

IODP Proposal Cover Sheet**695-Full2**☐ New☒ Revised☐ Addendum*Please fill out information in all gray boxes**Above For Official Use Only*

	Please check if this is Mission proposal <input type="checkbox"/>	
Title:	Continental Crust Formation at Intra-Oceanic Arc:Arc Foundations, Inception, and Early Evolution	
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Permission to post abstract on IODP Web site: ☒ Yes ☐ No*Abstract: (400 words or less)*

We propose to determine the lithology and composition of Layer 2 of the oceanic crustal basement on which the Izu-Bonin-Mariana (IBM) Arc was initiated, and recover the pyroclastic record from Layer 1 of this crust, from which we will determine the nature of the petrological and geochemical evolution of the first 30 million years of Arc history. The selected drill site (IBM-1) is located at the intersection of crossing multi-channel seismic lines in the Amami Sankaku Basin, located to the east of the Amami Plateau and west of the northern Kyushu-Palau Ridge. The specific aims here are threefold: Recover sediments from the 1300 m sedimentary section observed on MCS profiles. The lower part of the sedimentary section should preserve a valuable record of paleo-oceanographic conditions in easternmost Tethys during the late Mesozoic, including possible oceanic anoxic events, and earliest Paleogene. Above this the sediments should include pyroclastic debris that record conditions during IBM Arc inception and evolution, possible evolution of the Ryukyu Arc and the history of Asian monsoon/aridity. Our current understanding of these initial stages is a period of at least 5 million years dominated in the forearc by boninitic and low-K tholeiitic magmatism. It remains to be tested whether this type of magmatism persisted across the full width of the nascent Arc. We expect the sedimentary record at IBM-1 to preserve evidence of how the upper plate responded to subduction initiation, including possible uplift (unconformities; erosion). The response of the overriding plate during the initial stages of subduction initiation is predicted to result from forced convergence (uplift) vs. spontaneous nucleation of the subduction zone. Above this the sedimentary record should preserve the Paleogene history of IBM arc evolution, as tephra and as volcanoclastic units shed from KPR volcanoes. We plan to penetrate into basement in order to recover samples of oceanic crust to determine its petrological, geochemical, and age characteristics.

Scientific Objectives: (250 words or less)

1. Recover samples of the oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics, and from which to infer the geochemistry of the mantle prior to IBM arc inception and growth. Based on the Sr-Nd-Pb-Hf isotopic composition of Layer 2, we will be able to determine the “Indian” vs. “Pacific” character of the mantle source(s) of this arc foundation, and constrain the subsequent degree of involvement of this pre-arc basement in the subsequent development of the IBM Arc. This basement is likely to be the easternmost fragment of Neo-Tethys (Early Cretaceous or older) preserved in the oceans;
2. Recover sediments from the 1300m cover sequence in which the explosive ash and pyroclastic fragmental records of the pre-IBM history of the region, IBM arc inception, and 50 to 25 Ma (at least) history of arc growth are preserved, the history of Ryukyu Arc activity, and potentially a record of the East Asian aridity/monsoon conditions. Other indicators of paleoceanographic conditions in the region between the Tethyan and Pacific realms will be recovered;
3. Obtain sedimentary evidence for early uplift through the shedding of clastics associated with subduction initiation resulting from forced convergence (uplift) vs spontaneous (subsidence) nucleation of the subduction zone.

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

Proposed Site:

Site Name	Position	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
IBM-1	27.3°N 134.3°E	4720	1300	150	1450	Recovery of Layer 1 and uppermost Layer 2 oceanic crust

An IODP Proposal

Continental Crust Formation at Intra-Oceanic Arc:

Arc Foundations, Inception, and Early Evolution

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1. INTRODUCTION

1.1 Background.

Subduction zones are unique to Earth among the terrestrial planets, but as yet, we do not have a good understanding how they are initiated beyond the recognition that old ($>\sim 25$ million years) ocean lithosphere is gravitationally unstable with respect to the underlying asthenospheric mantle. Two general mechanisms have been advanced for subduction initiation: induced and spontaneous (Gurnis et al., 2004; Stern, 2004). The former results from continued convergence resulting from slab pull along strike of a given system despite local jamming of the subduction zone by buoyant continental or thickened oceanic lithosphere. Outboard stepping (e.g., incipient plate boundary south of India) or polarity reversal (e.g., Solomon Islands consequent to jamming of the Vitiaz Trench by the Ontong Java Plateau) may develop.

Stern (2004) suggests that the Izu-Bonin-Mariana (IBM) system is an example of spontaneous subduction zone nucleation wherein subsidence of relatively old Pacific lithosphere commenced along a system of transform faults/fracture zones adjacent to relatively buoyant lithosphere. Foundering of the old lithosphere is predicted to induce asthenospheric upwelling in an extensional regime forming boninites and eventual forearc ophiolites. The initial record on the overriding plate should be clear: induced subduction likely results in strong compression and uplift whereas spontaneous subduction commences with rifting, spreading and formation of magmas such as boninites and highly depleted, low-K tholeiites.

A diverse and international effort has been and is currently focusing on the processes in and above subduction zones (e.g., Margins¹, Institute for Frontier Research on Earth Evolution²) because the magmatic products of subduction zones seem to be the major building blocks of the continental crust, at least through the Phanerozoic (Davidson and Arculus, 2006). The IODP Initial Science Plan (ISP) identified the origin of continental crust as a primary target of the program: *'The creation and growth of continental crust remains one of the fundamental, unsolved problems in Earth science.'* The Plan further emphasizes: *'Arc magmatism is thought to be a principal process in continental creation. Bulk continental crust is andesitic in composition, but the primary melt extracted from the upper mantle in subduction zones is basaltic. We still do not understand what causes this compositional change'* (p.67).

¹ <http://www.margins.wustl.edu>.

² <http://www.jamstec.go.jp/jamstec-e/IFREE/index.html>

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 geochemists, this observation has been a prime motivation for studies of island and continental arc systems.

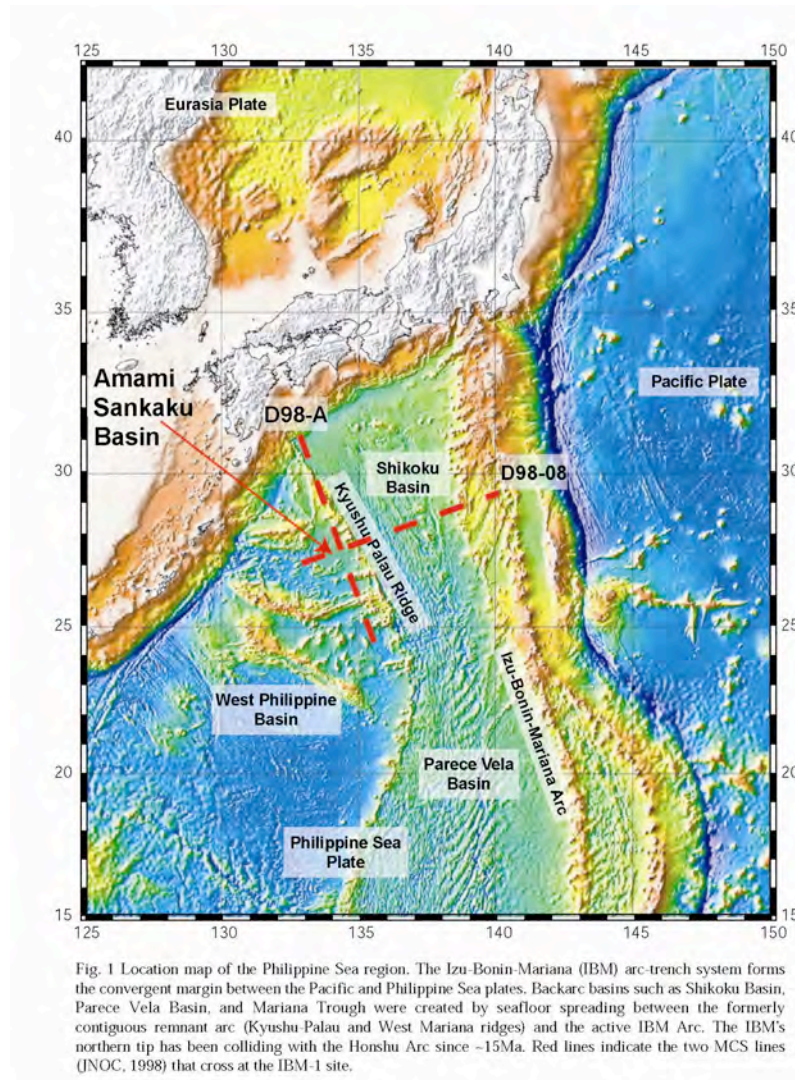
Subsequent studies have substantiated Taylor’s estimate of continental crust bulk composition, and have noted distinctive trace element fractionations (high U/Nb, low Ce/Pb) only found in supra-subduction zone magma types (Hofmann, 1988). During the 1970s, despite the wave of petrologic enthusiasm inspired by the plate tectonic paradigm, it became apparent that andesite is generally not a primary subducted slab- or mantle wedge-derived magma in Phanerozoic juvenile arcs, but overwhelmingly a derivative rock type from parental basaltic magmas (Arculus, 1981). A mass balance (andesite + ultramafic-mafic cumulate (UMC) = basalt) necessitates disposal of the complementary UMC, and is an acute volumetric problem for Phanerozoic arc systems. However, many believe that primary (high-Mg) andesite magmas were a significant component of the Archean continental crust, generated from hot and young subducted lithosphere. Modern seismically-determined arc crustal profiles, while confirming bulk intermediate- SiO_2 intra-oceanic arc compositions for the Izu-Bonin-Mariana system (Suyehiro et al., 1996), may also indicate a solution to the UMC disposal problem: the critical characteristic of cumulates from relatively wet ($\sim 2-6$ wt% H_2O) arc magmas is the delayed crystallisation of plagioclase and the likely sub-Moho predominance of dunite and wehrlite. Behn and Kelemen (2006) have demonstrated lower crustal arc gabbro-norite and pyroxenite are also gravitationally unstable with respect to underlying mantle and could delaminate.

