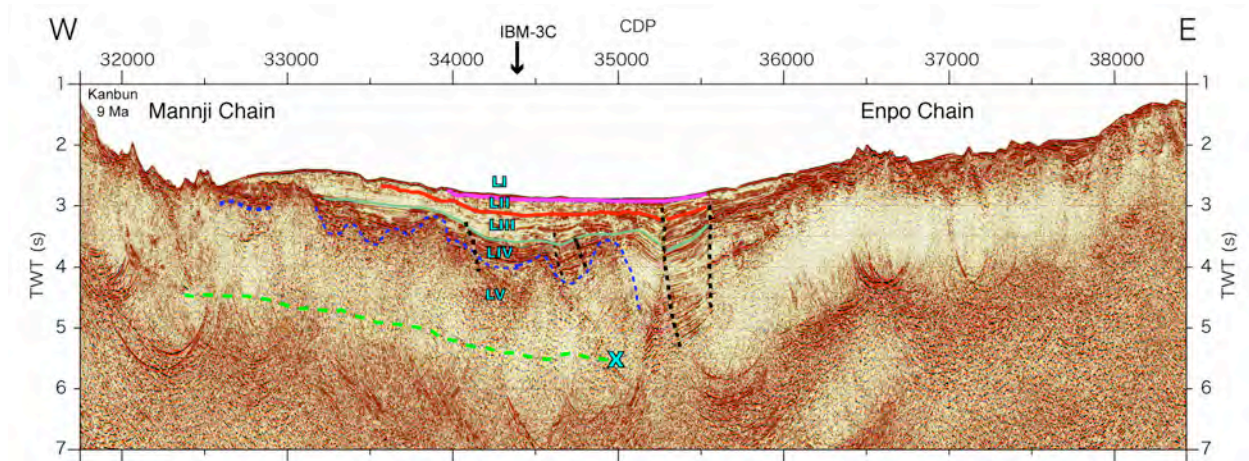
Figure 14. Seismic profile in line IBr5 with interpretation. Colored lines as in Fig. 13. Black dotted lines indicate faults. An eastward dipping reflector (X) is recognized beneath unit LV and is also observed in line IBr4 (Kodaira, personal communication). This might be the contact with Eocene basement lavas. We estimate the depth of the reflector to be 3100 mbsf.

In line IBr5 (Fig. 14), units below LI are deformed by contraction east of site IBM-3C, closer to the Enpo Chain. These structures are imaged as simple folds in other profiles. They may indicate the presence of a transcurrent fault at a high angle to line IBr5, with some faults propagated beneath unit LII.

An eastward dipping reflector (X) is recognized beneath unit LV in line IBr5 (Fig. 14). This boundary coincides with a velocity gradient in the rear arc crustal structure (Kodaira, unpublished) and may be the Eocene basement.

### 7.2 Volcanoes and their basements: examples of NE Japan arc volcanoes

The basement of Quaternary volcanoes in Northeast Japan consists of a wide variety of Tertiary and pre-Tertiary rocks. Interestingly, this basement is topographically higher in areas beneath the volcanoes than it is in surrounding areas, suggesting uplift of basement beneath volcanoes (Fig. 15). Moreover, (1) taller volcanoes rest on higher basement, and (2) most of the basement peaks have elevations more than half the height of the volcanoes (Tamura *et al.,* 2002). Thus, although volcanoes produce topographic highs, most of the height consists of rocks that are much older than, and are not directly related to, the erupted magmas (Fig. 15). We hypothesize that lavas and volcaniclastics dredged from Manji (6.5 Ma) and Kanbun (8.8 Ma) volcanoes of Figs. 13 and 14

constitute just the upper portion of topographic highs that are built on older basement as in Northeast Japan. If so, then the basement of Miocene volcanoes is Oligocene or even Eocene. We thus suggest that unit LV could be the uplifted Oligocene basement of these Miocene volcanoes.
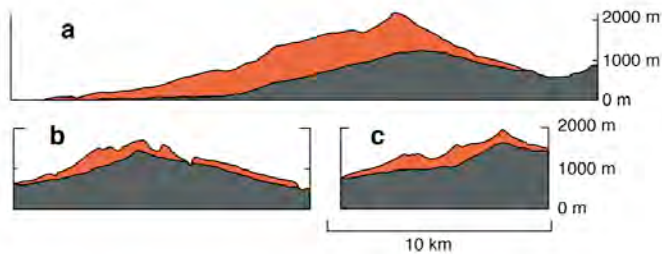
Fig. 15. Simplified geologic profile of three Quaternary volcanoes in Northeast Japan. Red and Gray show Quaternary volcanic rocks (lavas and pyroclastic rocks) and basement rocks (Tertiary volcanics and sedimentary rocks and/or Cretaceous granites), respectively. (a) Chokai volcano (Hayashi, 1984) (b) Zao volcano (Sakayari, 1992), and (c) Gassan volcano (Nakazato *et al.,* 1996). Quaternary volcanoes are generally underlain by topographically elevated basement rocks.
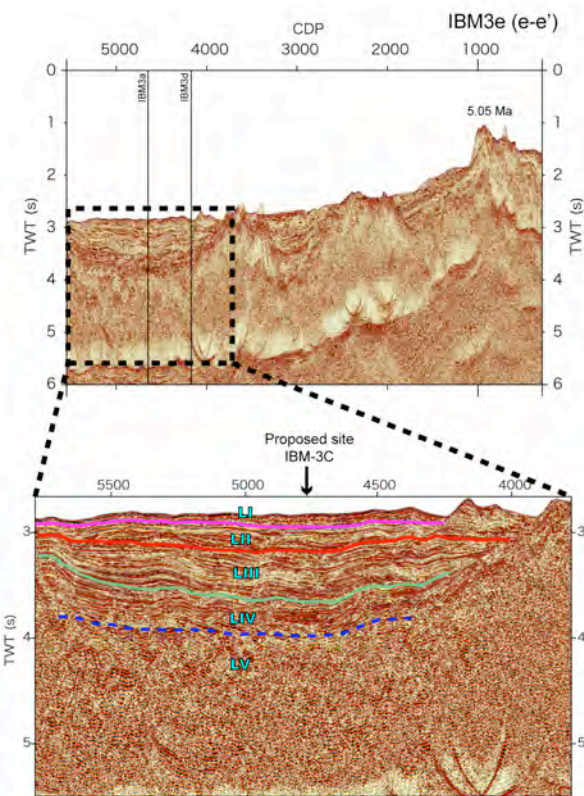

Figure 16. Upper: seismic profile in line IBM3e. Lower: interpreted profile around site IBM-3C. Colored lines as in Fig. 13.

7.3 Site Justification

After reviewing all rear arc sites for which MCS profiles are available, we remain persuaded that IBM-3C is the best single location for our proposed project. Most layers imaged in the MCS profiles are not laterally continuous indicating proximal sediment sources. Importantly, the modern topography (basins and ridges) has barriers between the volcanic front and the proposed site. The only arc front volcano that has easy access now is Myojin Knoll and even sediment from it must cross the small ridge at 139°40'E. In general, slopes are shallower toward the rear arc than toward the forearc. Although we have not been able to analyze the paleo-topography using the seismic lines, the large rear arc seamounts visible on line IBM3e (Fig. 16) are clear barriers once they formed (which is inferred to be 3-6 Ma based on the regional pattern of ages in Fig. 4). The location of the site on the south side of the Manji chain is a compromise to get the most sediment from both rift-type and rear-arc type sources with the least from the front. Thus, the main worry is getting so much proximal sediment that we can't reach the Oligocene easily, not that there will be too much sediment from the front.

