Earth and Planetary Science Letters 481 (2018) 80–90

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Age of Izu–Bonin–Mariana arc basement

Osamu Ishizuka [a,b,*], Rosemary Hickey-Vargas [c], Richard J. Arculus [d], Gene M. Yogodzinski [e], Ivan P. Savov [f], Yuki Kusano [a], Anders McCarthy [g,1], Philipp A. Brandl [h], Masafumi Sudo [i]

[a] Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST, Central 7, 1-1-1, Higashi, Tsukuba, Ibaraki, 305-8567, Japan
[b] Japan Agency for Marine-Earth Science and Technology, 2-15 Natsushima, Yokosuka, Kanagawa, 237-0061, Japan
[c] Earth and Environment Department, Florida International University, Modesto Maidique Campus, AHC5-394, Miami, FL, 33199, USA
[d] Research School of Earth Sciences, The Australian National University, 142 Mills Road, Acton, ACT, 2601, Australia
[e] School of Earth, Ocean, and Environment, University of South Carolina, 701 Sumter Street, EWSC617, Columbia, SC, 29208, USA
[f] School of Earth and Environment, The University of Leeds, Institute of Geophysics and Tectonics, Leeds, LS2 9JT, UK
[g] Institute of Earth Sciences, University of Lausanne, Geopolis, Lausanne, 1015, Switzerland
[h] GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstr. 1-3, 24148, Kiel, Germany
[i] Institut für Erd- und Umweltwissenschaften, Universität Potsdam, Karl-Liebknecht-Str. 24, Haus 27, 14476, Golm, Germany

ARTICLE INFO

Article history:
Received 23 June 2017
Received in revised form 2 October 2017
Accepted 8 October 2017
Available online xxxx
Editor: A. Yin

Keywords:
subduction initiation
Izu–Bonin–Mariana arc
arc basement
$^{40}Ar/^{39}Ar$ age

ABSTRACT

Documenting the early tectonic and magmatic evolution of the Izu–Bonin–Mariana (IBM) arc system in the Western Pacific is critical for understanding the process and cause of subduction initiation along the current convergent margin between the Pacific and Philippine Sea plates. Forearc igneous sections provide firm evidence for seafloor spreading at the time of subduction initiation (52 Ma) and production of "forearc basalt". Ocean floor drilling (International Ocean Discovery Program Expedition 351) recovered basement-forming, low-Ti tholeiitic basalt crust formed shortly after subduction initiation but distal from the convergent margin (nominally reararc) of the future IBM arc (Amami Sankaku Basin: ASB). Radiometric dating of this basement gives an age range (49.3–46.8 Ma with a weighted average of 48.7 Ma) that overlaps that of basalt in the present-day IBM forearc, but up to 3.3 m.y. younger than the onset of forearc basalt activity. Similarity in age range and geochemical character between the reararc and forearc basalts implies that the ocean crust newly formed by seafloor spreading during subduction initiation extends from fore- to reararc of the present-day IBM arc. Given the age difference between the oldest forearc basalt and the ASB crust, asymmetric spreading caused by ridge migration might have taken place. This scenario for the formation of the ASB implies that the Mesozoic remnant arc terrane of the Daito Ridges comprised the overriding plate at subduction initiation. The juxtaposition of a relatively buoyant remnant arc terrane adjacent to an oceanic plate was more favourable for subduction initiation than would have been the case if both downgoing and overriding plates had been oceanic.

1. Introduction

Among the proposed hypotheses for the fundamentally important process of subduction zone initiation, two seem most widely relevant (e.g., Stern, 2004; Gerya, 2011): spontaneous initiation (e.g., Matsumoto and Tomoda, 1983; Stern and Bloomer, 1992; Stern, 2004; Nikolaeva et al., 2010), and induced (or forced) initiation (e.g., McKenzie, 1977; Gurnis et al., 2004; Maffione et al., 2015). Induced initiation may be triggered by externally forced compression, for example, along a pre-existing discontinuity, such as a fracture zone. Spontaneous subduction initiation occurs when a change in plate motion allows the gravitationally unstable lithosphere to subside and be subducted. Stern (2004) suggested the Izu–Bonin–Mariana arc (IBM arc) in the Western Pacific represents an example of spontaneous subduction initiation wherein subsidence of relatively old and dense Pacific lithosphere commenced along transform faults/fracture zones bounded by relatively buoyant lithosphere. Thorough reconstruction of the plates involved is required for testing the competing hypotheses for process of subduction initiation. Constraining the nature and origin of the