Davidson and Arculus (2006) have suggested the low La/Yb of high mass flux, intra-oceanic arc magmas such as the Izu-Bonin or Tonga systems are a Phanerozoic dilutant of preexisting high La/Yb continental crust in crustal evolution. In other active and similar mass flux arcs such as the Aleutians, elevated La/Yb of some andesitic magmas are much closer to that of the continental crust (Kelemen et al., 2003).

Overall then, it is reasonable to argue a modified andesite model is still consistent with observed features of the continental crust. In this model however, the so-called “subduction zone signature” of arc magmas characterised by (over)abundance anomalies of alkalis, alkaline earths, Pb, Th and U

with respect to rare earth elements (REE) of similar mantle residue-melt incompatibilities (Hofmann, 1988) is attributed to mobilisation of these elements from altered and subducted oceanic crust (all crustal layers) plus underlying hydrated mantle lithosphere. The underabundance of some high field strength elements such as Nb and Ta with respect to REE of similar incompatibility, is conversely regarded by most of us as a true measure of the intrinsic abundances of unmodified mantle wedge overlying the subducted slab, from which basaltic magmas are derived.

An essential boundary condition for understanding arc evolution and continental crust formation is to know the composition, structure, and age of the crust and mantle that existed before subduction began. The objectives outlined in this Proposal are, therefore, a critical component of an overall effort to understand the formation of intermediate-SiO₂ continental crust in the Izu-Bonin-Mariana (IBM)



Arc system: the geochemical and geophysical characteristics of the foundations or basement of the Arc, and the events accompanying inception and possibly most of the first 25 to 30 million years volcanic activity of the Arc. Calculations of mass fluxes through the Arc, production and evolution of magmas including initial mantle wedge source character, are all critically dependent on achieving these objectives. We have identified a region in the Amami Sankaku Basin (ASB) where the foundations of the Arc can be investigated, straightforwardly recoverable

by orthodox riserless drilling (Fig. 1). This Proposal is a direct outcome of an extensive international dialog at workshops held in 2002 (Honolulu, USA), 2006 (Yokohama, Japan), and 2007 (Tokyo, Japan; Honolulu, USA), describes the consensus rationale and scientific objectives for drilling the

foundations of the IBM Arc, and forms one part of an integrated set of drilling proposals for the study of the evolution of this arc system.

1.2 *WHY IBM?*

The IBM system is globally important because we have clear evidence for the age and exact site of inception, duration of arc activity, changes in magmatic composition through time, intervals where backarc magmatism accompanied arc activity but at other times overwhelmed that of an isolated volcanic front and vice versa, and less directly, the nature of the sum product of magmatic activity in the form of seismically-determined crustal structure. It is possible to identify the oceanic basement on and in which the initial arc products following subduction inception were emplaced. For most arc systems the age of inception is unknown and the basement is obscured and/or deeply buried. The majority of currently active intra-oceanic arcs are located in the Western Pacific. Among these, the IBM system extends 2800 km from the Izu Peninsula to Guam and has been extensively surveyed. IBM is arguably the most suitable site for IODP expeditions to understand subduction initiation, arc evolution, and continental crust formation for a number of reasons, including:

- The tectonic history and evolution of the IBM arc and associated backarc basins is better known than any other intra-oceanic arc system;
- 2) The IBM system has been extensively and comprehensively studied in terms of element and material recycling associated with plate subduction, mantle melting, and magma production;
- 3) Studies to date of the IBM system have provided some of the best constrained estimates of mass fluxes in arc systems; these can be further tested and refined with the drilling program being proposed;
- 4) IBM is the intra-oceanic arc focus site for the NSF-MARGINS “Subduction Factory” experiment and for the Japanese Continental Shelf Project.

1.3 *Tectonic Evolution*

It has been generally accepted (Bloomer et al., 1995; Stern, 2004; Gurnis, et al., 2004) that the IBM subduction zone began as part of a hemispheric-scale foundering of old, dense lithosphere in the Western Pacific. This subduction initiation event may have been aided by mantle downwelling suggested to occur at the Indian-Pacific asthenospheric domain boundary (e.g., Okino et al., 2004) or by plate convergence (Hall et al., 2003). The beginning of large-scale subduction initiation is constrained by the age of igneous basement of the IBM fore-arc to have begun at about 50 Ma ago

(Bloomer et al., 1995; Cosca et al., 1998). During this stage, the fore-arc was the site of prodigious igneous activity. The sequence of initial magmatic products is similar everywhere the fore-arc has been sampled, implying a dramatic episode of asthenospheric upwelling and melting, associated with seafloor spreading over a zone that was hundreds of km broad and possible thousands of km long. This activity resulted in the formation of the IBM fore-arc as an in situ ophiolite (Stern, 2004; Ishiwatari et al., 2006).

There are complications however, with our overall understanding of the IBM inception event and some details remain controversial, especially the apparent equatorial latitude of its formation succeeded by possibly 90° of clockwise rotation since ~50 Ma (e.g., Hall, 2002). Other features are noteworthy: for example, if the bend at ~23°N of the Kyushu-Palau Ridge (KPR; Fig. 1) is an original feature, then a continuous strike slip boundary may not have been the locus of arc inception along the full length of the KPR, although continued spreading in the West Philippine Basin may have affected the geometry of the Eocene subduction initiation locus. In addition, continued spreading until ~30 Ma in the West Philippine backarc Basin (WPB) orthogonal to the KPR means the 50 Ma boninites recovered from the southern Mariana forearc may have been transported southwards from their initial location, and the KPR adjacent to the WPB may have been constructed after the inception identified in the IB portion of the Arc. The proposed IBM-1 Site avoids these complications, and has been selected as part of a conjugate set of drilling proposals which together traverse those parts of the Arc which record the earliest episode of arc construction, subsequent opening of the Shikoku Basin and continued active Arc growth during the Neogene (Fig. 2).

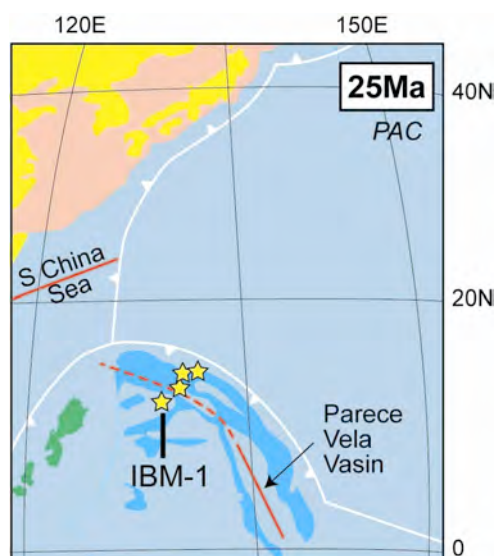


Fig. 2. Location of IBM-1 within the reconstructed IBM system at 25Ma (after Hall et al., 1995). The other yellow stars are proposed sites identified for IBM, and together with IBM-1 form a near-conjugate across-strike set of drilling targets. The initial opening locus of the Shikoku Basin at 25Ma is indicated by the red dashed line.

We note that much of the significance of the IBM-1 Site will be gained independent of the other proposed sites because the transect of previous DSDP-ODP holes provides a context in which to interpret the results from the ASB.

After ~5 million years of spreading, and a period of transition between 45-42 Ma, magmatic activity

localized at, and built, the first modern-style island arc, allowing the fore-arc lithosphere to cool (Taylor, 1992; Ishizuka et al., 2006). This marked the transition from asthenospheric upwelling over foundering lithosphere to true subduction dominated by down-dip motion of the lithosphere. IBM arc volcanism continued until about 30 Ma, accompanied until at least 33 Ma by spreading along a NNW-ESE (present co-ordinates) axis in the West Philippine Sea behind an east Philippines island arc (Deschamps and Lallemand, 2002; Taylor and Goodliffe, 2004). About this time, the IBM arc rifted along its entire N-S (present co-ordinates) length. Spreading began in the south to form the Parece Vela Basin and propagated north and south, resulting in the 'bowed-out' appearance of the Parece Vela basin (Okino et al., 1998).

A major controversy about the WPB is its paleogeography and tectonic nature before initiation of subduction near the Kyushu-Palau Ridge at circa 50 Ma. Published models suggest that the WPB is either a trapped piece of a much larger tectonic plate or that it formed as a back arc basin. Paleomagnetism has played a critical role in estimating the paleolatitude and a putative rotation of the WPB. Hall et al. (1995) have found poles of rotation that are consistent with on-shore samples on Halmahera island on southernmost WPB as well as sites from ODP Legs 125 and 126 on the Izu Arc. From 40 to 50 Ma, Hall et al. (1995) find a 50° clockwise rotation with a southward translation, no significant rotation between 25 and 40 Ma, and a 40° rotation with northward translation from 25 Ma to the present. These data suggested that the WPB was a small plate that formed near the equator, and has rotated nearly 90° since the Eocene. Several additional constraints on paleolatitude and rotation have appeared since. Preliminary analysis of the basaltic basement encountered at Site 1201 of ODP Leg 195 (on the WPB just west of the KPR; Figs. 1 & 4), suggested magnetic inclinations that are shallow and indicate a position of the Philippine Sea Plate near the equator during the Eocene (Salisbury et al., 2002).