Proposed Site IBM-3C is, thus, located at 31°47.38'N, 139°01.58'E, and 2114 m below sea level (mbsl) in the eastern half of the Izu-Bonin rear-arc seamount chains, about 90 km west of the arc volcano Myojin-sho (Fig. 4). It is located between the Manji and Enpo rear-arc seamount chains where Neogene rear arc sediments may lap onto an Oligocene basement. Seismic units at the site consist of LI (2.83-2.87 s), LII (2.87-3.17 s), LIII (3.17-3.58 s), LIV (3.58-3.90 s) and LV (3.90-5.41 s) (Fig. 17). Average sonic velocities of sediments at site 792 increases from 1.59 km/s through 1.85 km/s to 2.28 km/s from 0 to 708 mbsf. Velocity data in basement rocks at site 792 average 4.26 km/s (range = 2.62-5.09 km/s). We used these values to estimate the thickness
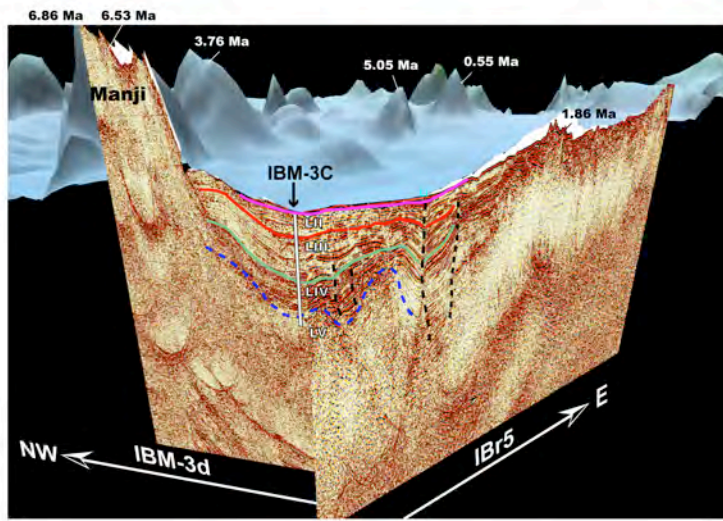
of each seismic unit at IBM-3: namely, LI, LII, LIII, and LIV have average seismic velocities of 1.59, 1.85, 2.28 and 2.62 km/s, respectively. The sonic velocity of unit V is assumed to be 4.26 km/s. The estimated depths of LI/LII, LII/LIII, LIII/LIV, and LIV/LV boundaries are, thus, ~32 mbsf, ~ 309 mbsf, ~777 mbsf, and ~ 1196 mbsf, respectively (Table 1).

Figure 17. Seismic profile of cross point between line IBr5 and line IBM-3d around site IBM-3C looking toward the volcanic front. Manji chain is to left; Enpo chain to right. Black dotted line indicates the fault. Colored lines as in Fig. 13.

Table 1. Estimated characteristics of seismic units of IBM-3C.

Seismic Unit	Age (Ma)	Two way time (sec)	Assumed sonic velocity (km/sec)	Sub-bottom depth (mbsf)	Thickness (m)	Sedimentation rate (m/My)
LI	0-1	2.83-2.87	1.59	0-32	32	32
LII	1-3	2.87-3.17	1.85	32-309	277	139
LIII	3-6.5	3.17-3.58	2.28	309-777	467	134
LIV	6.5-9	3.58-3.90	2.62	777-1196	419	168
LV	25-35	3.90-5.41	4.26	1196-4412	3216	322

The unit LII/LIII boundary should capture the transition between "rear-arc" cross-chain mostly-andesitic Upper Miocene volcanism (III) versus "rift-type" extensional zone, mostly

bimodal Pliocene volcanism (II). That is consistent with the ages in Ishizuka *et al.* (2003b) and the rock chemistry in Ishizuka *et al.* (2003a) and Hochstaedter *et al.* (2001). There are four dredges from the Manji side and four from the Enpo side within 30-km of the seismic lines. Everything north is felsic with rear-arc chemistry. Everything south is basaltic (MgO=5-8) with "rift-type" chemistry.

7.4 Overall Drilling and Logging Plan

We expect to drill through ca. 1,200 m of volcaniclastic Neogene sediment (LI, LII, LIII and LIV) above Oligocene-Eocene sediment (LV) (Table 1). This is consistent with sedimentation rates somewhat similar to the same time interval at ODP Site 792. Site 792 is much closer to, and more likely to receive sediment from, the Oligocene volcanic front.
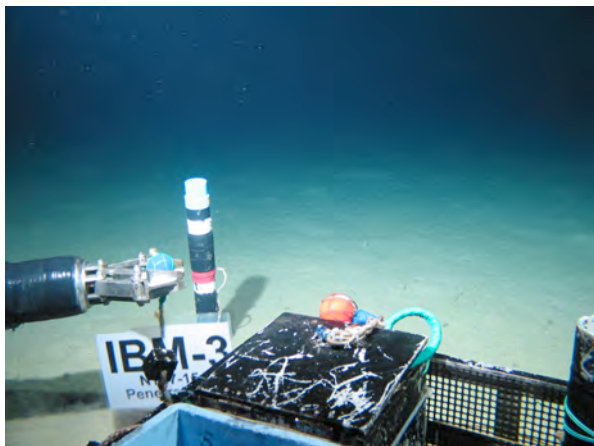
Figure 18. Seafloor of IBM3C taken by ROV Hyper-Dolphin during the R/V Natsushima-Hyper-Dolphin cruise (NT07-15) in July 2007. Heat-flow data are on (http://www.jamstec.go.jp/ifree/jp/03program/program02.html).

We do not expect a problem spudding-in based on discussions with Jay Miller at TAMU. JAMSTEC has bottom photography (Fig. 18) and sediment piston cores from the area. It is relatively flat and the surface sediments are parallel laminated to partly convoluted volcaniclastic sand containing fresh glass shards and calcareous ooze. In general, we expect drilling conditions to be similar to that of ODP Hole 792E where 800 m of volcaniclastic sediments overlying Late Eocene basement were drilled in 6-7 days with >50% core recovery. Thus IBM-3C could be drilled in two weeks with >50% recovery.

We expect to encounter Unit V at ~1,200m. If it consists of Oligocene sedimentary and lavas/sills, then Scientific Objective 5 also can be addressed there. We plan to drill at least 700 m into Unit V in order to establish the Oligocene magmatic history of the rear arc. Leg 125 Site 793 drilled ~250m into basement, most holes in the IBM outer-arc high on Leg 125 drilled 200-400m into basement, and Site 841 in Tonga drilled about 200m into basement. In each of these cases, the basement consisted of inter-bedded breccia and lava; 200-400 m was sufficient and necessary to obtain a representative range of rock types, and core recovery was good.

Logging will play an important role, of course. The gamma ray tool should clearly distinguish sediments derived from the proximal volcanic front (low K, U, Th, Th/U) from rear arc

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(opposite), although perhaps not between volcanic front versus rift-type. The FMS (formation microscanner) will help to identify the basal portions of turbidites and their flow direction as it did in the forearc (Hiscott *et al.*, 1992). We plan a VSP (Vertical Seismic Profile) experiment to tie our results to the MCS lines. The magnetic susceptibility tool may aid in interpreting the depositional environment of volcaniclastic units, as paleomagnetics did in the rear arc basin closest to the Izu volcanic front (Gill *et al.,* 1990; Koyama *et al.,* 1992).

Although we have given reasons why unit LV may be Oligocene basement, we have also acknowledged some uncertainty. If SSEP agrees that all other concerns have been addressed sufficiently in this revision, then we ask for external review of the overall proposal in general and Site IBM-3C in particular now, and a mandate to find an additional site, probably on the Kyushu-Palau Ridge, where the deeper objectives can be achieved with confidence.

7.5 Temperature and alteration

The currently available heat flow data show 50-150 mW/m^2 in the Izu-Bonin rear-arc seamount chains. Thus hydrothermal conditions are absent and drilling will be cooler than at the successful Site 504B, for example. Genroku Seamount, 90 km south of IBM-3, has higher heat flow (150 mW/m^2) possibly because rift-related volcanism continued there until 1 Ma (Ishizuka *et al.,* 2003). Another site on the Genroku seamount chain, ~25 km WSW of the previous site, has only 50 mW/m^2. There has been no volcanism anywhere on the Manji Chain since 5 Ma, and rift-related volcanism (< 1Ma) is more than 25 km east of this site. The latter volcanism appears to be monogenetic and short-lived, suggesting that heat flow of IBM-3C should be less than 50 mW/m^2. Five heat-flow measurements using a stand-alone heat flow meter from ROV Hyper-Dolphin were conducted at the exact point of IBM-3C during the R/V Natsushima-Hyper-Dolphin cruise (NT07-15) in July 2007 (http://www.jamstec.go.jp/ifree/jp/03program/program02.html). The data range from 31.9 to 56.97 mW/m^2 with an average of 45.2 mW/m^2. Even if gradients are slightly underestimated because of warm bottom water, temperatures in the target area are low enough not to impede drilling. Low-temperature alteration of the volcanogenic sediments might be observed as it was at Site 792 where there was a marked increase in smectite and zeolite at the expense of volcanic glass below 350 mbsf. If anything, such alteration should improve core recovery. We estimate that the temperature at the LIV/LV boundary, 1,200 mbsf, will be 50-90°C.

Volcanism prior to Miocene also may have caused hydrothermal alteration. Even in this case we can reconstruct rear arc magmatic history by using elements and isotopes that are resistant to

alteration, such as HFSE (high field strength elements) and HREE (heavy rare earth element), as discussed previously.

8. SUMMARY

Our hypotheses are that arc crust grows with fundamental asymmetry at least during steady state times after inception, that rear arc magma is more similar chemically to "average continental crust" through time, and that the asymmetry and similarity get amplified in felsic rocks that are created by intra-crustal differentiation, especially during non-steady state events like arc rifting. In addition, the rear arc is a more faithful monitor of mantle geochemistry through time, and is at least as important volumetrically (i.e., in crustal structure) as the volcanic front for fluxes of elements in subduction zones. These two latter points make it necessary to know the history of rear arc volcanism in order to have all the information necessary to integrate the history of arc outputs.