* Corresponding author at: Institute of Earthquake and Volcano Geology, Geological Survey of Japan, AIST, Central 7, 1-1-1, Higashi, Tsukuba, Ibaraki, 305-8567, Japan.
E-mail address: o-ishizuka@aist.go.jp (O. Ishizuka).
[1] Now at School of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Clifton, BS8 1RJ, UK.

https://doi.org/10.1016/j.epsl.2017.10.023
0012-821X/

overriding and subducting plates is especially important, because numerical modelling shows plate density is a key parameter controlling subduction initiation (e.g., Leng and Gurnis, 2015).

The IBM arc is an optimal place to investigate processes of subduction initiation. Extensive exposures of volcanic as well as plutonic lower crust and upper mantle sections in the present-day IBM forearc give access to a magmatic record preserved in the juvenile arc developed immediately after subduction initiation (e.g., Taylor et al., 1994; Ishizuka et al., 2006, 2011a, 2014a; Reagan et al., 2008, 2010, 2013). Disturbance of the exposed crustal section after its formation is minimal given the absence of overprinting by younger volcanism and significant tectonic movement. Erosion due to subduction of the Pacific Plate sustains exposure of the forearc section. The freshness of exposed samples allows most primary geochemical characteristics of the earliest magmatism to be characterised. Reliable age determination has provided a framework for constraining the temporal variation of magmatism associated with the development of subduction initiation and the formation of a subduction zone (Ishizuka et al., 2006, 2011a, 2014a; Reagan et al., 2008, 2010, 2013; Brounce et al., 2015).

Geochronology of igneous rocks from the IBM forearc section has revealed that the first basaltic magmatism (termed "forearc basalt" by Reagan et al., 2010) subsequent to subduction initiation was produced by decompression melting of highly-depleted mantle and commenced at 51–52 Ma (Ishizuka et al., 2011a; Reagan et al., 2013). Occurrence of sheeted dykes indicates that seafloor spreading took place in the overriding plate (Ishizuka et al., 2011a). The switch to fluxed melting of a harzburgitic (i.e., prior melt-depleted and refractory) mantle generating boninitic magma took place by 48 Ma, and the change to fluxed melting in a counterflowing mantle resulting in "normal" arc magmatism took place 7–8 m.y. after subduction initiation. Subduction initiation and subsequent magmatic evolution seem to have occurred nearly simultaneously along the length of the IBM subduction system.

Understanding magmatic evolution of the arc after subduction initiation has been significantly improved. However, characteristics of the overriding plate prior to subduction initiation, i.e., basement of the future IBM arc system, is still not well constrained. This hampers understanding of the tectonic setting leading to subduction initiation, and hence, the capacity to provide information needed to evaluate contrasting models of subduction initiation generally.

Seafloor drilling by IODP (International Ocean Discovery Program) Expedition 351 was conducted to recover rock samples formed in association with subduction initiation as well as the pre-inception basement of the IBM arc. It is particularly important to understand the age and origin of the arc basement to establish constraints on the tectonic situation at initiation, and reveal the duration and extent of seafloor spreading associated with subduction initiation.

In this contribution, we focus on the age of the present-day reararc basement as drilled in the Amami Sankaku Basin (ASB). We report $^{40}Ar/^{39}Ar$ ages of this basement as well as its major element composition. Based on this new dataset, the origin of the general arc basement crust, and the implications with respect to the tectonic setting at subduction initiation are discussed.