1.4 The Arc Basement: advancing our understanding of arc inception and growth

Exploration of basement characteristics for the IBM system is both globally and locally crucial for the following specific reasons: 1. nature of the upper mantle sources from which the oceanic basement was formed – whether of Indian or Pacific character, mid-ocean ridge- or backarc basin-like – and the possibility a lithospheric chemical/physical boundary existed in the western Pacific analogous to that present in the Southern Ocean at the Australian-Antarctic Discordance; 2. the age of the crust – crucial for determining likely lithospheric thickness and possibility of buoyancy contrast with juxtaposed

Pacific lithosphere; 3. geochemical properties of the arc basement given the ubiquity in arcs of assimilation/interaction processes of magmas during passage through the crust ; 4. the possibility that the basement forms all or part of a crustal protolith during subsequent anatexis and development of felsic magmas (i.e., dacite/tonalite); 5. the underlying mantle source of the basement became a primary source of magmas during the inception at ~ 50 Ma of the IBM system, which was dominated by boninites and low-K tholeiites (Pearce et al., 1992), and now preserved in the IBM forearc.

The current consensus with respect to arc magma generation is that fluids (and possibly silicate melts) of the downgoing plate are released into the overlying mantle, triggering melting and production of (mostly) basaltic magma. Sometimes this basalt erupts relatively unmodified at the surface, but more generally stalls en route, variably undergoing (inter alia) fractional crystallisation, wall rock assimilation, magma mixing, and vapor saturation. Knowledge of the crustal components that are possible protoliths for subsequent intra-crustal melts and/or assimilants-contaminants is a first-order requirement for understanding the overall chemical and physical evolution of the Arc crust. Crustal contamination/assimilation occurs in intra-oceanic arcs, and in the case of the IBM system, we have the opportunity to directly determine the nature of the pre-existing crust.

Seismic profiling of the IBM arc crust (Suyehiro et al. 1996; Takahashi et al., 2006) has revealed a thick middle crust with a P-wave velocity of ~6 km/s, interpreted to correspond broadly to an intermediate-to-felsic composition. Underlying this middle crust are velocities consistent with the presence of ordinary oceanic crust, and these persist into the forearc region. Refinement of the seismic models require knowledge of the possible lithologies (at least Layers 1 and 2) forming the initial Arc basement.

1.5 *Scientific Objectives*

Understanding how continental crust forms in intra-oceanic arcs requires knowledge of the inception (initial conditions) and evolution of a representative intra-oceanic arc, such as IBM. Key questions targeted specifically in this Full-Proposal for understanding IBM evolution are: 1. the nature of the original crust and mantle that existed in the region prior to the beginning of subduction in the middle Eocene; 2. the process of subduction initiation and initial (ophiolitic) arc crust formation; and 3. The geochemical and geophysical properties of the initial basement of the IBM Arc which are crucial for interpreting the seismic profiles now being obtained for the entire IBM system.

1.5.1 *The nature of pre-arc crust and mantle*

An essential boundary condition for understanding the evolution of island arcs is to know the composition, structure, and age of the crust and mantle that existed before subduction began. For example, unlike the case for calculations of the crust formation rate at mid-ocean ridges, estimates of intra-oceanic arc fluxes commonly subtract a standard 7 km thickness of oceanic crust within the total arc thickness as a probable pre-arc constituent (Reymer and Schubert, 1984; Flidner and Klemperer, 2000). Depending on the mode of arc growth, pre-existing, non-arc crustal components should contribute geochemically through assimilation and partial melting processes triggered during passage of later arc magmas, and could make up an important part of the lower arc crust. Typically the presence of such relict crust is assumed, because recovery of samples from sub-arc depths of 15 to 20 km is impossible.

In the northern IBM case however, the pre-existing oceanic crust exists under 1-1.5 km of sediments in the ASB adjacent to the Kyushu Palau Ridge (KPR) remnant arc, and perhaps also crops out on the lower forearc slope of the Bonin Trench (DeBari et al., 1999), making possible access to samples of the pre-arc oceanic crustal basement upon which the arc was constructed. We know the age of IBM inception was at ~ 50 Ma (Cosca et al., 1998). The ages of initial lithosphere foundering and the change to down-dip subduction are consistent with geochronology of the Hawaiian-Emperor seamount chain putatively recording the change in Pacific plate motion; recently published geochronology suggests that the bend in the sea mount chain started at ~50 Ma and occurred over a period of ~8 Myr (Sharp and Clague, 2006).

All of the backarc basins of the Philippine Sea Plate are underlain by asthenosphere of Indian Ocean character, geochemically distinct from mantle sources beneath the Pacific Plate now being subducted along its eastern margin (Hickey-Vargas, 1998). It is also clear the initial construction of the IBM Arc rather than developing solely upon oceanic crust, transected a series of Cretaceous-Paleocene ridges (e.g., Amami Plateau, Daito and Oki-Daito ridges) and intervening basins that formed, at least in part, an arc-backarc system (Taylor and Goodliffe, 2004; Hickey-Vargas, 2005; Fig. 1). Recent isotopic results for the Amami Plateau indicate the Philippine Sea Plate also contains Pacific Ocean-type lithosphere, and the nature of the lithosphere on which the proto-IBM Arc was built was likely diverse in character (Hickey-Vargas et al., 2008). It may be that decoding the nature of the magma source in the upper mantle that existed immediately before the IBM arc inception is a key to understanding the cause of initiation of subduction zones and intra-oceanic arc formation. It is also possible of course that the basement of the ASB is of backarc character, generated from upper mantle that was contaminated by Cretaceous subduction processes. These questions can only be

resolved by recovering and studying samples of the ASB basement.

1.5.2 The process of subduction initiation

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

1.5.3 Geochemical and geophysical properties of the initial basement of the IBM Arc

The basement of the IBM Arc comprises sedimentary and underlying igneous rock types that may be more easily studied in the ASB. Following the seminal seismic cross-section obtained by Suyehiro et al. (1996), several other across- and along-strike seismic surveys have expanded our knowledge of the velocity structure of the IBM system. Recovery of samples from and down-hole logging of physical properties of the pre-Arc basement will clearly advance our understanding of the overall nature of the Arc structure. The significance of the petrological and geochemical characteristics of the basement have been outlined above and will be explored in more detail in Section 2.6.

Summary: hypotheses to be tested

(1) The IBM arc inception occurred in a remnant of easternmost neo-Tethys.

This hypothesis can be tested by paleontological and geochemical examination of the pre-existing oceanic crustal rocks.

(2) Inception was induced or spontaneous.

Models show that the magnitude and horizontal wavelength of uplift are dependent on the age of the over-riding plate and knowledge of this age is an important geodynamics input (Gurnis, et al., 2004). The spontaneous model does not predict such a phase of uplift. Understanding the response of the overriding plate during the subduction zone initiation is key for testing these competing proposals.

- (3) *Inception was accompanied by voluminous boninite and low-K tholeiite magmas across the full width of the nascent Arc system.*

Recovery and analysis of pyroclastic materials derived from the KPR in the sedimentary sequences at IBM-1 will confirm or refute this hypothesis.

- (4) *The pre-existing, non-arc crustal and upper mantle component contributes geochemically through assimilation/ partial melting processes triggered during passage of later arc magmas.*

The critical constraints on this hypothesis are obtained by analyzing compositions of magmas produced at the initial and subsequent stages of arc evolution and comparing those with samples of pre-existing crustal materials.

The complete tephra record of forearc/arc/backarc volcanism prior to the inception of the Shikoku Basin at ~ 25 Ma (and possibly sporadically thereafter) will be obtained with proposed Izu rear-arc and ASB drill sites. The Neogene tephra record is relatively well studied but the Paleogene record is sparse. In combination with the known Eocene-recent lava/plutonic products, this will allow us to determine the output variation through time along a transect of the northern IBM Arc compared with Pacific Plate inputs. Geochemical modeling of this system and comparison to the global relationships will test this hypothesis.

2. DRILLING OBJECTIVES

2.1 Planning and Location of Site IBM-1

In order to achieve the scientific goals of this project, the following conditions for site planning and location should be met:

- (1) There must be remnants of drillable, oceanic crust that existed in the region immediately before the IBM arc inception;
- (2) The initial IBM magmatic record should be preserved and include geological evidence for inferring the tectonic setting of magmatism.
- (3) Temporal variations of magmatism in the rear IBM arc should be preserved as a sequence of volcanoclastic sediments and tephra
- (4) In order to highlight the temporal evolution of the IBM arc crust, the effect of along-strike variation in arc evolution should initially be minimized. Ideally, a well-defined section across the IBM arc must be selected.

On balance, based on the above requirements and considering the existing geophysical and seafloor sample data base (including existing DSDP-ODP data and operational experience), a site in the ASB (Fig. 3) and the section across the northern Izu arc along $\sim 32^\circ\text{N}$ (Fig. 2) best meet the proposal objectives.

2.2 Amami Sankaku Basin

The initial products of the IBM system are preserved today in two longitudinal belts: one forming the eastern margin of the WPB, abandoned as a remnant arc (the KPR; Fig. 1) when the Parece Vela-Shikoku Basin opened; the second belt is preserved in the IBM forearc, mostly submarine but sporadically as islands such as Chichi-jima and Guam. To address drilling targets 1 and 2 (above), remnants of pre-IBM oceanic crust could be sought in, or adjacent to, either belt. DeBari et al. (1999) examined basement rocks sampled by submersible and dredge from the inner slope of the IB trench at 32°N . The recovered basalts have mid-ocean ridge basalt (MORB) chemical compositions unlike any other rocks so far sampled in the IBM, and with Indian Ocean isotopic signatures.

