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Ancient oceanic crust in island arc lower crust: Evidence from oxygen isotopes in zircons from the Tanzawa Tonalitic Pluton

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ABSTRACT

Knowledge of the lithological variability and genesis of island arc crust is important for understanding continental growth. Although the volcanic architecture of island arcs is comparatively well known, the nature of island arc middle- and lower-crust remains uncertain owing to limited exposure. One of the best targets for deciphering the evolution of an island arc system is the Tanzawa Tonalites (4–9 Ma), in the intra-oceanic Izu–Bonin–Mariana arc. These tonalities which occupied a mid-crustal position were generated by partial melting of lower crust. To constrain protoliths of the plutonic rocks in the island arc lower crust, *in-situ* O-isotopic analysis using an IMS-1280 Secondary Ion Mass Spectrometer was carried out on 202 zircon grains separated from 4 plutons in the Tanzawa Tonalite. $\delta^{18}O$ value of the zircons ranges from 4.1‰ to 5.5‰ and some zircons have $\delta^{18}O$ slightly lower than the mantle range. The low zircon $\delta^{18}O$ values from the Tanzawa Tonalite suggest that their protoliths involved materials with lower $\delta^{18}O$ values than those of the mantle. Hydrothermally altered gabbros in the lower oceanic crust often have lower $\delta^{18}O$ values than mantle and can be primary components of arc lower crust. The Tanzawa Tonalite is interpreted to have been formed by partial melting of island arc lower crust. Thus the low $\delta^{18}O$ values in zircons from the Tanzawa Tonalites may originate by melting of the hydrothermally altered gabbro. Ancient oceanic crustal material was likely present in the Izu–Bonin–Mariana arc lower crust, at the time of formation of the Tanzawa Tonalites.

1. Introduction

Arc magmatism in subduction zones is recognized as a predominant mechanism for continental growth, because trace element patterns in arc crust are similar to those of continental crust (e.g., Rudnick, 1995). The average chemical composition of continental crust is andesitic (e.g., Taylor and White, 1965), and andesite is an important product of arc magmatism. Therefore, constraining the chemical composition and formation of immature arc crust can lead to a better understanding of the initial stage of the continental crustal growth. The Izu–Bonin–Mariana arc (IBM arc; Fig. 1A) in the Western Pacific Ocean is an active and immature intra-oceanic arc, and has attracted much interest from seismological and geochemical studies to reveal its structure and composition (e.g., Suyehiro et al., 1996; Cosca et al., 1998; Ishizuka et al., 2006; Takahashi et al., 2007; Reagan et al., 2010). Seismic investigations combined with geochemical data for exposed rocks suggest the presence of a ~5 km thick tonalitic middle crust overlying mafic lower crust in northern Izu arc, Mariana arc and West Mariana ridge (Suyehiro et al., 1996; Kitamura et al., 2003; Takahashi et al., 2007). Based on the seismic structure of the arc, evolution models from oceanic crust to present IBM arc were proposed by some researchers (e.g., Tatsumi et al., 2008). In general, the previous studies have focused on the process for generation and addition of new arc crust (e.g., Kuno, 1968; Garrido et al., 2006; Tatsumi et al., 2008), but not on the pre-existing oceanic crust in an immature arc. Kuno (1968) implied that ancient oceanic crust may be incorporated into island arc crust during the early stages of its evolution. For example, a *ca.* 10 km thick layer of oceanic crust has been imaged seismically in the mid crust below the Aleutian arc along the northwestern margin of Pacific Ocean (Holbrook et al., 1999; Shillington et al., 2004). Unfortunately geochemical evidence alone is insufficient to confirm the existence of former oceanic crust in island arcs because of difficulty of sampling. Nevertheless Kay et al. (1986) reported radiogenic Nd isotopic compositions from xenoliths and volcanic rocks that they interpreted as evidence for the presence of oceanic crust in the island arc crust. However, the Aleutian arc may not be a good analogue of other island arcs because the seismic structure of the Aleutian arc is clearly different from that of the IBM arc. For example the IBM arc has a ~5 km thick felsic middle layer, that is absent from the Aleutian arc (Suyehiro et al., 1996; Takahashi et al., 2007).