If we reach Oligocene without discovering proximally-derived Middle Miocene volcanics as predicted in this proposal, it will confirm that there was no 10-17 Ma magmatism this far east at that time, and thus Miocene rear arc magmatism migrated from west to east. This migration, which is expected theoretically (Honda & Yoshida, 2005; Honda *et al.,* 2007), would be closely related to convection within the mantle wedge and would explain the origin of the seamount chains as 'hot fingers' (Tamura *et al.,* 2002). Most arc segments have rearrarc magmatism so whatever explanation applies to Izu may have global importance.

If rear arc drilling reaches pre-Oligocene basement, then it also will be possible to assess whether there were across-arc variations in the composition of Eocene magmas. It may be that such variation requires establishment of relatively mature cold subduction with a well-developed volcanic front. If so, then consistent across-arc variations may not occur until the Oligocene or even Neogene. Comparison of across-arc variations through time will constrain the fundamental reasons for the variations themselves, and will show how the variations affect crustal development. Consequently, rear arc drilling is the necessary "Other Half" of subduction factory output.

REFERENCES

Allen, S.R. (2004). The Parnell Grit beds revisited: are they all the products of sector collapse of western subaerial volcanoes of the Northland Volcanic Arc? *New Zealand Journal of Geology & Geophysics* **47,** 209-524.

Arai, S. (1991). The circum-Izu massif peridotite, central Japan as cack-arc mantle fragtments of the Izu-Bonin arc system. *In:* Peters, Tj. Et al. (eds) *Ophiolite genesis and evolution of the Oceanic lithosphere.* Ministry of Petroleum and Minerals, Sultanate of Oman, 801-816.

Bandy, W. L. & Hilde, T. W. C. (1983). Structural features of the Bonin arc: implications for its tectonic history. *Tectonophysics* **99,** 331-353.

Bednarz, U. & Schmincke, H.U. (1994). "Composition and origin of volcaniclastic sediments in the Lau Basin (Southwest Pacific), Leg 135 (Sites 834-839)." In: Hawkins, J.W., Parson, L.M., Allan, J.F. *et al.* (eds.) *Proceedings of the Ocean Drilling Program, Scientific Results* **135,** 51-74.

Bloomer, S.H., B. Taylor, C.J. MacLeod, R.J. Stern, P. Fryer, J.W. Hawkins, and L.E. Johnson (1995). Early arc volcanism and the ophiolite problem; a perspective from drilling in the western Pacific. In B. Taylor and J. Natland (eds.) *Active margins and marginal basins of the western Pacific*, AGU Geophysical Monograph, Washington, D.C., 1-30.

Bryant, C. J., Arculus, R. J. & Eggins, S. M. (2003). The geochemical evolution of the Izu-Bonin arc system: A perspective from tephras recovered by deep-sea drilling. *Geochemistry, Geophysics, Geosystems* **4,** 1094, doi:10.1029/2002GC000427.

Cashman, K. V. & Fiske, R. S. (1991). Fallout of pyroclastic debris from submarine eruption columns. *Science* **253,** 275-280.

Cosca, M.A., R.J. Arculus, J.A. Pearce, and J.G. Mitchell (1998). $^{40}Ar/^{39}Ar$ and K-Ar geochronological age constraints for the inception and early evolution of the Izu-Bonin-Mariana arc system. *The Island Arc* **7,** 579-598.

Deschamps, A., & S. Lallemand (2002). The West Philippine Basin: An Eocene to early Oligocene back arc basin opened between two opposed subduction zones. *Journal of Geophysical Research* **107,** doi:10.1029/2001JB001706.

Deschamps, A., K. Okino, & K. Fujioka (2002) Late amagmatic extension along the central and eastern segments of the West Philippine Basin fossil spreading axis. *Earth and Planetary Science Letters* **203,** 277-293.

Dickinson, W. R. & Hatherton, T. (1967). Andesite volcanism and seismicity around the Pacific. *Science* **157,** 801-803.

Egeberg, P.K. (1992) Thermodynamic aspects of Leg 126 interstitial water. In: Taylor, B., Fujioka, K. *et al.* (eds) *Proceedings of the Ocean Drilling Program, Scientific Results* **126**, 519-530.

Fisher, R. V. & Schmincke, H.-U. (1984). Pyroclastic Rocks. Springer-Verlag, Berlin.

Gill, J. 1981. *Orogenic andesites and slab tectonics.* Berlin: Springer-Verlag.

Gill, J *et al.* (1990). Explosive deep water basalt in the Sumisu backarc rift. *Science* **248,** 1214-1217.

Gill, J. B., Hiscott, R. N. & Vidal, Ph. (1994). Turbidite geochemistry and evolution of the Izu-Bonin arc and continents. *Lithos* **33,** 135-168.

Haeckel, M., J. van Beusekom, M. G. Wiesner & I. König (2001). The impact of the 1991 Mount Pinatubo tephra fallout on the geochemical environment of the deep-sea sediments in the South China Sea. *Earth and Planetary Science Letters* **193,** 151-166.

Hall, R. (2002). Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: Computer-based reconstructions, model and animations. *Journal of Asian Earth Sciences* **20,** 353-431.

Hall, C.E., M. Gurnis, M. Sdrolias, L.L. Lavier, & R.D. Müller (2003). Catastrophic initiation of subduction following forced convergence across fracture zones. *Earth and Planetary Science Letters* **212,** 15-30.

Hasegawa, A. & Nakajima, J. (2004). Geophysical constraints on slab subduction and arc magmatism, AGU Geophys. Monograph, 150, IUGG volume **19,** 81-94.

Hayashi, S. (1984). Geology of Chokai volcano. *J. Jpn. Assoc. Miner. Petrol. Econ. Geol.* **79,** 249-265.

Hirano, N., Ogawa, Y., Saito, K., Yoshida, T., Sato, H., Taniguchi, H. (2003). Multi-stage evolution of the Tertiary Mineoka ophiolite at Boso TTT triple junction in the NW Pacific as revealed by new geochemical and age constraints. *In:* Dilek, Y. & Robinson, P. T. (eds). Ophiolites in Earth History, Spec. Publ. Geol. Soc. Londo. **218,** 279-298.

Hiscott, R. N., Colella, A., Pezard, P., Lovell, M. A. & Malinverno, A. (1992). Sedimentology of deep-water volcaniclastics, Oligocene Izu-Bonin forearc basin, based on formation microscanner images. In: Taylor, B., Fujioka, K. *et al.* (eds) *Proceedings of the Ocean Drilling Program, Scientific Results* **126**, 75-96.

Hochstaedter, A. G., Gill, J. B., Kusakabe, M., Newman, S., Pringle, M., Taylor, B. & Fryer, P. (1990a). Volcanism in the Sumisu rift, I. Major element, volatile, and stable isotope geochemistry. *Earth and Planetary Science Letters* **100,** 179-194.

Hochstaedter, A. G., Gill, J. B. & Morris, J. D. (1990b). Volcanism in the Sumisu rift, II. Subductiion and non-subduction related components. *Earth and Planetary Science Letters* **100,** 195-209.

Hochstaedter, A.G., Gill, J. B., Taylor, B., Ishizuka, O., Yuasa, M. & Morita, S. (2000) Across-arc geochemical trends in the Izu-Bonin arc: Constraints on source composition and mantle melting, *Journal of Geophysical Research* **105**, 495-512.

Hochstaedter, A., Gill, J., Peters, R., Broughton, P. & Holden, P. (2001). Across-arc geochemical trends in the Izu-Bonin arc: Contributions from the subducting slab. *Geochemistry Geophysics Geosystems* **2,** 2000GC000105.

Hofmann, A. W. (1988). Chemical differentiation of the Earth: the relationship between mantle, continental crust, and oceanic crust. *Earth Planet. Sci. Lett.* **90,** 297-314.

Honda, S. and Yoshida, T. (2005). Application of the model of small-scale convection under the island arc to the NE Honshu subduction zone. *Geochemistry Geophysics Geosystems* **6,** Q01002, doi:10.1029/2004GC000785.

Honda, S., Yoshida, T. & Aoike, K. (2007). Spatial and temporal evolution of arc volcanism in the northeast Honshu and Izu-Bonin arcs: evidence of small-scale convection under the island arc? *Island Arc* **16,** 214-223.

Ishizuka, O. (2008). Volcanic and tectonic framework of the hydrothermal activity of the Izu-Bonin arc *Resource Geology* **in press.**

Ishizuka, O., Uto, K., Yuasa, M. & Hochstaedter, A. G. (1998). K-Ar ages from seamount chains in the back-arc region of the Izu-Ogasawara arc. *The Island Arc* **7,** 408-421.