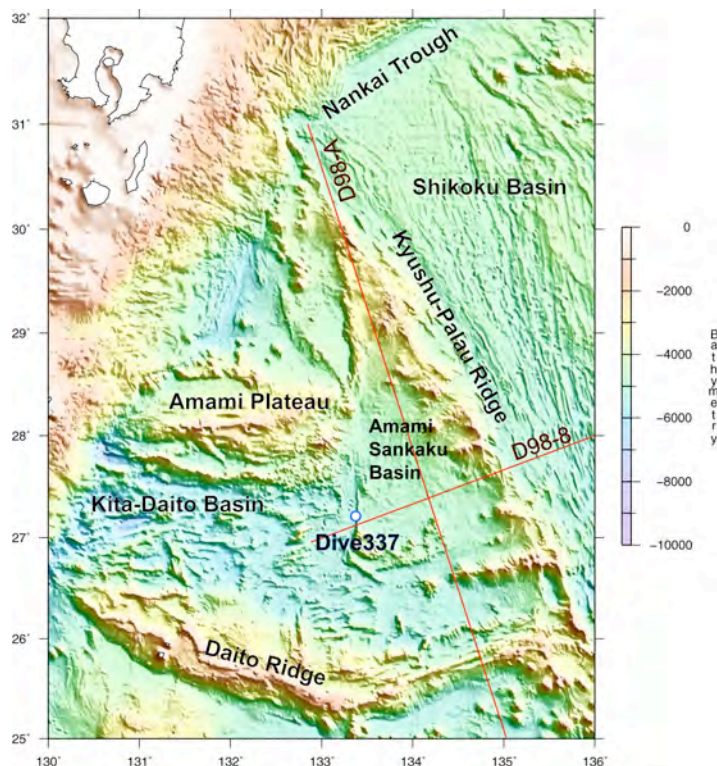


Figure 3. Bathymetry in the region of the ASB; The Amami Plateau and Daito Ridges appear to be Cretaceous island arcs (e.g., Hickey-Vargas, 2005). Observations from Shinkai Dive 337 on the Minami Amami Escarpment are described in the text. IBM-1 is located at the intersection of the two seismic lines (D98-8 and D98-A).

It is suggested these samples could represent a trapped remnant of Philippine Sea Plate on which the IBM arc was built. Because these rocks are limited in their distribution to steep trench-slopes, in >6 km water depths, and without

sedimentary cover, this particular site should not be selected as a drilling target.

After allowing for closure of the Shikoku Basin, the prime IBM drilling targets at $\sim 32^\circ\text{N}$ would have been juxtaposed adjacent to the portion of the KPR that is constructed on the northeastern

margin of the distinctive ASB (Fig. 2). The ASB is bordered to the west, across a major fault scarp (Minami Amami Escarpment) by the Amami Plateau (Fig. 3), whose arc-like basement is Ar/Ar dated at 113-117 Ma (Hickey-Vargas, 2005). Basement on the east Daito Ridge to the south of the ASB has an Ar/Ar date of 118 Ma (Ishizuka, unpublished data). Thus the early ASB sediments and basement are likely to be Early Cretaceous or older (i.e., Neo-Tethyan). A grid of Japanese multi-channel seismic profiles across the ASB (JNOC, 1998) reveal a sedimentary section 1-1.5 km thick, underlain by igneous basement with a Moho reflection a further 2 seconds TWTT below, typical of normal oceanic crust. We selected one drill site (IBM-1) in the ASB at the crossing of two MCS profiles where the sediments are about 1300 m thick, based on MCS stacking velocities (see below).

Drilling through the sediments and into the pre-IBM oceanic crust of the ASB is proposed here to achieve the following significant aims:

1. recover samples of the oceanic basement to determine its petrological, geochemical, and age characteristics, and from which to infer the geochemistry of the mantle prior to IBM arc inception and growth. This is likely to be the easternmost fragment of Neo-Tethys (Early Cretaceous or older) preserved in the oceans.
2. recover sediments from the 1300 m cover sequence in which the explosive ash and pyroclastic fragmental records of the pre-IBM history of the region, IBM arc inception, and 50 to 25 Ma (at least) history of arc growth are preserved (see below). There is the possibility sediments deposited during Cretaceous Period anoxic events (e.g., OAE 3 at 85.8Ma, OAE 2 at 93 to 94 Ma, and possibly OAEs 1a to 1d between 121 and 98 Ma) could be recovered, providing an important link between the classic European and Pacific locations (Schlanger and Jenkyns, 1976).
3. recover sedimentary evidence for early uplift (unconformities; erosion) or subsidence (basin deepening) associated with subduction initiation. These different responses of the overriding plate during the initial stages of subduction initiation are predicted to result from forced convergence (uplift) vs. spontaneous nucleation of the subduction zone (Stern 2004);

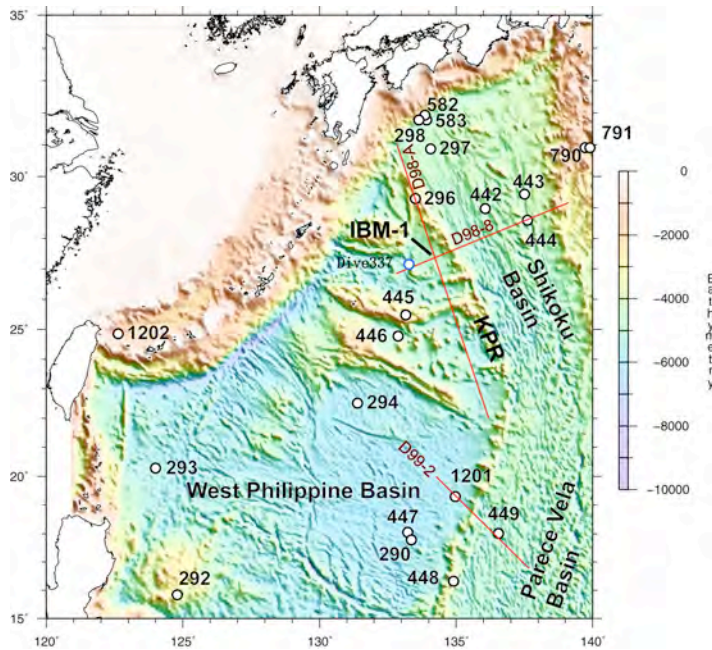


Figure 4. Location of previous DSDP and ODP sites in the region of the ASB, together with Shinkai 6500 Dive 337, and proposed Site IBM-1.

2.3 Seismic imaging of the crust and upper mantle

Multi-channel seismic reflection (MCS) data have been extensively acquired in the northern part of the Philippine Sea Plate by the Japan Oil, Gas and Metals National Corporation (JOGMEC). Although

these surveys cover a wide area of the IBM-KPR as well as the Amami Plateau and Daito Ridge regions, the major target is to obtain detailed images of the sedimentary and deeper crustal structures. These data can provide important information for drilling into the sedimentary and igneous sections, particularly in the ASB.

The interpretation of these profiles coupled with information from DSDP holes (e.g., 296, 445, and 448), and ODP Site 1201 (Fig. 4), has resulted in interpretation of five notable stratigraphic layers in the ASB. The top layer A is (~110m thick) estimated to comprise Plio-Pleistocene pelagic sediments. The second layer is (~160m) estimated to be Upper Miocene turbidites which may come from the KPR but is more likely pelagite given the termination of eruptive activity on the KPR by this time. The third layer C (310m) is suggested to be Lower Miocene turbidite which may be derived from a now-extinct KPR. The fourth layer D (490m) is estimated to be Oligocene and Eocene volcanoclastic turbidites from the KPR. The thickness of layer D increases toward the KPR with a maximum exceeding 1 km, consistent with a prominent source on the Ridge. The nature of this section is important with respect to the “back-arc” IBM proposal of Y. Tamura and colleagues, being considered concurrently with this Proposal. Layer E (230m) is suggested to be pelagic sediments of Eocene or older age; the distribution of this layer is discontinuous across the ASB but present at IBM-1.