A number of studies have shown that deep parts of the continental crust can be exposed in collision zones (e.g., Fountain and Salisbury,

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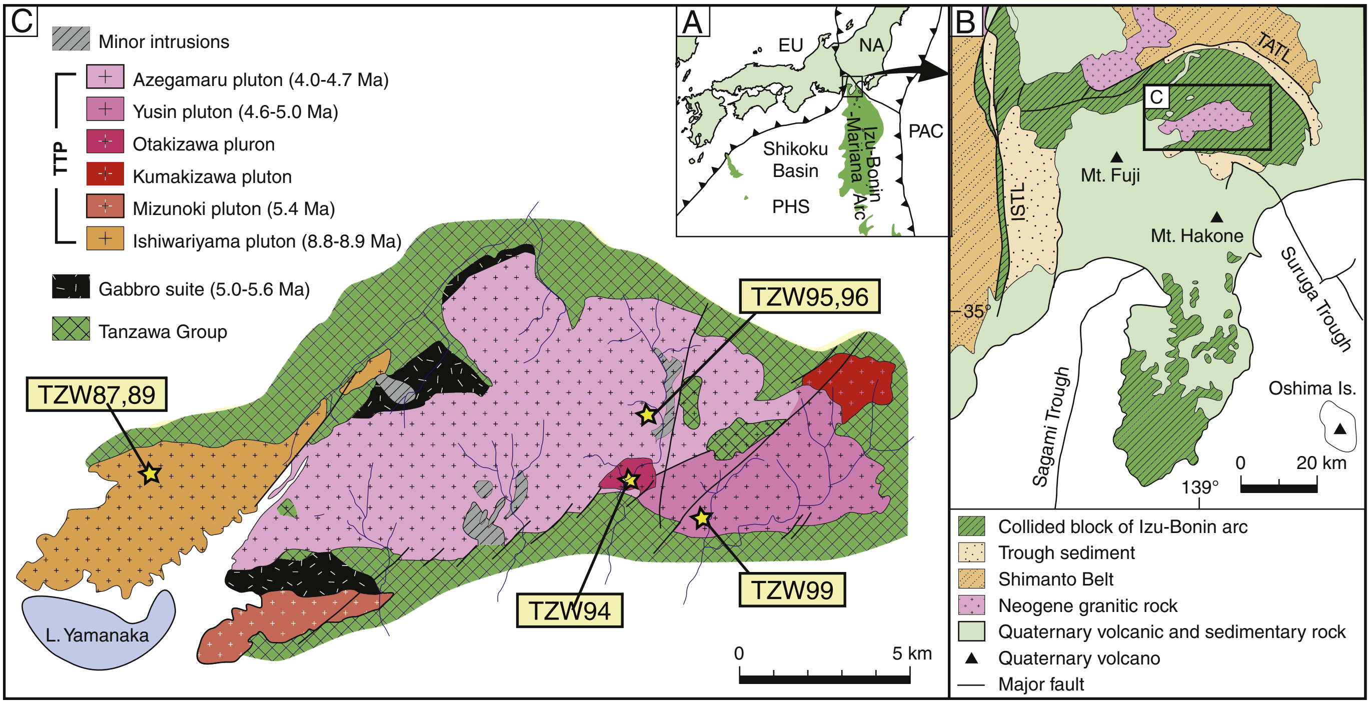

Fig. 1. (A) Tectonic map of the northern end of the IBM-arc. EU, Eurasian Plate; NA, North American Plate; PHS, Philippine Sea Plate; PAC, Pacific Plate. (B) Geological map of the Izu-Collision-Zone. ISTL, Itoigawa–Shizuoka tectonic line; TATL, Tonoki-Aikawa tectonic line. (C) Geological map of the Tanzawa Tonalitic Pluton (modified from Kawate and Arima (1998)) showing sampling localities. We collected tonalities from Ishiwariyama, Otakizawa, Yusin and Asegamaru plutons. Age data are from Tani et al. (2010).