Ishizuka, O., Uto, K., Yuasa, M. & Hochstaedter, A.G. (2002). Volcanism in the earliest stage of back-arc rifting in the Izu-Bonin arc revealed by laser-heating ^{40}Ar/^{39}Ar dating, *Journal of Volcanology and Geothermal Research* **120**, 71-85.

Ishizuka, O., Yuasa, M. & Uto, K. (2002). Evidence of porphyry copper-type hydrothermal activity from a submerged remnant back-arc volcano of the Izu-Bonin arc: implications for the volcanotectonic history of back-arc seamounts. *Earth and Planetary Science Letters* **198,** 381-399.

Ishizuka, O., Taylor, R.N., Milton, J.A. & Nesbitt, R.W. (2003a). Fluid-mantle interaction in an intra-oceanic arc: constraints from high-precision Pb isotopes. *Earth and Planetary Science Letters* **211**, 221-236.

Ishizuka, O., Uto, K. &Yuasa, M. (2003b). Volcanic history of the back-arc region of the Izu-Bonin (Ogasawara) Arc. *In:* Larter R.D. & Leat P.H. (eds) 2003. *Intra-Oceanic Subduction Systems: Tectonic and Magmatic Processes*. Geol. Soc. London Spec. Publ. **219,** 187-205.

Ishizuka, O., Taylor, R.N., Milton, J.A., Nesbitt, R.W., Yuasa, M., Sakamoto, I. (2006). Variation in the source mantle of the northern Izu arc with time and space -Constraints from high-precision Pb isotopes -. *Journal of volcanology and Geothermal Research* **156,** 266-290.

Ishizuka, O., Kimura, J-I., Li, Y.B., Stern, R. J., Reagan, M. K., Taylor, R. N., Ohara, Y., Bloomer, S. H., Ishii, T., Hargrove III, U. S., Haraguchi, S. (2006). Early stages in the evolution of Izu-Bonin arc volcanism: new age, chemical, and isotopic constraints. *Earth and Planetary Science Letters* **250,** 385-401.

Ishiwatari, A. (1991). Ophiolites in the Japanese island: typical segment of the circum-Pacific multiple ophiolite belts. *Episode* **14,** 274-279.

Karig, D. E. & Moore, G. F. (1975). Tectonic complexities in the Bonin arc system. *Tectonophysics* **27,** 97-118.

Kimura, J. & Yoshida, T. (2006). Contributions of slab fluid, mantle wedge and crust to the origin of Quaternary lavas in the NE Japan arc. *Journal of Petrology* **47,** 2185 - 2232.

Kodaira, S., Sato, T., Takahashi, N., Ito, A., Tamura, Y., Tatsumi, Y. & Kaneda, Y. (2007a). Seismological evidence for variable growth of crust along the Izu intraoceanic arc. *Journal of Geophysical Research* **112,** B05104, doi:10.1029/2006JB004593.

Kodaira, S., Sato, T., Takahashi, N., Miura, S., Tamura, Y., Tatsumi, Y., Kaneda, Y. (2007b). New seismological constraints on growth of continental crust in the Izu-Bonin intra-oceanic arc. *Geology* **35,** 1031-1034, doi: 10.1130/G23901A.

Koyama, M., Cisowski, S. M. & Pezard, P. (1992). Paleomagnetic evidence for northward drift and clockwise rotation of the Izu-Bonin forearc since the early Oligocene. In: Taylor, B.,

Fujioka, K. *et al.* (eds) *Proceedings of the Ocean Drilling Program, Scientific Results* **126**, 353-370.

Kuno, H. (1959). Origin of Cenozoic petrographic provinces of Japan and surrounding areas. *Bulletin of Volcanology* **32,** 141-176.

Kushiro, I. (1994). Recent experimental studies on partial melting of mantle peridotites at high pressures using diamond aggregates. *Journal of Geological Society of Japan* **100,** 103-110.

Machida S. & Ishii, T. (2003). Backarc volcanism along the en echelon seamounts: the Empo seamount chain in the northern Izu-Ogasawara arc. *Geochemistry Geophysics Geosystems* **4,** 9006, doi: 10.1029/2003GC000554.

Malyarenko, A. N. & Lelikov, E. P. (1995). Granites and associated rocks in the Philippine Sea and the East China Sea. *In:* Tokuyama, H., Shcheka, S. A. & Isezaki, N. (eds) *Geology and Geophysics of the Philippine Sea.* Terrapub, Tokyo, 311-328.

McPhie, J. & Allen, R.L. (2003). Submarine, syn-eruptive, silicic pyroclastic units in the Mount Read Volcanics, western Tasmania: Influence of vent setting and proximity on facies characteristics. *American Geophysical Union, Monograph* **140,** 245-258.

McPhie, J. & Allen, R.L. (1992). Facies architecture of mineralized submarine volcanic sequences; Cambrian Mount Read Volcanics, western Tasmania. *Economic Geology* **87,** 587-596.

Mizuno, A., Shibata, K., Uchiumi, S., Yuasa, M., Okuda, Y., Nohara, M. & Kinoshita, Y. (1977). Granodiorite from the Minami-koho seamount on the Kyushu-Palau ridge, and its K-Ar age. *Chishitsu Chosajo Geppo Bulletin, Geological Survey of Japan* **28,** 5-9.

Nakazato, H., Oba, T. & Itaya, T. (1996). The geology and K-Ar ages of the Gassan volcano, northeast Japan. *J. Jpn. Assoc. Miner. Petrol. Econ. Geol.* **91,** 1-10.

Nishimura, A., Rodolfo, K.S., Koizumi, A., Gill, J. & Fujioka, K. (1992). Episodic deposition of Pliocene-Pleistocene pumice from the Izu-Bonin arc, Leg 126. doi:10.2973/odp.proc.sr.126.115.1992

Ogawa, Y. & Takahashi, A. (2004). Seafloor spreading, obduction and triple junction tectonics of the Mineoka Ophiolite, central Japan. *Tectonophysics* **392,** 131-141.

Ogawa, Y. & Taniguchi, H. (1987). Ophiolitic mélange in forearc area and formation of the Mineoka Belt. *Science Report, Kyushu University Geology* **15,** 1-23.

Ogawa, Y. & Taniguchi, H. (1988). Geology and tectonics of the Miura-Boso peninsulas and the adjacent area. *Mod. Geol.* **12,** 147-168.

Okino, K., K. Matsuda, D. Christie, Y. Nogi, and K. Koizumi (2004). Development of oceanic detachment and asymmetric spreading at the Australian-Antarctic Discordance. *Geochemistry, Geophysics, Geosystems* **5(12),** Q12012, doi:10.1029/2004GC000793.

Rudnick, R. L. & Gao, S. (2003). 3.01 Composition of the Continental Crust. In: *Treatise of Geochemistry* **3,** 1-64.

Sakuyama, M. & Nesbitt, R.W. (1986). Geochemistry of the Quaternary volcanic rocks of the Northeast Japan arc. *Journal of Volcanology and Geothermal Research* **29,** 413-450.

Sakayori, A. (1992). Geology and petrology of Zao volcano. *J. Jpn. Assoc. Miner. Petrol. Econ. Geol.* **87,** 433-444.

Sato, H., Taniguchi, H., Takahashi, N., Mohiuddin, M. M., Hirano, N. & Ogawa, Y. (1999). Origin of the Mineoka ophiolite. *J. Geogr., Tokyo Geogr. Soc.* **108,** 203-215.

Sharp, W. & Clague, D.A. (2006). 50-Ma initiation of Hawaiian-Emperor bend records major change in Pacific plate motion. *Science* **313,** 1281-1284.

Shibata, K. & Okuda, Y. (1975). K-Ar age of a granite fragment dredged from the 2nd Komahashi Seamount. *Chishitsu Chosajo Geppo Bulletin, Geological Survey of Japan* **26,** 19-20.

Shiraki, K., Ohashi, F., Wada, N., Ito, J. & Ono, H. (2005). Boninite-like rocks and meimechite in the Setogawa ophiolite, Shizuoka Prefecture. *Nagoya Journal of Space & Earth Sciences* **67,** 25-38.

Skilling, I. P., White, J.D.L. & McPhie, J. (2002). Peperite: a review of magma-sediment mingling. *Journal of Volcanology and Geothermal Research* **114,** 1-17.

Stern, R.J. (2004). Subduction Initiation: Spontaneous and Induced *Earth and Planetary Science Letters* **226,** 275-292.

Straub, S.M. (2003). The evolution of the Izu Bonin - Mariana volcanic arcs (NW Pacific) in terms of major elements. *Geochemistry Geophysics Geosystems* **4**(2): 1018, doi: 10.1029/2002GC000357.