Site IBM-1 has been selected at the intersection of two multi-channel seismic profiles (D98-A and D98-8) obtained by JOGMEC (Fig. 5), located about 50 to 80 km southwest of the nearest part of the KPR. At this intersection, the water depth is 4720 m and the depth of the Moho is about 11.5

km. Our interpretation of the stratigraphy at the intersection is:

interval	age	thickness	type
4720-4830 m	Plio/Pleistocene	110m	Pelagite
4830-4990 m	Upper .Miocene	160m	Turbidite
4990-5300 m	Lower Miocene	310m	Turbidite
5300-5790 m	Oligocene/Eocene	490m	Turbidite
5790-6020 m	Eocene or older	230m	Hemipelagite
6020 m-	Basement		
11500 m	Moho		

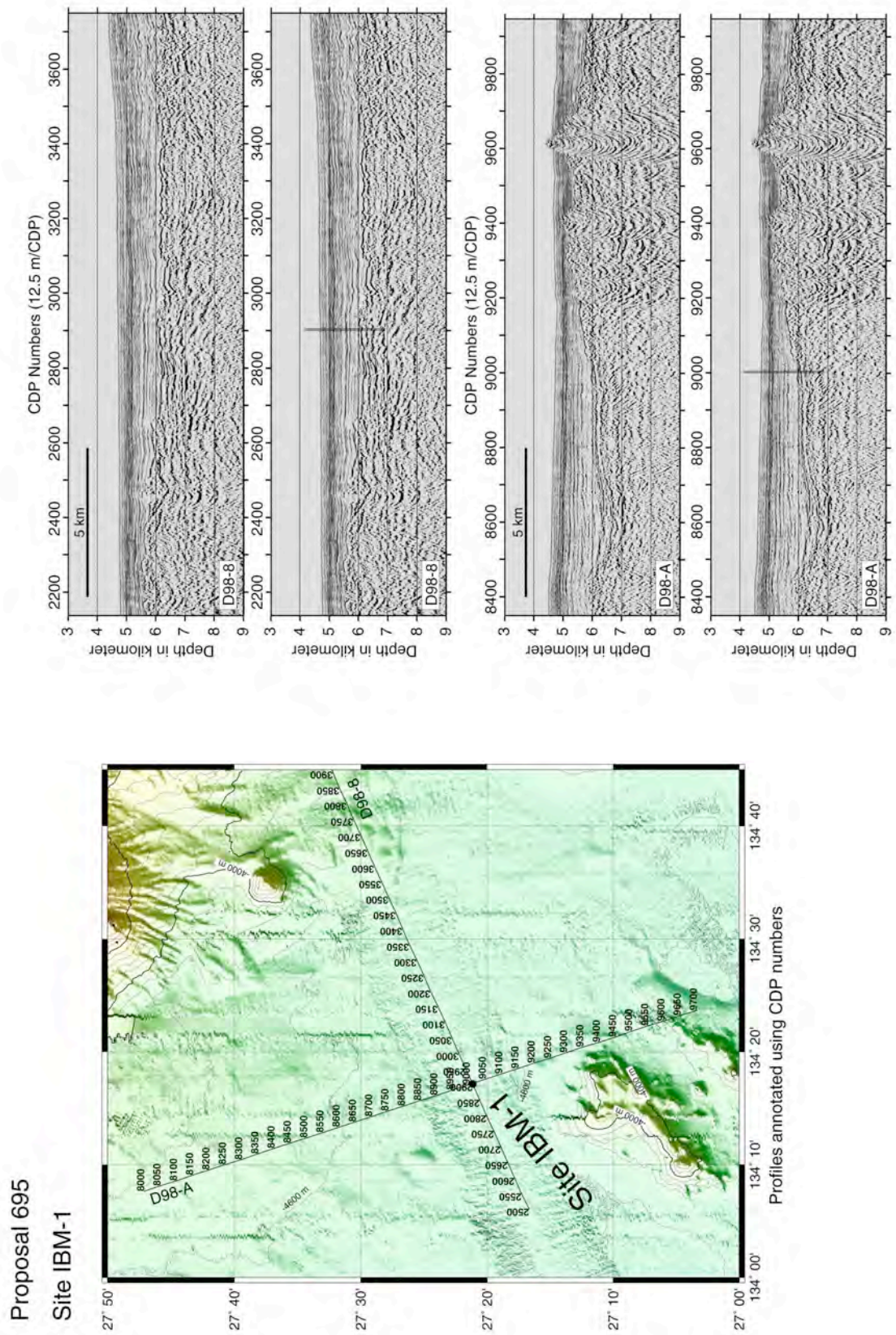


Figure 5. Multi-channel seismic profiles (D98-8 and D98-A) intersecting at IBM-1 (indicated on depth-CDP profiles by a vertical line).

Details of the seismic lines at the location of IBM-1 are shown in Figure 6, with our estimate of the sediment-igneous basement interface and Moho location.

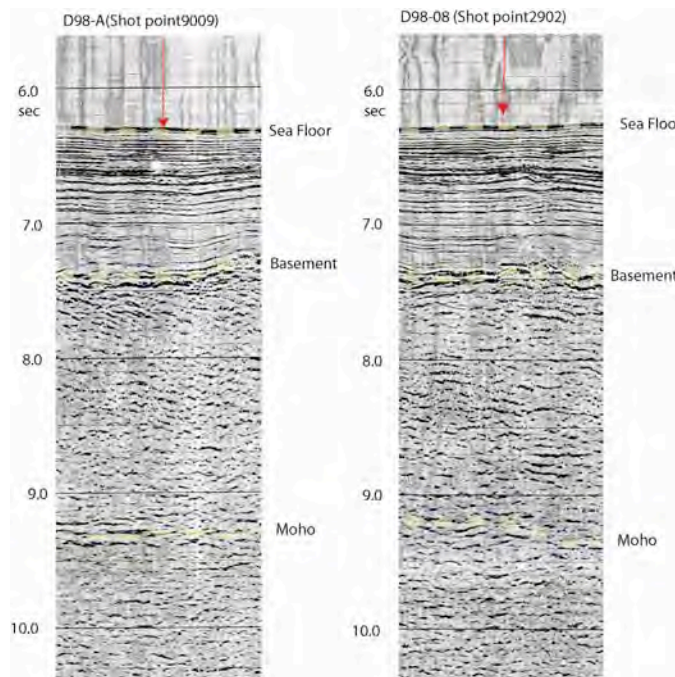


Figure 6. Details of the multi-channel seismic profiles (see Fig. 5 for location) that intersect at IBM-1.

2.3 Minami Amami Escarpment - Shinkai 6500 Dive 337

Reconnaissance of the subseafloor crust in the western margin of the ASB was initiated on a Shinkai 6500 dive (337), conducted at the Minami Amami Escarpment (MAE) (Figs. 3 and 4) in 1996. The dive started at the foot of a 1 km-high steep cliff, and ascended to the top of the Escarpment. Identified lithologies on the dive transect from the

shallower to deeper parts along the submersible track line were the following: ash turbidite with burrows, altered tuffs, calcareous chalk, scoria and basalt breccia with calcareous matrices all covered with pelagic mud and manganese sediments. Occasional pumice blocks were scattered on the sediment surface.

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

2.4 Seismic Profiles of ODP Site 1201

It is useful to examine the seismic and lithologic structures of a recently drilled site in the WPB because of the anticipated shedding of pyroclastic debris and ash from the KPR at IBM-1. One of the objectives of ODP Leg 195 was coring and casing a hole (at Site 1201) in the WPB (Fig. 4) for the installation of a broadband seismometer as part of the International Ocean Network seismometer net

(Shipboard Scientific Party, 2002). The Site lies ~100km west of the KPR on 49Ma-old crust (near Chron 21) formed at the Central Basin Spreading Center of the WPB. We emphasise that while the results from Site 1201 cannot be used to satisfy the specific objectives for IBM-1, some aspects of the sedimentologic processes at the former location are contextually important. The WPB may have formed by slow north-south to northwest-southeast oriented backarc spreading between two opposed subduction zones (Deschamps and Lallemand, 2002; Okino et al., 2004; Hickey-Vargas, 2005). As Site 1201 drifted away from the Central Basin Spreading Center, volcanism ceased and as reported by Salisbury et al. (2002), about “0.5 km of sediments were deposited in three stages: (1) quiescent marine sedimentation in deep water into the late Eocene; (2) pelagic sedimentation mixed with, and finally overwhelmed by, volcanoclastic turbidites from the KPR from the late Eocene through the early Oligocene; and (3) waning turbidite deposition, followed by barren, deep-sea pelagic sedimentation below the CCD from the early Oligocene to the early Pliocene, when sedimentation ceased altogether”.

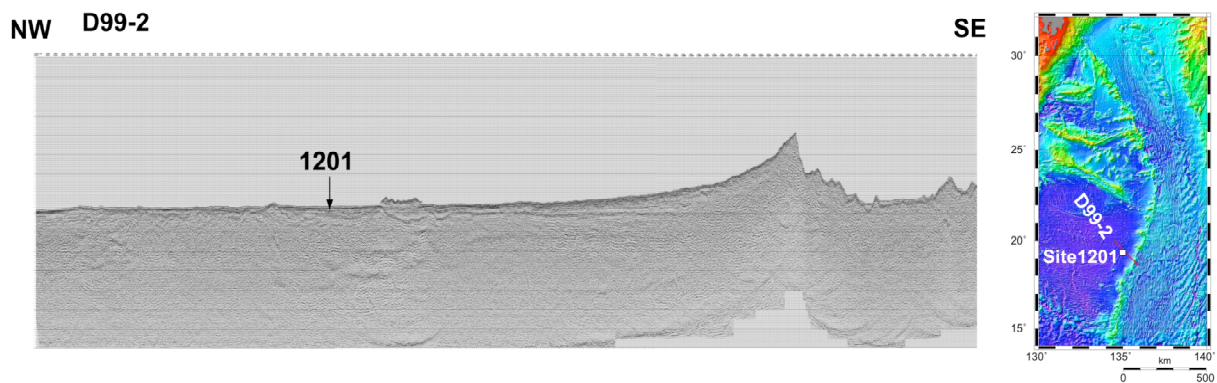


Figure 7. Multichannel seismic line 99-2; lower panel is the SE extension of the upper panel adjoining at the right. The prominent topographic high in the upper panel is the KPR. Location of Site 1201 is to the SW of Line 99-2 and has been projected onto the cross section.

Subsequent to the ODP drilling at Site 1201, a new multichannel seismic line (D99-2; Fig. 4) has been run northwest to southeast through the Site and across the KPR into the Parece Vela Basin. This Line is reproduced in Figure 7. The most obvious feature of this Line is the thickening of the upper part of the sedimentary packages towards the prominent topographic high of the KPR, and the relative constancy in thickness of the lower parts.

