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Pleistocene intraplate magmatism in the Goto Islands, SW Japan: Implications for mantle source evolution and regional geodynamics

Nguyen Hoang*, Kozo Uto, Aki Matsumoto, Jun'ichi Itoh

Geological Survey of Japan, AIST, Higashi 1-1-1, Tsukuba Central 7th, Tsukuba 305-8567, Japan

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ABSTRACT

We present geochemical, Sr, Nd and Pb isotopic data for the youngest back-arc tholeiitic and alkali basalts in the southern tip of Goto Islands along the Taiwan–Shinji Folded Belt in northwestern Kyushu, SW Japan. The data are compared with those more-or-less contemporaneous back-arc basalts elsewhere in the region and interpreted accordingly. Our sampling loci included Ukujima (ca. 1 Ma), Ojikajima and Kamigoto (from 0.6 Ma to 0.14) and six locations in the Fukue island area (ages between 0.7 and 0.02 Ma). The Ukujima tholeiites show the highest SiO_2 (ca. 52.5 wt%), FeO* (13 wt%), TiO_2 (>2.5 wt%) and lowest MgO (4 wt%) and CaO (7.5 wt%) contents whereas the alkali Kamigoto and most Ojikajima magmas show lower SiO_2 (48 wt%) and higher MgO (8.5 wt%) and CaO (11 wt%). The Ukujima tholeiites also show the least radiogenic lead with closely similar $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios ranging between 0.7038 and 0.7042, and between 0.51280 and 0.51285, respectively. Mantle-normalized incompatible element distributions are of alkali basalt-type exhibiting, along with the major element, significant spatio-temporal variations. Regardless of such differences the younger basalts, as compared with older 6–15 Ma eruptive products in Hirado (and those in Kita-Matsuura), northeastward along the belt, are the least radiogenic. The 15 Ma volcanics were erupted during episodes of lithospheric extension and show effects of crustal contamination. The 6–9 Ma tholeiites and alkali basalts appeared as regional extension gave way to compression and show hybrids of depleted mid-ocean ridge basalt-like (N-MORB) mantle and heterogeneous EM2 (enriched mantle type 2) (Uto et al., 2004). As extension diminished, deeper asthenospheric sources were tapped producing a range of enriched mantle type 1 (EM1)-contaminated N-MORB-like magmas in the younger (<1 Ma) Ukujima, Ojikajima-Kamigoto and Fukue volcanoes. This composition is believed to present throughout East and Southeast Asian asthenosphere.

1. Background of the study

Cenozoic volcanic rocks of intraplate affinity are distributed over a wide area of northern and northwesters Kyushu, in south western Japan (Fig. 1). The lack of deep earthquakes in this area suggests the volcanism is not associated with Philippine Sea Plate subduction (e.g. Okino et al., 1999; Honda and Nakanishi, 2003). Rather, evidence suggests that magmatic activity in this region is associated with opening of the Japan and East China Seas (e.g. Nakada and Kamata, 1991; Uto and Tatsumi, 1996; Seno, 1999; Uto et al., 2004; cf. Nakamura et al., 1989, 1990; Iwamori, 1992; Kimura et al., 2005).

The geochemical character of the Kyushu basalts has mostly been linked to tectonic processes associated with Japan Sea opening (23–15 Ma, e.g. Kaneoka et al., 1992; Jolivet et al., 1994). Eruptives older than 15 Ma are contemporaneous with Japan Sea opening, termed as syn-opening volcanism, and are characterized by high SiO_2 and low MgO contents (in wt%). They have relatively low ratios of high field strength element (HFSE) such as Nb, Ta, Zr, and Ti to large ionic lithophile element (LILE) contents. They have high $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, and low $^{143}Nd/^{144}Nd$ ratios, suggesting the involvement of lithospheric mantle and/or crustal material (Nakamura et al., 1989; Uto et al., 1995; Uto and Tatsumi, 1996; Nakada et al., 1997; Higo and Mashima, 2004; Hoang and Uto, 2003a,b; Uto et al., 2004; Mashima, 2005). On the other hand, post-(Japan Sea) opening basalts younger than 15 Ma characteristically show low SiO_2 and high MgO contents (wt%), and high HFSE/LILE ratios. They show higher $^{143}Nd/^{144}Nd$ and $^{208}Pb/^{204}Pb$ ratios, lower $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ ratios than those coeval with Japan Sea opening (Uto and Tatsumi, 1996; Hoang and Uto, 2003a,b, 2006; Uto et al., 2004). This compositional range has been interpreted to reflect partial melts of deep, asthenospheric sources

* Corresponding author at: Institute of Geological Sciences, Vietnam Academy of Science and Technology, 84 Chua Lang, Dong Da, Hanoi, Viet Nam.
Tel.: +81 29 861 3637; fax: +81 29 861 3637.
E-mail addresses: hoang-nguyen@aist.go.jp, hoang.geol@hotmail.com (N. Hoang).