Suyehiro, K., Takahashi, N., Ariie, Y., Yokoi, Y., Hino, R., Shinohara, M., Kanazawa, T., Hirata, N., Tokuyama, H. & Taira, A. (1996). Continental crust, crustal underplating, and low-Q upper mantle beneath and oceanic island arc. *Science* **271**, 390-392.

Tamura, Y., Koyama, M. & Fiske, R. S. (1991). Paleomagnetic evidence for hot pyroclastic

debris flow in the shallow submarine Shirahama Group (upper Miocene-Pliocene), Japan, *Journal of Geophysical Research* **96**, 21779-21787.

Tamura, Y. & Tatsumi, Y. (2002). Remelting of an andesitic crust as a possible origin for rhyolitic magma in oceanic arcs: an example from the Izu-Bonin arc. *Journal of Petrology* **43,** 1029-1047.

Tamura, Y., Tatsumi, Y., Zhao, D., Kido, Y. & Shukuno, H. (2002). Hot fingers in the mantle wedge: new insights into magma genesis in subduction zones. *Earth and Planetary Science Letters* **197**, 107-118.

Tamura, Y., Tani, K., Ishizuka, O., Chang, Q., Shukuno, H. & Fiske, R. S. (2005). Are arc basalts dry, wet, or both? Evidence from the Sumisu caldera volcano, Izu-Bonin arc, Japan. *Journal of Petrology* **46,** 1769-1803.

Tamura, Y., Tani, K., Chang, Q., Shukuno, H., Kawabata, H., Ishizuka, O. & Fiske, R. S. (2007). Wet and dry basalt magma evolution at Torishima volcano, Izu-Bonin arc, Japan: the possible role of phengite in the downgoing slab. *Journal of Petrology* **48,** 1999-2031, doi:10.1093/petrology/egm048.

Tani, K., Fiske, R. S., Tamura, Y., Kido, Y., Naka, J., Shukuno, H. & Takeuchi, R. (2007) Sumisu volcano, Izu-Bonin arc, Japan: site of a silicic caldera-forming eruption from a small open-ocean island. *Bulletin of Volcanology* **70,** 10.1007/s00445-007-0153-2.

Taniguchi, H. & Ogawa, Y. (1990). Occurrence, chemistry and tectonic significance of alkali basaltic rocks in the Miura Peninsula, central Japan. *J. Geol. Soc. Jpn.* **96,** 101-116.

Tatsumi, Y., Sakuyama, M., Fukuyama, H. & Kushiro, I. (1983). Generation of arc basalt magmas and thermal structure of mantle wedge in subduction zones. *Journal of Geophysical Research* **88,** 5815-5825.

Tatsumi, Y., Shukuno, H., Tani, K., Takahashi, N., Kodaira, S. & Kogiso, T. (2008). Structure and growth of the Izu-Bonin-Mariana arc crust: 2. Role of crust-mantle transformation and the transparent Moho in arc crust evolution. *Journal of Geophysical Research* **113,** doi:10.1029/2007JB005121.

Taylor, S. R. (1967). The origin and growth of continents. *Tectonophysics* **4,** 17-34.

Taylor, B. (1992). Rifting and the volcanic-tectonic evolution of the Izu-Bonin-Mariana Arc, edited by B. Taylor, K. Fujioka, T.R. Janecek, J.C. Aitchison, et al., in Proceedings of the Ocean Drilling Program, Bonin Arc-Trench System; covering Leg 126 of the cruises of the

drilling vessel JOIDES Resolution, pp. 627-652, Texas A & M University, Ocean Drilling Program. College Station, TX, Tokyo.

Taylor, B. & A.M. Goodliffe (2004). The west Philippine Basin and the initiation of subduction, revisited. *Geophyrical Research Letters* **31,** 10.1029/2004GL020136.

Taylor, R. N. & Nesbitt, R. W. (1998). Isotopic characteristics of subduction fluids in an intra-oceanic setting, Izu-Bonin arc, Japan. *Earth and Planetary Science Letters* **164,** 79-98.

Whittaker, J. M., Muller, R. D. Leitchenkov, G., Stagg, H., Sdrolias, M. Gaina, C. Goncharov, A. (2007). Major Australian-Antarctic plate reorganization at Hawaiian-Emperor bend time. *Science* **318,** DOI: 10.1126/science.1143769.

Wiesner, M. G., A. Wetzel, S. G. Catane, E. L. Listanco & H. T. Mirabueno (2004). Grain size, areal thickness distribution and controls on sedimentation of the 1991 Mount Pinatubo tephra layer in the South China Sea. *Bulletin of Volcanology* **66,** 226-242.

Yamazaki, T. & Yuasa, M. (1998). Possible Miocene rifting of the Izu-Ogasawara (Bonin) arc deduced from magnetic anomalies. *The Island Arc* **7,** 374-382.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes
Revised 7 March 2002

New ☐　　Revised ■

Section A: Proposal Information

Title of Proposal: **697-Full3: The rear arc: the missing half of the subduction factory**

Date Form Submitted: 1st April, 2007

Site Specific Objectives with Priority
(Must include general objectives in proposal)

Our goal is to establish the temporal history of across-arc variations during five time periods that stand out in the rear-arc evolution.

3 Ma to the present. We will determine whether rear-arc and rift-type magmatism have overlapped since the onset of rifting at 3 Ma, and whether rift-type mafic and felsic magmatism changes during that time.

9 to 3 Ma. We will also establish whether rear arc magmatism changed with time and how felsic rear arc magmatism is distributed through time and compares in composition between the rear arc and volcanic front.

17 to 9 Ma. We will determine whether rear arc magmatism migrates from west to east and the rocks of this age are missing in the proposed site.

25 to 17 Ma. We will determine whether volcanism stopped in the rear arc during opening of the nearby Shikoku Basin as it did at the volcanic front.

>25 Ma. We will determine whether rear arc magmatism changed with time, whether Oligocene rear arc and frontal arc magmas differed in the Oligocene, whether there were across arc variations in even at the initial stage of arc development, and especially whether felsic materials differ in their abundance, character, and mode of origin during arc evolution.

List Previous Drilling in Area: ODP Leg 125,126

Section B: General Site Information

Site Name:
(e.g. SWPAC-01A)
IBM-3C
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site #

Area or Location: Izu-Bonin arc

Latitude: Deg: 31°N　　Min: 47.3874'

Jurisdiction: Japanese EEZ

Longitude: Deg: 139°E　　Min: 01.5786'

Distance to Land: 100 km

Coordinates System: WGS 84,　　Other (　　　)

Priority of Site: Primary:　　Alt:

Water Depth: 2114 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	1,200 m What is the total sed. thickness? 1,200　　m	700 m

Total Penetration: | 1,900 | m

General Lithologies:	Volcaniclastic turbidites, tephra layers, calcareous sediments	massive basaltic to andesitic lavas and breccia

Coring Plan: *(Specify or check)*

1-2-3-APC ■　VPC* □　XCB ■　MDCB* □　PCS □　RCB ■　Re-entry ■　HRGB □
* Systems Currently Under Development

Wireline Logging Plan:

Standard Tools		Special Tools		LWD	
Neutron-Porosity	■	Borehole Televiewer ■	Formation Fluid Sampling ■	Density-Neutron	□
Litho-Density	■	Nuclear Magnetic Resonance □	Borehole Temperature & Pressure ■	Resistivity-Gamma Ray	□
Gamma Ray	■	Geochemical ■	Borehole Seismic ■	Acoustic	□
Resistivity	■	Side-Wall Core Sampling □			
Acoustic	■				
Formation Image	■		Others ( )	Others ( )	

Max.Borehole Temp. :

Expected value (For Riser Drilling)

_____°C

Mud Logging: *(Riser Holes Only)*

Cuttings Sampling Intervals

from _____ m　to _____ m,　_____ m intervals

from _____ m　to _____ m,　_____ m intervals

Basic Sampling Intervals: 5m

Estimated days:	Drilling/Coring:	Logging:	Total On-Site:

Future Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Hazards/Weather:

Please check following List of Potential Hazards

						What is your Weather window? (Preferable period with the reasons)
Shallow Gas	■	Complicated Seabed Condition □	Hydrothermal Activity	□		From April to November (To avoid winter monsoon)
Hydrocarbon	□	Soft Seabed □	Landslide and Turbidity Current	□		
Shallow Water Flow	□	Currents □	Methane Hydrate	□		
Abnormal Pressure	□	Fractured Zone □	Diapir and Mud Volcano	□		
Man-made Objects	■	Fault □	High Temperature	□		
H$_2$S	□	High Dip Angle □	Ice Conditions	□		
CO$_2$	□					

Form 2 - Site Survey Detail

IODP Site Summary Forms:

Please fill out information in all gray boxes

New [ ]   *Revised* [█]