2.5 Overall Drilling Plan

In order to characterize the pre-existing oceanic crust and to estimate the tectonic setting before the

In order to characterize the pre-existing oceanic crust and to estimate the tectonic setting before the IBM arc inception, we propose drilling the ASB (IBM-1). Drilling will recover sediments from the 1300m sedimentary section and 150m of igneous basement observed on MCS profiles. Given previous ODP experience, we plan a combination of APC, XCB and RCB riserless drilling: APC coring to refusal, XCB to basement and then RCB penetration of 150m into basement. The hole will be logged with the triple combination and FMS-sonic tools. This hole will require a cased re-entry hole given the requirement of bit replacements. Based on ODP Leg 126 experience with forearc sites 787, 792, and 793 (cased to 600 mbsf), the mid-Oligocene and older sedimentary section is likely to be well lithified and not require casing below that depth.

2.6 Expected Results and their Interpretation

The proponents comprise a multi-disciplinary group of petrologists, geochemists, geophysicists, sedimentologists, and paleontologists brought together to study the diverse samples and logging results anticipated for Site IBM-1.

The sedimentary column at IBM-1 Site was likely always deposited in abyssal water depths. The sediment-unloaded depth to basement places the modern basement at 5.2 km depth, which is typical for oceanic crust of ~ 80 Ma age (Stein and Stein, 1992). This is a little younger than the assumed age derived from the nearby basement sampling and suggests that the crust is thicker than normal oceanic in this place or has been thermally rejuvenated since crustal generation. Assuming a simple thermal evolution of the lithosphere, this places the site above the CCD until the Miocene ~24 Ma (Van Andel, 1975), suggesting good biostratigraphic control with nannofossils.

The lower part of the sedimentary section should preserve a valuable record of paleo-oceanographic conditions in easternmost Tethys during the late Mesozoic and earliest Paleogene. Above this the sediments should include pyroclastic debris that record conditions during IBM Arc inception and evolution. Our current understanding of these initial stages is a period of at least 5 million years dominated in the forearc by boninitic and low-K tholeiitic magmatism. It remains to be tested whether this type of magmatism persisted across the full width of the nascent Arc. The bulk of the section postdates the initiation of subduction of the IBM Arc and thus the sediments are expected to largely comprise mass wasting deposits, the bulk of which would be turbidites derived from the Arc prior to opening of the Parece Vela Basin after ~25 Ma (Ishizuka et al., 2007). The volcanoclastic debris will allow the initial magmatic evolution of the arc to be reconstructed from 30-50 Ma. Such old materials will clearly have suffered some diagenesis and may be generally unsuitable for the

study of how the volatile flux through the subduction zone has varied through time using fresh glassy materials. However, these types of sediment do provide a relatively well dated record of the water-immobile element evolution (high field strength elements) that provides an image of the degree of depletion of the evolving mantle wedge after the initiation of subduction. This in turn has implications for the nature of mantle flow in a new trench system. In addition, isotope systems such as Nd and Li can provide measures of how much sediment and crustal recycling the arc is experiencing during that time. This is important because the long-term history of crustal recycling is important to understanding how the arc crust is constructed.

Since 25 Ma, the IBM-1 Site has been more distal from the active arc and would not have received volcanoclastic materials in the same way. Indeed the rapid cessation of mass wasting would provide timing for the rifting and subsidence of the KPR arc prior to seafloor spreading in the Parece Vela Basin. Since that time the Site would have derived distal ashes from the Ryukyu and SW Japan arcs, as well as the Izu Arc. These should be readily distinguished on the basis of their more evolved continental chemistry and allow constraints be placed on its evolution. This is a non-trivial issue because the history of Ryukyu and SW Japan magmatism is debated and is central to understanding the evolution of the SW Japan subduction zone and the arc accretion history in Taiwan, the global type example of arc-continent collision. In one model, the Ryukyu is a long-lived arc and collision of the Luzon Arc with the margin is a recent process, only occurring close to the modern orogen (Hall, 2002; Huang et al., 2006). Alternatively the Ryukyu may be a recently generated arc formed in the wake of a progressive arc-continent collision migrating to the SW along with a rifting Okinawa Trough (Clift et al., 2003; Suppe, 1984). Kimura et al. (2003) argue that the modern episode of subduction beneath SW Japan began in the early Miocene. Dating the onset of Ryukyu and SW Japan arc volcanism is important to constraining regional tectonic models, with implications for more general processes.

The Neogene history of sedimentation may have application to the reconstruction of the East Asian monsoon. It is well accepted that the winter monsoon and spring storms are responsible for blowing dust from central Asia into the Pacific Ocean (Rea, 1994), including the area of IBM-1. Thus, grain size analysis can be employed to identify the eolian silt material and quantify the rates of mass accumulation (MAR) at much more proximal site than the North Pacific. This MAR can be used as a proxy for the aridity of central Asia. In contrast, the grain size can be used to measure the strength of winds and test the hypothesis that initial intensification of the winter monsoon occurred between 20 and 30 Ma (Rea, 1994), while aridification of Asia dates largely from ~8 Ma (Guo et al.,

2002). Although the region does lie over the edge of the Western Pacific Warm Pool, its use in reconstructing the formation of this feature is limited by the depth, which would tend to eliminate the crucial foraminifer record below the CCD since the Middle Miocene when current models would predict the onset of warming (Kuhnt et al., 2004).

In summary, there are three putative stratigraphic intervals we hope to recover from the ASB core: the sequence immediately overlying basement, an intermediate sequence reflecting subduction initiation, and the final sequence. The proposed IBM-1 hole is ideally located to distinguish between the geodynamic models described in Section 1.1, through sedimentary horizons that can be seismically traced eastward to the KPR. A sequence of pelagic sediments overlying the basement and eventually overlain by ash or volcanoclastic layers from the new arc is expected. However, in the forced nucleation model, we predict that coarse-grained terrigenous sediments eroded from basalts and gabbros making up the uplifted, nucleating margin would occur between these sequences. The intervening terrigenous layer would be missing if the subduction zone self-nucleated, which should occur in an extensional setting.

Coarse-grained layers have been recovered in comparable settings and used to infer rapid uplift. For example, cobbles have been recovered in an Eocene conglomerate from DSDP Hole 446 adjacent to the now flat-topped Daito Ridge (just south of ASB) suggesting rapid uplift in the Eocene [Mills, 1980]. However, this Hole was located in a confined basin 18 km in width adjacent to the Ridge. ODP site 833 located in the New Hebrides may be a better example for what we could expect to find at IBM-1. At this Site, breccia and conglomeratic layers were found in Miocene deepwater clastics 50 km from their inferred source (Espiritu Santo; Greene et al., 1994). Finally, within continents, distances of gravel deposition (measured normal to orogenic front) with respect to their orogenic source areas are up to 50 km but usually confined because of the width of the flexural basins (Heller and Paola, 1989). However, in the absence of a confining basin, as expected from geodynamic models (Gurnis et al., 2004), gravels can extend to substantially greater distances (up to several hundred kilometers) (Heller et al., 2003). Consequently, a variety of examples from oceanic and continental settings indicate coarse-grained sediments could be found at IBM-1 which is sited about 50 to 80 km from the KPR.

If we find breccia layers indicating forced subduction, then there is the possibility of learning even more from the lithology and age of the breccia providing additional diagnostic constraints on the tectonics of incipient subduction. Taking the Macquarie Ridge Complex (MRC) south of New Zealand as a prime example of forced subduction, we note the basement is thrust upward as a ridge

with a width of ~100 km, locally becoming subaerial (at Macquarie Island) or with a sea-level beveled top. In this situation, basement-derived breccia fragments have the same (high temperature) Ar-Ar age as the basement. Lower temperature chronometers (such as fission track and U-He) could reveal important information on the thermal history of the incipient ridge. If the high temperature age of the breccia is substantially less than the ASB basement age, this indicates spontaneous subduction initiation.

We plan to penetrate into basement sufficiently deeply in order to recover 20 or more flow units representing relatively fresh samples of oceanic crust Layer 2 to determine its petrological, geochemical, age, and potentially magnetic characteristics. Establishing the presence or otherwise of local variations in geochemical composition are vital for unravelling the melting processes in the mantle sources and further evolution during crustal fractionation (e.g., Langmuir et al., 1992). It is possible for example that variations in the nature of the upper mantle occurred during the development of the ASB igneous crust from interchange between Pacific- and Indian-type mantle sources, but recovery of multiple flow units will be necessary to detect these influences.

Salisbury et al. (2002) report considerable low-temperature (100 to 150°C) zeolite facies hydrothermal alteration in the uppermost 20m of the 90m of pillow basalt recovered at Hole 1201D, and alteration to zeolites and clays of vitric shards has occurred in the overlying volcanoclastic turbidites. Despite these alteration effects, Savov et al. (2006) were able to separate sufficiently fresh samples for extensive petrologic and geochemical studies, especially from the deeper samples. Based on the Sr, Nd, Pb, and Hf isotopic characteristics of these pillow basalts, Savov et al. (2006) propose a back-arc basin tectonic setting for these materials, sourced from an Indian Ocean-type mantle, consistent with prior knowledge regarding the Central Basin Spreading Center of the WPB. Trace element and isotopic differences between the basement basalts and overlying volcanoclastic turbidites are explained by the addition of a subducted sediment component together with hydrous fluids from the subducted Pacific Plate into the Indian Ocean-type mantle wedge source.

We anticipate also recovering a substantial subaerially-derived, IBM Paleogene ash record for which limited data have so far been obtained in IBM forearc sites (e.g., Bryant et al., 2003). Given the likely relatively low heat flow in the ASB, preservation of the ashes is likely to be sufficient for the type of detailed microanalytical studies that have established the temporal record of geochemical evolution in the IBM system (e.g., Arculus et al., 1995).