2. Geological background

The drill site of IODP Expedition 351, U1438, is located in the Amami Sankaku Basin now located in a reararc position relative to the Kyushu–Palau Ridge (KPR), and assumed reararc area of the proto-IBM arc (Fig. 1a, b). The KPR is a remnant arc separated from the IBM arc by arc rifting and backarc spreading after 25 Ma in the Shikoku and Parece-Vela Basins (Ishizuka et al., 2011b). The KPR was active in the Eocene and Oligocene (e.g., Mizuno et al., 1977; Ishizuka et al., 2011b). The extinct spreading centre of the West Philippine Basin (CBF rift) is truncated by the KPR at ∼15°N (Fig. 1a). Radiometric ages for volcanic rocks collected from the northern to central KPR range in age between 43 and 25 Ma but are mostly between 27 and 25 Ma, indicating arc volcanism ended on the KPR at about this time (Ishizuka et al., 2011b). This observation has been reinforced by studies of the volcaniclastic deposits recovered at U1438 (Arculus et al., 2015; Brandl et al., 2017). The core record shows that the input of volcanic debris from the KPR ended abruptly around 25 Ma (Fig. 2), implying that arc rifting and opening of the Shikoku and Parece Vela Basins initiated at ∼25 Ma (Ishizuka et al., 2011b). This interpretation is generally consistent with the estimated timing of rifting and spreading of the Shikoku Basin based on magnetic anomaly data and seafloor fabric observations. Okino et al. (1994) identified a magnetic lineation corresponding to Anomaly 7 in the westernmost (oldest) margin of the basin and suggested spreading started at 26 Ma. The lack of systematic age variations of volcanic rocks along the KPR indicates that rifting was initiated almost concurrently along the entire ridge between 30°N and 11°N.

Regarding the oldest volcanic record of the KPR, Brandl et al. (2017) reported on the geochemical compositions of glasses (occurring as inclusions in minerals) formed at the KPR from ∼25 to 40 Ma at U1438. The sedimentary section containing the oldest volcaniclastic material above the igneous basement of U1438 was estimated to be between 40 and 57 Ma based on micropaleontological information (Fig. 2; Arculus et al., 2015). This is consistent with the oldest age of an andesitic rock recovered (43.29 Ma) and a 48.5 Ma granodiorite from Minami-Koho seamount at the intersection between the KPR and Daito Ridge (Fig. 3; Mizuno et al., 1977; Ishizuka et al., 2011b). However, direct and conclusive age data for the oldest volcanism on the KPR has not been previously obtained.

Crustal models based on wide-angle seismic profiles indicate that the KPR has a variable crustal thickness of 8–23 km (Nishizawa et al., 2016); the thicker parts of the ridge include an expanded middle crust section with Vp of 6.0–6.8 km/s, indicating a similar crustal structure to that observed beneath the IBM arc (e.g., Kodaira et al., 2007). In its reararc area, significant structural variation along the KPR is present, such as the ocean basins like the ASB and Kikai Basin (Fig. 1b), and remnant arcs preserved as the Daito Ridges, indicating a complex geologic and tectonic evolution in this region (Nishizawa et al., 2016) prior to subduction initiation to form the IBM arc.

The Daito Ridges region is a complex array of ridges and basins (Fig. 1a, b). The region comprises three remnant arcs: the Amami Plateau, the Daito and Oki-Daito Ridges, and two ocean basins between these ridges (the Kita-Daito and Minami-Daito Basins). Granitoids and arc-related volcanic rocks of Cretaceous age are exposed on the Amami Plateau (e.g., Hickey-Vargas, 2005) which has a crustal thickness of up to 19 km (Nishizawa et al., 2014). Geochemical characteristics of the volcanic rocks are consistent with formation of the Plateau by Cretaceous subduction zone magmatism (Hickey-Vargas, 2005). The Daito Ridge is generally east–west trending and intersects the KPR at its eastern end. Low-grade metamorphic rocks, sedimentary rocks, and some volcanic rocks were recovered by dredging, apparently from beneath Eocene sedimentary rocks (Mizuno et al., 1978). Recent shallow drilling using the Deep Sea Boring Machine System (BMS) recovered fresh volcanic rocks from the eastern part of the Daito Ridge. The recovered andesites, with distinctive trace element characteristics of arc magmas, yielded $^{40}Ar/^{39}Ar$ ages of 116.9 and 118.9 Ma (Ishizuka et al., 2011b). These ages are significantly older than any other volcanism in the IBM arc, and reinforce the crucial point that the Daito Ridge comprises Mesozoic arc rocks overlain by middle Eocene sedimentary rocks.