Proposal #: 697-Full3	Site #: IBM-3C	Date Form Submitted: 1st April, 2008

	Data Type	SSP Requir-ements	Exists In DB	Details of available data and data that are still to be collected
1	High resolution seismic reflection		Yes	Primary Line(s) :Location of Site on line (SP or Time only) IBr5 (collected by JAMSTEC using 204 streamer cable) Crossing Lines(s):
2	Deep Penetration seismic reflection		Yes	Primary Line(s): Location of Site on line (SP or Time only) IBM3e (collected by JAMSTEC using 12 ch streamer cable) Crossing Lines(s): IBM3d (collected by JAMSTEC using 12 ch streamer cable)
3	Seismic Velocity†			
4	Seismic Grid		Yes	Deep penetration reflection, 3 NE-SW x 2 NW-SE x 1E-W
5a	Refraction (surface)			
5b	Refraction (near bottom)			Processing by JAMSTEC
6	3.5 kHz			Location of Site on line (Time)
7	Swath bathymetry			Multi-narrow-beam data complied by Japan Coast Guard
8a	Side-looking sonar (surface)			
8b	Side-looking sonar (bottom)			
9	Photography or Video			ROV still image
10	Heat Flow			http://www.jamstec.go.jp/ifree/jp/03program/program02.html
11a	Magnetics			Map complied by AIST, Japan, is published.
11b	Gravity			Map complied by AIST, Japan, is published.
12	Sediment cores			
13	Rock sampling			dredges
14a	Water current data			Available on JODC web page (hhttp://www.jodc.go.jp)
14b	Ice Conditions			
15	OBS microseismicity			Acquired by JAMSTEC, and data are now processing.
16	Navigation			
17	Other			

SSP Classification of Site:	SSP Watchdog:	Date of Last Review:

SSP Comments:

X=required; X*=may be required for specific sites; Y=recommended; Y*=may be recommended for specific sites;
R=required for re-entry sites; T=required for high temperature environments; † Accurate velocity information is required
for holes deeper than 400m.

IODP Site Summary Forms:

New ☐   *Revised* ■

Proposal #: 697-Full3	Site #: IBM-3C	Date Form Submitted: 1ˢᵗ April, 2008
Water Depth (m): 2,114	Sed. Penetration (m): 1,200	Basement Penetration (m): 700

Do you need to use the conical side-entry sub (CSES) at this site?   Yes ☐   No ■

Are high temperatures expected at this site?   Yes ☐   No ■

Are there any other special requirements for logging at this site?   Yes ☐   No ■

     If "Yes" Please describe requirements: _____

_____

What do you estimate the total logging time for this site to be:_ 7 days

Measurement Type	Scientific Objective	Relevance (1=high, 3=Low)
Neutron-Porosity	Volcaniclastic sediment and dike and lava porosity; relate core to bulk crustal properties	1
Litho-Density	Volcaniclastic sediment and dike and lava density for mechanical properties and synthetic seismogram	1
Natural Gamma Ray	Hydrothermal alteration (particularly K, Th and U profiles) and relate core to bulk crust	1
Resistivity-Induction	Estimation of electro-magnetic properties, bulk density and mineral composition in sedimentary sequences and basement	1
Acoustic	Crustal velocities (Vp and Vs) for synthetic seismogram	1
FMS	Fracturing (dip angle and azimuth), lithology, sedimentary structures, magnetic field	1
BHTV	Downhole stresses, active faulting, borehole stability, lithology	1
Resistivity-Laterolog	Lithology (thickness, geometry)	
Magnetic/Susceptibility	Magnetic polarity	1
Density-Neutron (LWD)	no	
Resitivity-Gamma Ray (LWD)	no	
Other: Special tools (CORK, PACKER, VSP, PCS, FWS, WSP	Borehole temperature and pressure sensor: Determination of thermal gradient and environment VSP: core-log-seismic integration	1

IODP Site Summary Forms:

Form 4 – Pollution & Safety Hazard Summary

Please fill out information in all gray boxes

New ☐   *Revised* ■

Proposal #: 697-Full3	Site #: IBM-3C	Date Form Submitted: 1st April, 2008

1	Summary of Operations at site: (Example: Triple-APC to refusal, XCB 10 m into basement, log as shown on page 3.)	Drill rear-arc of the Izu-Bonin arc from Neogene sediments through Paleogene sediments into Paleogene basement at this site (1,900 m bsf) APC to refusal, then XCB to refusal. RCB to 1,900m
2	Based on Previous DSDP/ODP drilling, list all hydrocarbon occurrences of greater than background levels. Give nature of show, age and depth of rock:	None
3	From Available information, list all commercial drilling in this area that produced or yielded significant hydrocarbon shows. Give depths and ages of hydrocarbon-bearing deposits.	None
4	Are there any indications of gas hydrates at this location?	No
5	Are there reasons to expect hydrocarbon accumulations at this site? Please give details.	No
6	What "special" precautions will be taken during drilling?	Standard
7	What abandonment procedures do you plan to follow:	Standard
8	Please list other natural or manmade hazards which may effect ship's operations: (e.g. ice, currents, cables)	Some cables
9	Summary: What do you consider the major risks in drilling at this site?	Drilling of volcanic sediments similar to Site 792, but to relatively deep penetration (1,200 m).

IODP Site Summary Forms:

Form 5 – Lithologic Summary

New ▢　　*Revised* ▮

Proposal #: 697-Full3	Site #: IBM-3C	Date Form Submitted: 1st April, 2008

| Sub-bottom depth (m)	Key reflectors, Unconformities, faults, etc	Age	Assumed velocity (km/sec)	Lithology	Paleo-environment	Avg. rate of sed. accum. (m/My)	Comments
0-32	None	0-1	1.59	Turbidites, tephra	Rear arc	32	
32-309	None	1-3	1.85	Turbidites, tephra	Rear arc	139	
309-777	None	3-7	2.28	Turbidites, tephra	Rear arc	134	
777-1196	None	7-9	2.62	Turbidites, tephra	Rear arc	168	
	Unconformity						
1196-4412	None	25-35	4.26	Turbidites, tephra lavas	Rear arc	322	