The logging results from IBM-1 will include density, porosity, and velocities; all of these are critical in terms of understanding the seismic structure of the upper crust of the ASB and its possible

extension into the KPR.

2.7 Risks and their Circumvention

Proposed Site IBM-1 is typical of many that have been successfully drilled in riserless mode by the IODP and its predecessor programs. The seismic section is consistent with a relatively thick Layer 1 overlying igneous basement. Given the recent experience at Site 1201D, there should be few problems in terms of orthodox drilling although we note some hole instabilities there led to an abbreviation of the logging program.

3. DISCUSSION AND SUMMARY

3.1 New Information and Better Scientific Understanding

This proposal seeks to determine the lithology and composition of Layer 2 of the oceanic crustal basement on which the northern portion of the IBM Arc was initiated, and recover the pyroclastic record from Layer 1 of this crust, from which the nature of the petrological and geochemical evolution of the first 25 million years of Arc history will be discovered. It is not an easy global task to identify straightforwardly a location where pre-Arc basement is accessible. We believe the selected drill site at IBM-1 is one of these rare examples, accessible only through deep sea drilling.

The Site is located at the intersection of crossing multi-channel seismic lines in the Amami Sankaku Basin, located to the east of the Amami Plateau and west of the northern KPR. The specific aims here are threefold: Recover sediments from the 1300m sedimentary section observed on MCS profiles. The lower part of the sedimentary section should preserve a valuable record of paleo-oceanographic conditions in easternmost Tethys during the late Mesozoic and earliest Paleogene including possible ocean anoxic events in the Late Cretaceous. Above these strata, the sediments should include pyroclastic debris that record conditions during IBM Arc inception and evolution, and records of the evolution of the Rykyu and SW Japan arcs and the aridity of eastern Asia. Between these sequences there is the possibility of coarse-grained clastics indicative of subduction initiation.

Our current understanding of these initial stages is a period of at least 5 million years dominated in the forearc by boninitic and low-K tholeiitic magmatism. It remains to be tested whether this type of magmatism persisted across the full width of the nascent Arc. We expect the sedimentary record at IBM-1 to preserve evidence of how the upper plate responded to subduction initiation, including possible uplift reflecting the response of the overriding plate during the initial stages of subduction initiation, either from forced convergence (uplift) vs. spontaneous nucleation of the subduction zone.

Above this the sedimentary record should preserve the Paleogene history of IBM arc evolution, as tephra and as volcanoclastic units shed from the KPR. All of these results in the best possible outcome will provide fundamentally important new information regarding the formation of the basement, paleoceanographic conditions in the region between the Tethys and Pacific, and most significantly the inception and earliest evolution of an archetypal intraoceanic arc. The minimum results will be fundamentally depend on the degree of alteration of the pyroclastic materials and Layer 2, but we have a battery of geochemical tools with which to address these problems based on past experience with previous drilling recoveries in similar materials.

The following are the specific scientific objectives: 1. Recover samples of the oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics, and from which to infer the geochemistry of the mantle prior to IBM arc inception and growth. Based on the Sr-Nd-Pb-Hf isotopic composition of Layer 2, we will be able to determine the “Indian” vs. “Pacific” character of the mantle source(s) of this arc foundation. This is likely to be the easternmost fragment of Neo-Tethys (Early Cretaceous or older) preserved in the oceans. 2. Recover sediments from the 1300 m cover sequence in which the explosive ash and pyroclastic fragmental records of the pre-IBM history of the region, IBM arc inception, and 50 to 25 Ma (at least) history of arc growth are preserved, the history of Rykyu and SW Japan activity, and potentially a record of the East Asian aridity/monsoon conditions; 3. Obtain sedimentary evidence for any early uplift through the shedding of clastics associated with subduction initiation resulting from forced convergence (uplift) vs. spontaneous (subsidence) nucleation of the subduction zone.

4. SITE DESCRIPTION

Site IBM-1 is in the ASB at 27.3°N, 134.3°E in 4720m water depth. The structure of the ASB crust appears to be typically oceanic with 1300m of sediments overlying a basement of 5.48km thickness.

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PERSONAL DATA

Born: 20th January 1949 in Calcutta, India
Home: 32 Macdonnell Street, Yarralumla, ACT 2600, Australia

PROFESSIONAL EXPERIENCE

1994-present	Professor and 8-years as Head of Department of Geology/Department of Earth & Marine Sciences, Australian National University
1989-94	Professor and Head of Department of Geology and Geophysics, University of New England, Armidale, NSW.
1983-89	Assistant then Associate Professor, Department of Geological Sciences, University of Michigan.
1977-83	Research Fellow, Research School of Earth Sciences, Australian National University, Canberra, ACT, Australia.
1975-76	Assistant Professor, Department of Geology, Rice University, Houston, Texas.
1973-75	Post-doctoral Fellow of the Carnegie Institution of Washington, Geophysical Laboratory, Washington DC.

EDUCATION

1973	PhD, University of Durham, UK
1970	BSc, University of Durham, UK

ODP EXPERIENCE

1988	Shipboard Scientist, ODP Leg 125
1991-94	Director of Australian ODP Secretariat and PCOM representative for the Canada-Australia-(Korea-ROC) consortium

RESEARCH VESSEL EXPERIENCE

2004	Chief Scientist NoToVE research voyage, Shipboard Scientist NZAPLUME III, Chief Scientist CoTroVE research voyage
2000-02	Shipboard Scientist and Co-Proponent on 4 research voyages

PUBLICATIONS

125 refereed papers in international journals and book chapters

Selected Publications

- Davidson, J.P., and Arculus, R.J. (2006) The significance of Phanerozoic arc magmatism in generating continental crust. In M. Brown and T. Rushmer (Eds) *Evolution and Differentiation of the Continental Crust*, Cambridge University Press, 135-172.
- McConachy, T.F., Arculus, R.J., Yeats, C.J., Binns, R.A., Barriga, F.J.A.S., McInnes, B.I.A., Rakau, B., Sestak, S., Sharpe, R., Tevi, T. (2005) New hydrothermal activity and alkalic volcanism in the Coriolis Back Arc troughs, Vanuatu. *Geology*, 33, 61-64.
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Position held: researcher

Date of Employment: 1 April, 1994

also Part-time researcher at IFREE, JAMSTEC (since 1 June, 2006) and
associate professor at Tsukuba University (since 1 April, 2006)

Education and Qualification:

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 $^{40}\text{Ar}/^{39}\text{Ar}$ 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., Ishizuka, O., Sudo, M., Uto, K.: $^{40}\text{Ar}/^{39}\text{Ar}$ 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. 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. 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. Ishizuka, 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., 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. *J. Petrol.*, 46, 1769-1803, 2005
8. Ishizuka, O., 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. Ishizuka, O., 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. Ishizuka, O., 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 $^{40}\text{Ar}/^{39}\text{Ar}$ dating, *J. Volcanol. Geothermal Res.* 120, 71-85, 2002.
11. Ishizuka, O., Yuasa, M., Uto, K.; 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 Planet. Sci. Lett.* 198, 381-399, 2002.
12. Iizasa, K., Fiske, R. S., Ishizuka, O., 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.

IODP Site Summary Forms:

Form 1 - General Site Information

Please fill out information in all gray boxes

Revised 7 March 2002

New

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Revised

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Section A: Proposal Information

Title of Proposal:

Continental Crust Formation at Intra-Oceanic Arc:
Arc Foundations, Inception, and Early EvolutionDate Form
Submitted:April 1st 2008Site Specific
Objectives with
Priority
(Must include general
objectives in proposal)

1. Recover samples of the oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics, and from which to infer the geochemistry of the mantle prior to IBM arc inception and growth. Based on the Sr-Nd-Pb-Hf isotopic composition of Layer 2, we will be able to determine the "Indian" vs. "Pacific" character of the mantle source(s) of this arc foundation, and constrain the subsequent degree of involvement of this pre-arc basement in the subsequent development of the IBM Arc. This basement is likely to be the easternmost fragment of Neo-Tethys (Early Cretaceous or older) preserved in the oceans;

2. Recover sediments from the 1300m cover sequence in which the explosive ash and pyroclastic fragmental records of the pre-IBM history of the region, IBM arc inception, and 50 to 25 Ma (at least) history of arc growth are preserved, the history of Ryukyu Arc activity, and potentially a record of the East Asian aridity/monsoon conditions. Other indicators of paleoceanographic conditions in the region between the Tethyan and Pacific realms will be recovered;

3. Obtain sedimentary evidence for early uplift through the shedding of clastics associated with subduction initiation resulting from forced convergence (uplift) vs spontaneous (subsidence) nucleation of the subduction zone.

