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Shallow submarine volcano group in the early stage of island arc development: Geology and petrology of small islands south off Hahajima main island, the Ogasawara Islands

Kyoko Kanayama [a,*], Susumu Umino [a], Osamu Ishizuka [b]

[a] College of Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 920-1192, Japan
[b] Institute of Geology and Geoinformation, Geological Survey of Japan/AIST, Central 7, 1-1-1, Higashi, Tsukuba, Ibaraki 305-8567, Japan

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ABSTRACT

Small Islands south off Hahajima, the southernmost of the Ogasawara Archipelago, consist of primitive basalts (<12 wt.% MgO) to dacite erupted during the transitional stage immediately following boninite volcanism on the incipient arc to sustained typical oceanic arc. Strombolian to Hawaiian fissure eruptions occurring on independent volcanic centers for the individual islands under a shallow sea produced magnesian basalt to dacite fall-out tephras, hyaloclastite and a small volume of pillow lava, which were intruded by NE-trending dikes. These volcanic strata are correlated to the upper part (<40 Ma) of the Hahajima main island. Volcanic rock samples have slightly lower FeO^*/MgO ratios than the present volcanic front lavas, and are divided into three types with high, medium and low La/Yb ratios. Basalt to dacite of high- and medium-La/Yb types show both tholeiitic (TH) and calc-alkaline (CA) differentiation trends. Low-La/Yb type belongs only to TH basalt. The multiple magma types are coexistence on the each island. TH basalts have phenocrysts of olivine, clinopyroxene and plagioclase, while CA basalts are free from plagioclase phenocrysts.

1. Introduction

Recent geological and geophysical investigations in the Izu–Ogasawara–Mariana (Izu–Bonin–Mariana, or IBM) forearc have revealed an early history of the development of the IBM arc (e.g. Kodaira et al., 2010; Reagan et al., 2010; Ishizuka et al., 2011) (Fig. 1). Subduction of the Pacific Plate initiated at ca. 50 Ma (Sharp and Clague, 2002; Wessel et al., 2006) is coupled with voluminous igneous activity, perhaps seafloor spreading which produced MORB-like basalt followed by arc tholeiite, along the entire eastern margin of the overriding Philippine Sea Plate (Stern and Bloomer, 1992; Reagan et al., 2010; Ishizuka et al., 2011). This tholeiitic magmatism was followed by high-Si boninite magmatism at 48 Ma, which continued down to 46 Ma and gradually changed to low-Si boninite (high-Mg andesite) by 45 Ma (Ishizuka et al., 2006; Umino and Nakano, 2007; Kanayama et al., 2012). Subsequent submarine and subaerial volcanism on the Ogasawara Ridge (Figs. 1 and 2a) is dominated by arc tholeiitic (TH) and calc-alkaline (CA) magmas which were active simultaneously with low-Si boninite magma for the first 2 million years and continued down to 36 Ma (Fig. 3) (Taylor and Nesbitt, 1995; Ishizuka et al., 2006; Umino et al., 2009; Ishizuka, unpubl. data). This transition of magmatism is considered to have been caused by the change in thermochemical condition of the mantle wedge since the subduction initiation to the establishment of stable mantle convection like the present IBM subduction system. In order to clarify the thermochemical evolution of the mantle wedge through the progress of subduction of the Pacific Plate, it is essential to understand the temporal and spatial variations of geochemistry of primitive magmas during the transitional stage of the IBM subduction zone development, which is still unknown in detail.

Hahajima Island Group (Fig. 2) on the Ogasawara Ridge mainly consists of arc TH and CA lavas and pyroclastic rocks during the transitional stage at 45–40 Ma (Taylor and Nesbitt, 1995; Yajima et al., 2001; Ishizuka et al., 2006; Umino et al., 2009) (Fig. 3). Amongst the Hahajima Island Group, magnesian arc basalt is widely distributed on small islands south off Hahajima (Kuroda et al., 1982, 1983; Maehara and Maeda, 2004; Kanayama et al., 2011), which are of the youngest age (40–37 Ma) on the Ogasawara Ridge and erupted just before the establishment of the stable subduction zone by 35 Ma (Ishizuka et al., 2006). The magnesian bas-

* Corresponding author. Tel.: +81 076 264 6540; fax: +81 076 264 6545.
E-mail address: kkanayama@staff.kanazawa-u.ac.jp (K. Kanayama).

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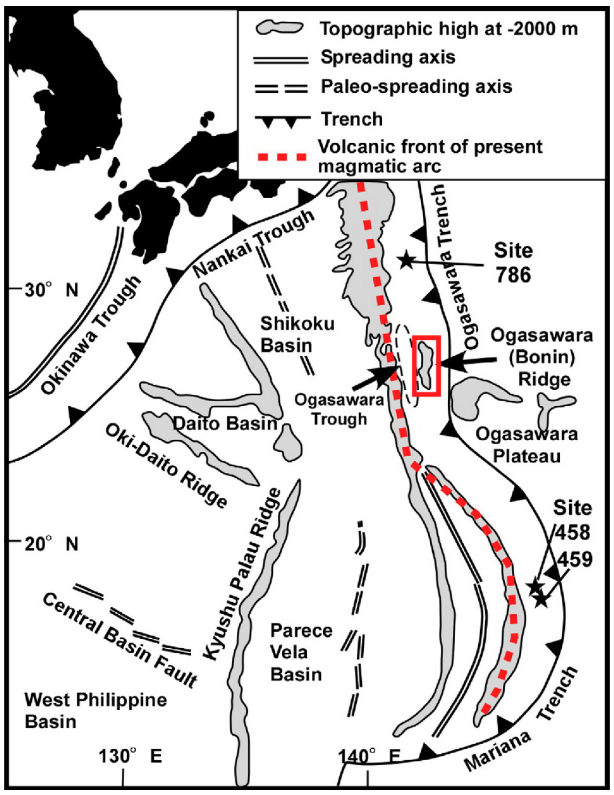