These seismic sections are based on data in the SSDB:
IODP-SSDB_P697_20070119142038_ky0614_ibm3e.pdf
IODP-SSDB_P697_20070119142036_ky0614_ibm3d.pdf
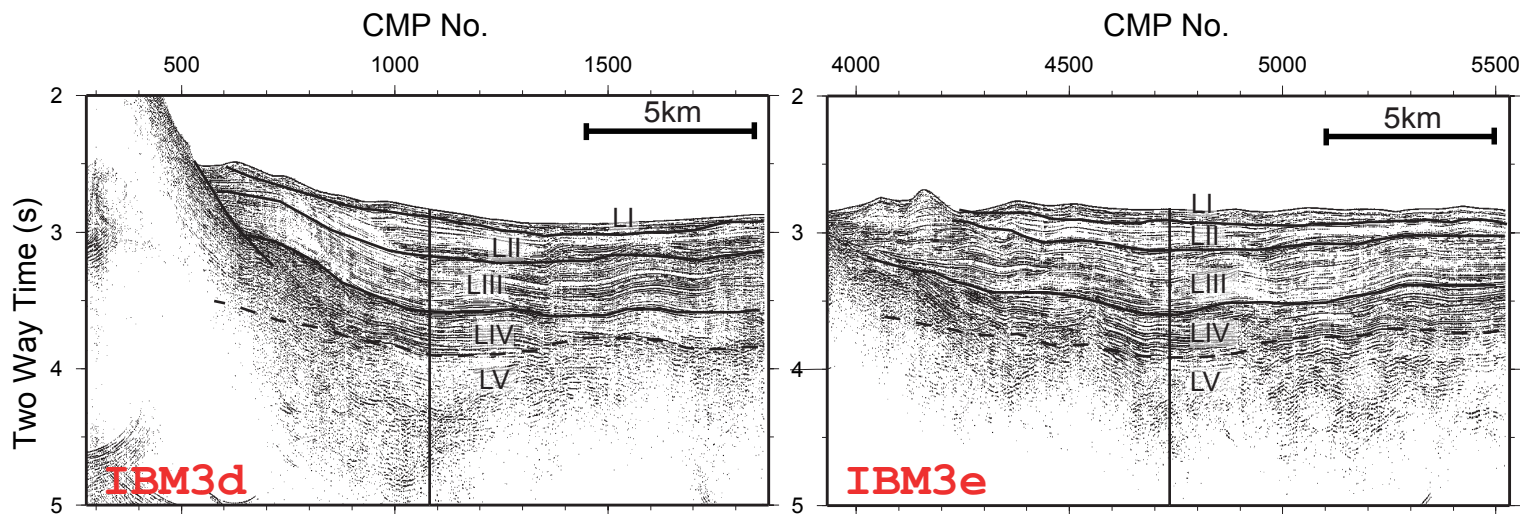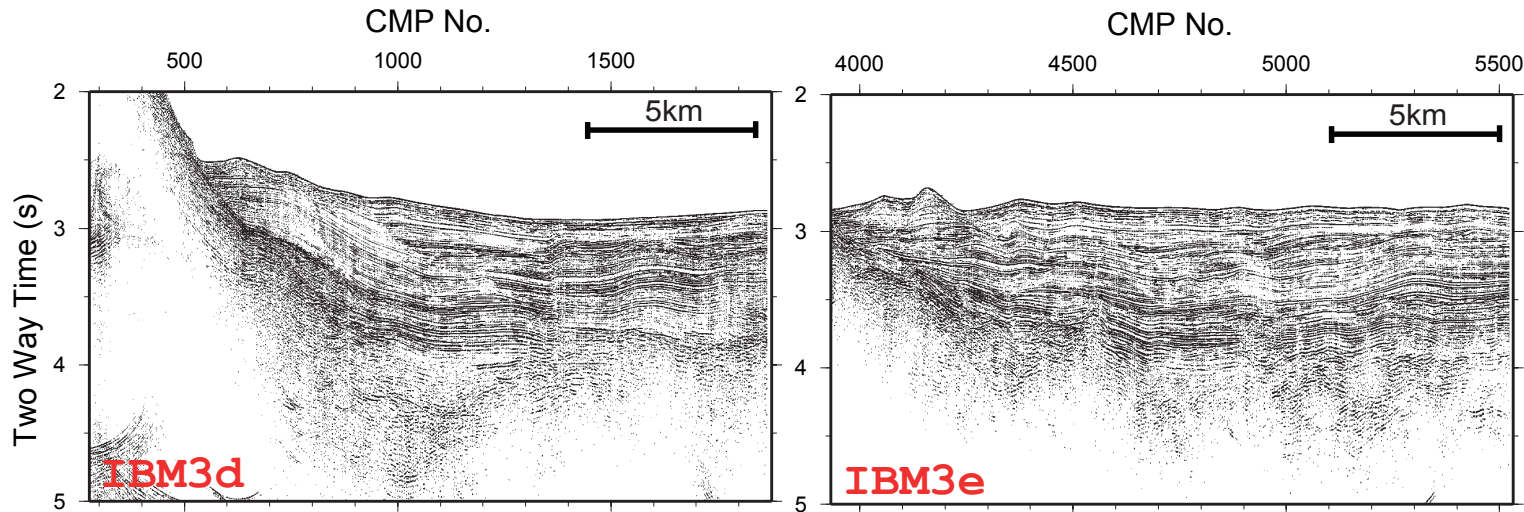
LII, LII and LIV are Neogene sediment. LV is Oligocene-Eocene sediment.
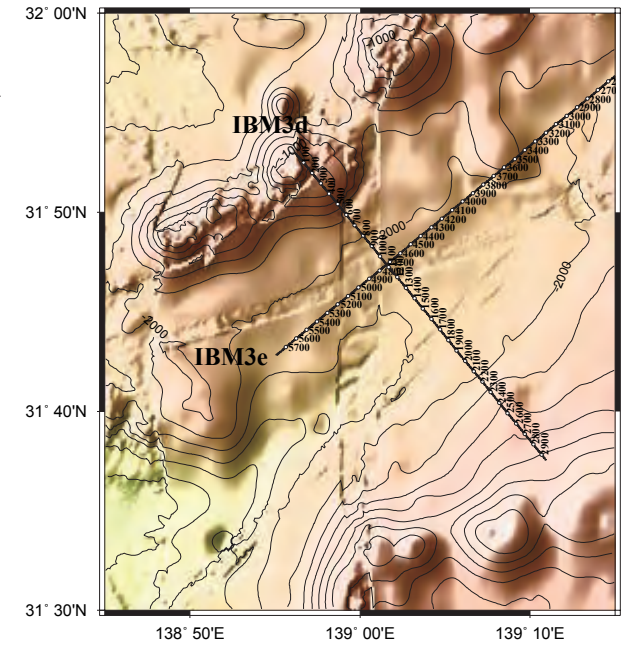
697-Full3: List of potential reviewers

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Education: B.S. (Geology): University of Tokyo, 1986

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Ph. D. (Geology): University of Tokyo, 1991

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Specialty: Igneous Petrology

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2001-present: Group Leader, IFREE, JAMSTEC.

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Selected Publications

Tamura, Y., K. Tani, Q. Chang, H. Shukuno, H. Kawabata, O. Ishizuka, and R. S. Fiske, Wet and Dry Basalt Magma Evolution at Torishima Volcano, Izu-Bonin Arc, Japan: the Possible Role of Phengite in the Downgoing Slab. *Journal of Petrology* **48,** 1999-2031, 2007.

Tamura, Y. & Wysoczanski, R., Silicic volcanism and crustal evolution in oceanic arcs: introduction. *Journal of Volcanology and Geothermal Research* **156,** v-vii, 2006.

Shukuno, H., Tamura, Y., Tani, K., Chang, Q., Suzuki, T. & Fiske, R. S., Origin of silicic magmas and the compositional gap at Sumisu submarine caldera, Izu-Bonin arc, Japan. *Journal of Volcanology and Geothermal Research* **156,** 187-216, 2006.

Embley, R. W. Chadwick, Jr., W. W., Baker, E. T., Butterfield, D. A., Resing, J. A., de Ronde, C. E. J., Tunnicliffe, V., Lupton, J. E., Juniper, S. K., Rubin, K. H., Stern, R. J., Lebon, G. T., Nakamura, K., Merle, S. G., Hein, J. R., Wiens, D. A., & Tamura, Y. , Long-term eruptive activity at a submarine arc volcano. *Nature* **441,** 494-497, 2006.

Tamura, Y., Tani, K., Ishizuka, O., Chang, Q., Shukuno, H. & Fiske, R. S., Are arc basalts dry, wet, or both? Evidence from the Sumisu caldera volcano, Izu-Bonin arc, Japan. *Journal of Petrology* **46,** 1769-1803, 2005.

Tamura, Y., Some geochemical constraints on hot fingers in the mantle wedge: evidence from NE Japan. *In* Larter, R. D. & Leat, P. T. 2003. *Intra-oceanic subduction systems: tectonic and magmatic processes. Geological Society, London, Special Publication* **219**, 221-237, 2003.

Tamura, Y., Yuhara, M., Ishii, T., Irino, N. & Shukuno, H., Andesites and dacites from Daisen volcano, Japan: partial-to-total remelting of an andesite magma body. *Journal of Petrology* **44,** 2243-2260, 2003.

Tamura, Y., Tatsumi, Y. Zhao, D., Kido, Y. & Shukuno, H., Hot fingers in the mantle wedge: new insights into magma genesis in subduction zone. *Earth and Planetary Science Letters* **197**, 105-116, 2002.

Tamura, Y. & Tatsumi, Y., Remelting of an andesitic crust as a possible origin for rhyolitic   magma in oceanic arcs: an example from the Izu-Bonin arc. *Journal of Petrology* **43**, 1029-1047, 2002.

Tamura, Y., Yuhara, M. & Ishii, T., Primary arc basalts from Daisen volcano, Japan: equilibrium crystal fractionation versus disequilibrium fractionation during supercooling. *Journal of Petrology* **41,** 431-448, 2000.

Tamura, Y. & Nakamura, E., The arc lavas of the Shirahama Group, Japan: Sr and Nd isotopic data indicate mantle-derived bimodal magmatism. *Journal of Petrology* **37,** 1307-1319, 1996.

Tamura, Y., Liquid lines of descent of island arc magmas and genesis of rhyolites: evidence from the Shirahama Group, Japan. *Journal of Petrology* **36,** 417-434, 1995.

Tamura, Y., Genesis of island arc magmas by mantle-derived bimodal magmatism: evidence from the Shirahama Group, Japan. *Journal of Petrology* **35,** 619-645. 1994.

Tamura, Y., Koyama, M. & Fiske, R. S., Paleomagnetic evidence for hot pyroclastic debris flow in the shallow submarine Shirahama Group (upper Miocene-Pliocene), Japan. *Journal of Geophysical Research* **96,** 21779-21787, 1991.

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1992   B.Sc. (Geology) at Faculty of Science, University of Tokyo

1994   M. Sc. (Geology) at Geological Institute, School of Science, University of Tokyo

1999   D.Sc.(Geology) for a thesis entitled "Temporal and spatial variation of volcanism and related hydrothermal activity in the back-arc region of the Izu-Ogasawara Arc –application of laser-heating $^{40}Ar/^{39}Ar$ dating technique– at the Geological Institute, School of Science, University of Tokyo in March, 1999. Work supervised by Dr. Kozo Uto of Geological Survey of Japan.