List Previous
Drilling in Area:

Section B: General Site Information

Site Name:
(e.g. SWPAC-01A)

IBM-1

If site is a reoccupation
of an old DSDP/ODP
Site, Please include
former Site #

Area or Location:

Amami Sankaku Basin
Between the Kyushu Palau
Ridge and Amami Plateau

Latitude:

Deg: 27

Min: 18

Jurisdiction:

Japan

Longitude:

Deg: 134

Min: 18

Distance to Land:

350 km (Kitadaito Island)

Coordinates
System:

WGS 84,

Other ()

Priority of Site:

Primary:

Alt:

Water Depth:

4720 m

Section C: Operational Information

	Sediments	Basement
Proposed Penetration: (m)	1300	150m (assuming 2m hr-1 with 75 hour (new bit) life)
	What is the total sed. thickness? 1300 m	
	Total Penetration: 1450 m	
General Lithologies:	Pelagic sediments, volcanoclastic turbidites, tephra layers	Massive pillow lavas and breccia
Coring Plan: (Specify or check)	1-2-3-APC <input checked="" type="checkbox"/> VPC* <input type="checkbox"/> XCB <input checked="" type="checkbox"/> MDCB* <input type="checkbox"/> PCS <input type="checkbox"/> RCB <input checked="" type="checkbox"/> Re-entry <input checked="" type="checkbox"/> HRGB <input type="checkbox"/> <i>* Systems Currently Under Development</i>	
Wireline Logging Plan:	Standard Tools Neutron-Porosity <input checked="" type="checkbox"/> Litho-Density <input checked="" type="checkbox"/> Gamma Ray <input checked="" type="checkbox"/> Resistivity <input checked="" type="checkbox"/> Acoustic <input checked="" type="checkbox"/> Formation Image <input checked="" type="checkbox"/>	Special Tools Borehole Televiwer <input checked="" type="checkbox"/> Nuclear Magnetic Resonance <input type="checkbox"/> Geochemical <input type="checkbox"/> Side-Wall Core Sampling <input type="checkbox"/> Others ()
		LWD Density-Neutron <input type="checkbox"/> Resistivity-Gamma Ray <input type="checkbox"/> Acoustic <input type="checkbox"/> 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:26.5	Logging:5
Future Plan:	Longterm Borehole Observation Plan/Re-entry Plan	
Hazards/ Weather:	Please check following List of Potential Hazards Shallow Gas <input type="checkbox"/> Complicated Seabed Condition <input type="checkbox"/> Hydrothermal Activity <input type="checkbox"/> Hydrocarbon <input type="checkbox"/> Soft Seabed <input type="checkbox"/> Landslide and Turbidity Current <input type="checkbox"/> Shallow Water Flow <input type="checkbox"/> Currents <input type="checkbox"/> Methane Hydrate <input type="checkbox"/> Abnormal Pressure <input type="checkbox"/> Fractured Zone <input type="checkbox"/> Diapir and Mud Volcano <input type="checkbox"/> Man-made Objects <input type="checkbox"/> Fault <input type="checkbox"/> High Temperature <input type="checkbox"/> H ₂ S <input type="checkbox"/> High Dip Angle <input type="checkbox"/> Ice Conditions <input type="checkbox"/> CO ₂ <input type="checkbox"/>	What is your Weather window? (Preferable period with the reasons) May to August is Optimal; typhoon risk in late August to September

Form 2 - Site Survey Detail

IODP Site Summary Forms:

Please fill out information in all gray boxes

New

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Revised

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Proposal #: 695-Full2	Site #: IBM-1	Date Form Submitted: April 1 st 2008
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	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			Primary Line(s) :Location of Site on line (SP or Time only) Crossing Lines(s):
2	Deep Penetration seismic reflection		to be submitted in April, 2008	Primary Line(s): Location of Site on line (SP or Time only): D98-8 collected by JOGMEC Crossing Lines(s): D98-A collected by JOGMEC
3	Seismic Velocity [†]			
4	Seismic Grid			
5a	Refraction (surface)			
5b	Refraction (near bottom)			
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			
10	Heat Flow			
11a	Magnetics			Map complied by AIST, Japan, is published.
11b	Gravity			Map complied by AIST, Japan, is published.
12	Sediment cores			
13	Rock sampling			
14a	Water current data			
14b	Ice Conditions			
15	OBS microseismicity			
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.

Form 3 - Detailed Logging Plan

IODP Site Summary Forms:

New ☐ Revised ☒

Proposal #: 695-Full2	Site #: IBM-1	Date Form Submitted: April 1 st 2008
Water Depth (m): 4720	Sed. Penetration (m): 1300	Basement Penetration (m): 150

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: 5 days

Measurement Type	Scientific Objective	Relevance (1=high, 3=Low)
Neutron-Porosity	Volcaniclastic and pelagic sediments, and igneous basement porosity; relate core to bulk crustal properties	1
Litho-Density	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	Velocities (Vp and Vs) of different sediment facies and igneous basement for synthetic seismogram	1
FMS	lithology, sedimentary structures, magnetic field	1
BHTV	Downhole stresses, borehole stability, lithology	1
Resistivity-Laterolog	Lithology (thickness, geometry)	1
Magnetic/Susceptibility	Magnetic polarity	1
Density-Neutron (LWD)	No	
Resistivity-Gamma Ray (LWD)	No	
Other: Special tools (CORK, PACKER, VSP, PCS, FWS, WSP)	VSP: core-log-seismic integration	1

<p>For help in determining logging times, please contact the ODP-LDEO Wireline Logging Services group at:</p> <p>borehole@ldeo.columbia.edu http://www.ldeo.columbia.edu/BRG/brg_home.html Phone/Fax: (914) 365-8674 / (914) 365-3182</p>	<p>Note: Sites with greater than 400 m of penetration or significant basement penetration require deployment of standard toolstrings.</p>
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Form 4 – Pollution & Safety Hazard Summary

IODP Site Summary Forms:

Please fill out information in all gray boxes

New

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Revised

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Proposal #: 695-Full2	Site #: IBM-1	Date Form Submitted: April 1 st 2008
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1	Summary of Operations at site: (Example: Triple-APC to refusal, XCB 10 m into basement, log as shown on page 3.)	Recover pelagic sediment and volcanoclastic turbidite filling the basin and penetrate into oceanic basement to determine its petrological, geochemical, age, and magnetic characteristics APC to refusal, then XCB to igneous basement. Then RCB to 1450m
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 submarine cables
9	Summary: What do you consider the major risks in drilling at this site?	Drilling of volcanoclastic material.

IODP Site Summary Forms:

Form 5 – Lithologic Summary

New

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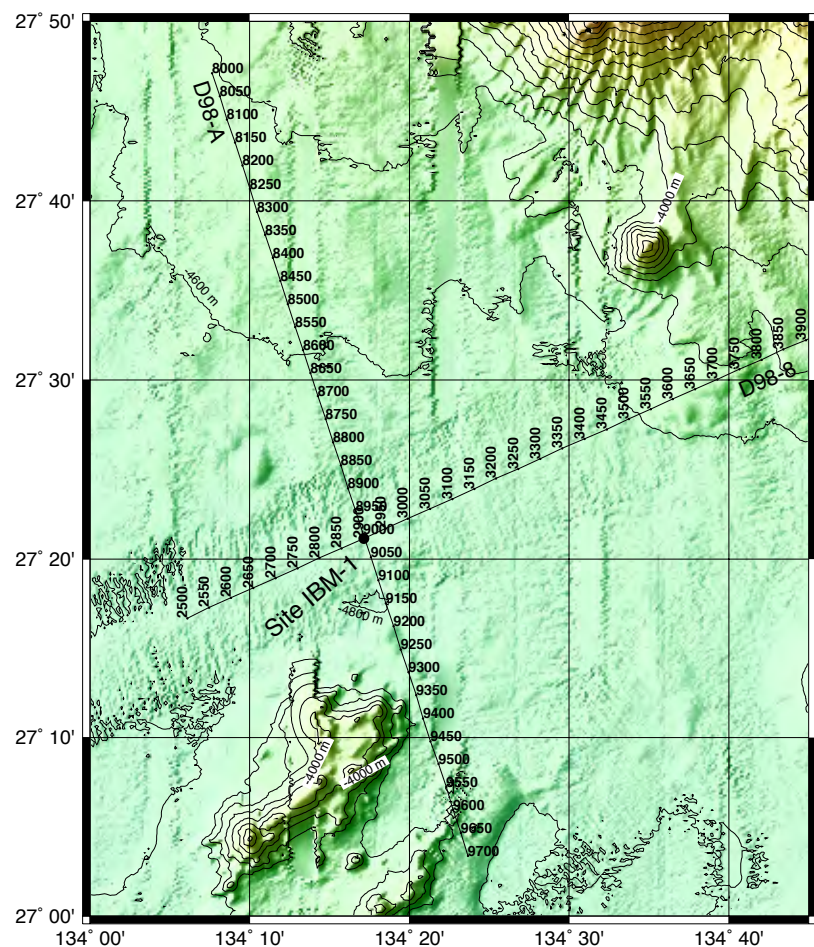
Revised

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Proposal #: 695-Full2	Site #: IBM-1	Date Form Submitted: April 1 st 2008
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<i>Sub-bottom depth (m)</i>	<i>Key reflectors, Unconformities, faults, etc</i>	<i>Age</i>	<i>Assumed velocity (km/sec)</i>	<i>Lithology</i>	<i>Paleo-environment</i>	<i>Avg. rate of sed. accum. (m/My)</i>	<i>Comments</i>
0-110	acoustic basement	Plio/Pliocene	1.9	Pelagite	oceanic basin	20	
110-270		Upper Miocene	1.9	Turbidite	oceanic basin	20	
270-580		Lower Miocene	2.4	Turbidite	oceanic basin	20	
580-1070		Oligocene/Eocene	2.4	Turbidite	rear arc	25	
1070-1300		Eocene or older	3.2	Hemipelagite	oceanic basin	20	
1300-1450	acoustic basement	Cretaceous	4.2	basalt lava, sill and dyke	oceanic basin		

Site IBM-1



Profiles annotated using SP numbers

The data appeared in this form 6 have not yet been submitted to the IODP Site Survey Data Bank (SSDB)

Site IBM-1
SP 2902 on D98-8
SP 9009 on D98-A