1981; Mezger, 1992). A similar situation occurs in the Tanzawa Block in the Izu-Collision-Zone with the exposure of tonalitic rocks younger than 9 Ma (e.g. Tani et al., 2010) due to collision between the active IBM arc and the Honshu arc. The Tanzawa Tonalite is interpreted to be the mid crust of the proto-IBM arc. It exhibits the geochemical characteristics and isotopic features of M-type granites, i.e., low K content and unradiogenic initial Sr isotopic composition (Ishihara et al., 1976; Kawate and Fujimaki, 1996). It is also similar to felsic igneous rocks in the IBM (Ishizaka and Yanagi, 1977; Takahashi, 1989; Kawate and Arima, 1998). Thus, the Tanzawa Tonalite is an excellent suite to trace process during island arc evolution, from oceanic crust to mature arc crust. The experimental research (Nakajima and Arima, 1998) suggests that the Tanzawa Tonalites were generated by partial melting of mafic lower crust of the IBM arc. This implies that the Tanzawa Tonalite inherited the chemical characteristics of deeper part of the proto-arc crust. However, although U–Pb ages and REE data for zircon in mafic enclaves in the Tanzawa Tonalite were derived from the arc lower crust (Suzuki et al., 2014), the protoliths containing these zircons have not yet been identified.

Oxygen isotope data for whole rocks and minerals have been used to constrain the nature of protolith that were melted to form volcanic and plutonic rocks (e.g., Matsuhisa, 1979; Lackey et al., 2008). Although Ishihara and Matsuhisa (2005) determined whole rock oxygen isotope ratios for samples of Tanzawa Tonalite, they could not constrain $\delta^{18}O$ of the source rocks, because whole rock oxygen isotope ratios increase with increasing SiO_2 content (Matsuhisa, 1979; Taylor and Sheppard, 1986; Lackey et al., 2008) and because magmatic whole rock $\delta^{18}O$ is commonly overprinted by subsolidus alteration. However, oxygen isotopic ratios of non-metamict zircons are resistant to alteration and effectively reflect the $\delta^{18}O$ of their parental host rock through the whole rock-zircon fractionation factor (Valley et al., 1994; Lackey et al., 2008).

Therefore, to better understand the nature of the lower arc crust and thus, the evolution of intra-oceanic arcs, we performed *in-situ* O-isotopic analysis on zircon grains separated from the 4 tonalitic plutons (Ishiwariyama, Otakizawa, Yusin, Azegamaru) in the Tanzawa Block. The data was obtained using a secondary ion mass spectrometer (SIMS), combined with *in-situ* trace element analysis using laser ablation-inductively coupled plasma-mass spectrometer (LA-ICP-MS).

2. Geology

2.1. Geological setting of the Tanzawa Tonalitic Pluton

The IBM arc has been formed by subduction of Pacific Sea plate beneath the Philippine Sea plate, and has collided with the Honshu arc in the Izu-Collision-Zone, central Japan (Fig. 1A; Matsuda, 1978). The Tanzawa block is located in the Izu-Collison Zone, *ca.* 300 km northwest of the triple junction of the Eurasia, North America, and Philippine Sea plates (Fig. 1B). The Tanzawa block has three main components: (1) the Tanzawa Group (3–17 Ma), (2) the Tanzawa gabbro suite (5–6 Ma), and (3) the Tanzawa Tonalitic Pluton (TTP; 4–9 Ma). The Tanzawa Group, with thickness estimated to be greater than 10 km (Takita, 1974), is composed mainly of basaltic volcaniclastic rocks deposited at *ca.* 3–17 Ma. The group was initially formed in a pelagic environment before 11 Ma (Shimazu, 1989; Aoike et al., 1995) as part of the upper crust of the IBM arc, and approached near the Honshu arc via continuous movement of the Philippine Sea Plate to the north. The age of the gabbro suite is constrained from zircon U–Pb dating using SHRIMP-II (5–6 Ma; Tani et al., 2010). The relationship between the Tanzawa Group and gabbro suite is not clear because of limited exposure, but in areas, the Group is intruded by the gabbro suite (Aoike et al., 1997). Both of them are cut by the TTP (Takita, 1974).

The TTP includes tonalite and quartz-diorite, both of which are rich in magnetite with high magnetic susceptibility (Ishihara et al., 1976). Based on its very low K_2O (mainly 0.13 to 1.90 wt.%; Ishihara et al., 1976; Kawate and Arima, 1998; Takahashi et al., 2004), low K_2O/Na_2O (<0.55; Ishihara et al., 1976; Kawate and Arima, 1998), low Rb, Rb/Sr and moderately high K/Rb (541–630; Ishizaka and Yanagi, 1977), and extremely unradiogenic initial $^{87}Sr/^{86}Sr$ ratios near the mantle value (0.70331–0.70370; Kawate and Fujimaki, 1996), the Tanzawa Tonalite is interpreted to have the most typical characteristics of M-type granite compared to the other granitoids in Japan (Takahashi, 1985).