2000-2002 Post Doctoral Research Fellow at the Southampton Oceanography Centre

2000   Awarded the prize for young scientist from the society of Resource Geology

2003   Awarded the prize for young scientist from the Volcanological Society of Japan

Speciality

Ar/Ar geochronology, igneous geochemistry

List of selected publication

1. Ishizuka, O., Geshi, N., Itoh, J., Kawanabe, Y., Tuzino, T., The magmatic plumbing of the submarine Hachijo NW volcanic chain, Hachijojima, Japan: long distance magma transport?, *Journal of Geophysical Research*, in press.

2. Ishizuka, O., Volcanic and tectonic framework of the hydrothermal activity of the Izu-Bonin arc, *Resource Geology,* in press.

3. Ishizuka, O., Taylor, R.N., Milton J.A., Nesbitt, R.W., Yuasa, M., Sakamoto, I.: Processes controlling along-arc isotopic variation of the southern Izu-Bonin arc, *Geochemistry,*

Geophysics, Geosystems, Q06008, doi:10.1029/2006GC001475, 2007.

4. Yamamoto, Y., <u>Ishizuka, O.,</u> Sudo, M., Uto, K.: $^{40}Ar/^{39}Ar$ ages and paleomagnetism of transitionally magnetized volcanic rocks in the Society Islands, French Polynesia: Raiatea excursion in the upper-Gauss Chron, *Geophysical Journal International*, 169, 41-59, 2007.

5. <u>Ishizuka, O</u>, Kimura, J.I., Li, Y.B, Stern, R.J., Reagan, M.K., Taylor, R.N., Ohara, Y., Bloomer, S. H., Ishii, T., Hargrove III, U. S., Haraguchi, S. Early stages in the Evolution of Izu-Bonin Arc volcanism: new age, chemical, and isotopic constraints, *Earth and Planetary Science Letters*, 250, 385-401, 2006.

6. <u>Ishizuka</u>,O., Taylor,R. N., Milton, J. A., Nesbitt, R. W., Yuasa, M., Sakamoto, I. : Variation in the source mantle of the northern Izu arc with time and space -Constraints from high-precision Pb isotopes -, Journal of volcanology and Geothermal Research, 156, 266-290, 2006.

7. Tamura, Y., Tani, K., <u>Ishizuka, O.,</u> Chang, Q., Shukuno, H., Fiske, R.S. :　Are arc basalts dry, wet, or both? Evidence from the Sumisu caldera volcano, Izu-Bonin arc, Japan. *J. Petrol.,* 46, 1769-1803, 2005

8. <u>Ishizuka, O.,</u> Uto, K., Yuasa, M.: Volcanic history of the back-arc region of the Izu-Bonin (Ogasawara) Arc. In: R.D. Larter and P.H. Leat (Eds.), Intra-Oceanic Subduction Systems: Tectonic and Magmatic Processes, *Geol. Soc. Spec. Publ.* 219, 187-205, 2003.

9. <u>Ishizuka, O.,</u> Taylor, R.N., Milton, J.A., Nesbitt, R.W.; Fluid-mantle interaction in an intra-oceanic arc: constraints from high-precision Pb isotopes. *Earth Planet. Sci. Lett.* 211, 221-236, 2003.

10. <u>Ishizuka, O.,</u> Uto, K., Yuasa, M., Hochstaedter, A.G.; Volcanism in the earliest stage of back-arc rifting in the Izu-Bonin arc revealed by laser-heating $^{40}Ar/^{39}Ar$ dating, *J. Volcanol. Geothermal Res.* 120, 71-85, 2002.

11. <u>Ishizuka, O.,</u> Yuasa, M., Uto, K.; Evidence of porphyry copper-type hydrothermal activity from a s＊ubmerged remnant back-arc volcano of the Izu-Bonin arc-implications for the volcanotectonic history of back-arc seamounts-. *Earth Planet. Sci. Lett.* 198, 381-399, 2002.

12. Iizasa, K., Fiske, R. S., <u>Ishizuka, O.,</u> Yuasa, M., Hashimoto, J., Ishibashi, J., Naka, J., Horii, Y., Fujiwara, Y., Imai, A. and Koyama, S. ; A Kuroko-type polymetallic sulfide deposit in a submarine silicic caldera. *Science*, 283, 975-977, 1999.

Biographical Sketch

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Ten representative publications

Closed to open system differentiation at Arenal Volcano (1968-2003). *J. Volcanol. Geothermal Res.* 157, 75-93. C. Ryder, J. Gill, F. Tepley, F. Ramos, M. Reagan. (2006)

Timescales of degassing and crystallization implied by ^{210}Po-^{210}Pb-^{226}Ra disequilibria for andesitic lavas erupted from Arenal volcano. *J. Volcanol. Geothermal Res.* 157, 135-146. M. Reagan, F. Tepley, J. Gill, M. Wortel, and J. Garrison. (2006)

Hf isotope and concentration systematics of the Mariana arc. *Geology* 33, 737-740. D. Tollstrup and J. Gill. (2005)

U-Series isotopes and magma genesis at convergent margins. S. Turner, B. Bourdon, J. Gill. In: Uranium-series Geochemistry (eds. B. Bourdon, G. Henderson, C. Lundstrom, S. Turner) Reviews in Mineralogy and Geochemistry Vol. 52, p. 255-316. (2003)

Across-arc geochemical trends in the Izu-Bonin arc: contributions from the subducting slab. *Geophysics, Geochemistry, Geosystems* Paper No. 2000GC000105. A. G. Hochstaedter, J. Gill, R. Peters, P. Broughton, P. Holden, and B. Taylor. (2001)

Across-arc geochemical trends in the Izu-Bonin arc: constraints on source composition and mantle melting. *J. Geophys. Res*. 105, 495-512. A.G.. Hochstaedter, J. Gill, B. Taylor, O. Ishizuka, M. Yuasa, and S. Morita. (2000)

Volcanologic, tectonic, and geochemical evolution of the Kasuga Seamounts, northern Mariana Trough: ALVIN submersible investigations. *J. Volcanol. Geotherm. Res*. 79, 277-311. P. Fryer, J. Gill, and M. Jackson. (1997)

Geochemical evolution of arc systems in the western Pacific: the ash and turbidite record recovered by drilling. R.J. Arculus, J. Gill, H. Chambray, W. Chen, and R.J. Stern. In: Active Margins and Marginal Basins of the Western Pacific (B. Taylor ed.), AGU Monograph 88, p. 45-65. (1995)

Turbidite geochemistry and the evolution of island arcs and of continents. *Lithos* 33, 135-168. J. Gill, R. Hiscott, Ph. Vidal. (1994)

Explosive deep water basalt in the Sumisu Backarc Rift. *Science* 248, 1214-17. J. Gill and 15 others. (1990)

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Selected publications

Squire RJ and **McPhie J** 2007 Complex facies architecture resulting from prolonged Ordovician to Early Silurian arc-related volcanism, Cadia-Neville region, Lachlan Fold Belt, New South Wales. *Australian Journal of Earth Sciences* 54: 273-292

Stewart AL and **McPhie J** 2006 Facies architecture and Late Pliocene-Pleistocene evolution of a felsic volcanic island, Milos, Greece. *Bulletin of Volcanology* 68: 703-726

Stewart AL and **McPhie J** 2004 An Upper Pliocene coarse pumice breccia generated by a shallow submarine explosive eruption, Milos, Greece. *Bulletin of Volcanology* 66: 15-28

McPhie J and Allen RL 2003 Submarine, syn-eruptive, silicic pyroclastic units in the Mount Read Volcanics, western Tasmania: Influence of vent setting and proximity on facies characteristics. *American GeophysicalUnion, Monograph* 140, 245-258

Raos A and **McPhie J** 2003 The submarine record of a large-scale explosive eruption in the Vanuatu arc: ~1 Ma Efate Pumice Formation. *American GeophysicalUnion, Monograph* 140, 273-284

Skilling I, White J and **McPhie J** 2002 Peperite: A review of processes and products. *Journal of Volcanology and Geothermal Research* 114:1-17

Large RR, **McPhie J**, Gemmell JB, Herrmann W and Davidson G 2001 The spectrum of ore deposit types, volcanic environments, alteration haloes and related exploration vectors in submarine volcanic belts: Some examples from Australia. *Economic Geology* 96: 913-938

Allen SR and **McPhie J** 2000 Water-settling and resedimentation of submarine rhyolitic pumice at Yali, eastern Aegean, Greece. *Journal of Volcanology and Geothermal Research* 95: 285-307

McPhie J 1995 A Pliocene shoaling basaltic seamount: Ba Volcanic Group at Rakiraki, Fiji. *Journal of Volcanology and Geothermal Research* 64: 193–210

McPhie J, Doyle M and Allen R 1993 *Volcanic Textures*. CODES, University of Tasmania, Hobart, 190 pp.

McPhie J and Allen R 1992 Facies architecture of mineralized submarine volcanic sequences: Cambrian Mount Read Volcanics, western Tasmania. *Economic Geology* 87: 587–596