Fig. 1. Map of the Philippine Sea Plate showing the location of the Ogasawara Ridge and some tectonic features. Modified after Fryer and Pearce (1992) (Fig. 1). Stars: borehole sites of Ocean Drilling Program (ODP). Location of volcanic front of the present magmatic arc after e.g. Taylor and Nesbitt (1998). Rectangle is enlarged in Fig. 2.

alts from the small islands have been proposed to retain primitive magma compositions which can coexist with the wedge mantle beneath the immature IBM arc during <40 Ma (Ishizuka, unpubl. data). However, stratigraphy and geochemical variations of these primitive magmas are yet to be investigated.

Boninitic strata on Chichijima and Mukojima on the Ogasawara Ridge (Fig. 2a) are estimated to have begun with quiet extrusion of pillow lava under deep water (>several thousand meters) at 48 Ma, and then changed into moderately explosive eruptions of pyroclastic rocks that took place in shallow submarine or subaerial environment (Dobson, 1986; Umino, 1985; Umino and Nakano, 2007; Kanayama et al., 2012) (Fig. 3). On the other hand, Hahajima arc TH and CA rocks were emplaced under shallow submarine to subaerial environments, occurring as hyaloclastite, fall-out tephras, subaerial aa lava and pyroclastic flow deposits interbedded with submarine debris flow deposits (Umino et al., 2009, 2011). Meanwhile, the eruptive environment changed with the growth of volcanic edifices and uplift of the entire Ogasawara Ridge during the Eocene period (Umino and Nakano, 2007; Umino et al., 2009). Detailed studies on subaqueous volcanic products on the Hahajima Island Group can also contribute to the understanding of shallow-water subaqueous arc volcanism (Yamagishi, 1994).

We provide the first thorough study on the geology, petrography and geochemistry of the islands south off Hahajima and discuss the style of volcanic activities and stratigraphic relationships among the Hahajima Island Group. Detailed geochemistry and genetic conditions of parent magmas for these volcanoes will be presented elsewhere in our companion paper (Kanayama et al., in preparation).

2. Geological review of the Hahajima main island

The Hahajima main island comprises Eocene volcanic and sedimentary rocks, which are subdivided into three units by unconformity (Fig. 4; Umino et al., 2011). Volcanic rocks from Hahajima show two geochemical trends: arc TH and CA rock series which correspond to Arculus's (2003) discrimination of medium- and low-Fe suites, respectively (Fig. 5) (Yamamoto, 1993, Taylor and Nesbitt, 1995; Yajima et al., 2001; Umino et al., 2009). Andesite with 57–61 wt.% SiO_2 is a majority in the volcanic rocks of the

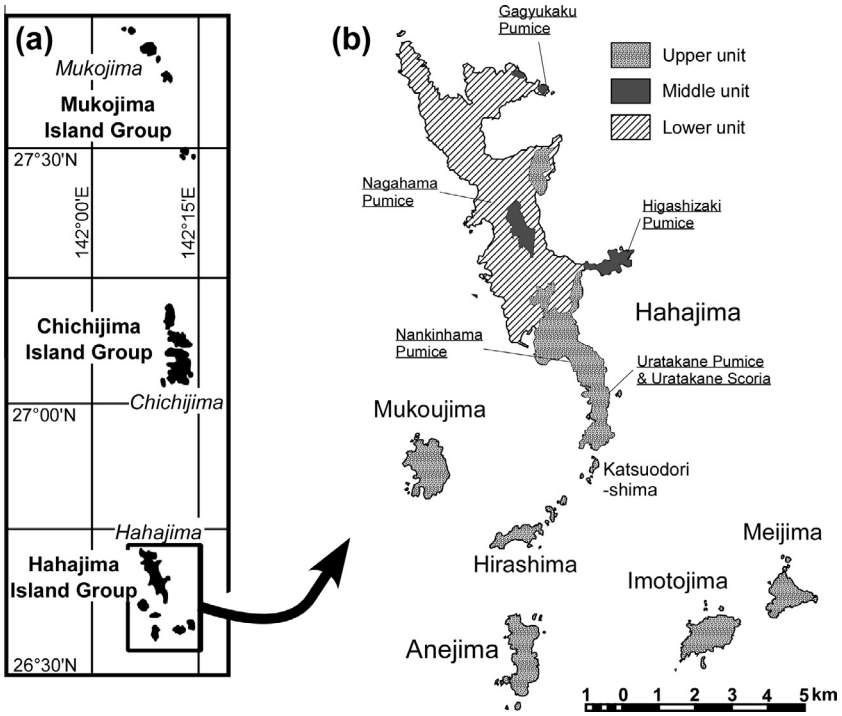

Fig. 2. (a) Enlarged rectangle in Fig. 1 showing the Ogasawara Island Groups. (b) Simplified geological map of Hahajima Island Group after Umino et al. (2011). Localities of tephra samples of the Hahajima main island are shown by underlined characters.