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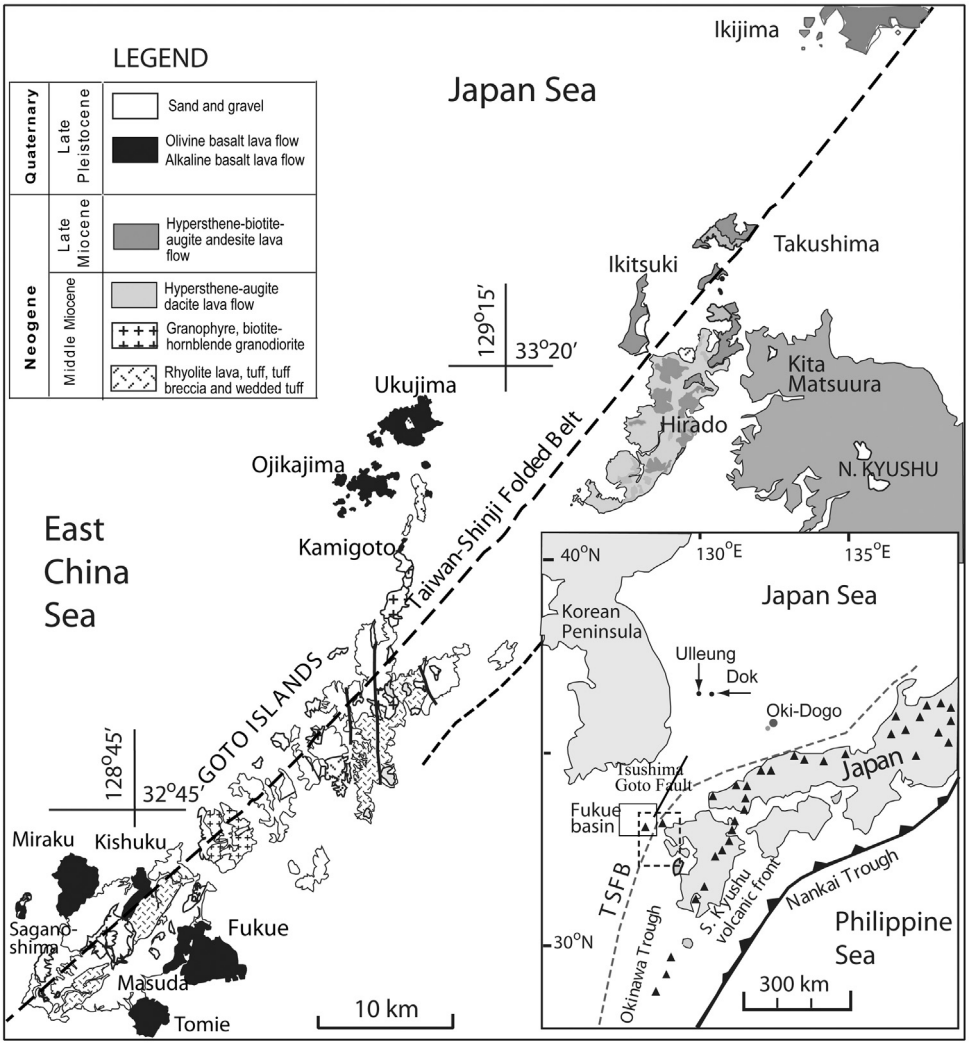

Fig. 1. Schematic distribution of Neogene basaltic centers along the Taiwan–Shinji Folded Belt (TSFB) relative to the Japanese islands and the Japan and East China Seas, simplified from Emery and Niino (1968), Wageman et al. (1970), Matsui and Kawada (1985), Uto et al. (1994) and Itoh (2001). Solid triangles represent Cenozoic basalt centers along the Southwest Japan volcanic front. Study area is dashed square.

(Tatsumoto and Nakamura, 1991; Uto et al., 1994; Miyake, 1994; e.g. Tatsumi et al., 1989; Mashima, 2009). Hoang and Uto (2003a, 2006), recognizing a clearly defined spatio-temporal geochemical and isotopic distribution, interpreted the magmas as products of interaction of asthenospheric melts with lithospheric mantle and/or crust (e.g. Nakada et al., 1997). In addition, on the basis of geochronology and their geochemical and isotopic character Uto et al. (2004) attributed those eruptives in the Hirado area, northern section of the Taiwan–Shinji Fold Belt (TSFB) (e.g. Jolivet et al., 1994) (Fig. 1) to two periods: 15 Ma syn-opening tholeiites and their differentiated andesites and dacites, and 6–9 Ma post-opening alkali basalts. However, despite their compositional differences, the isotopic character vastly represents hybrids of depleted mantle (N-MORB-like) and enriched mantle type 2 (EM2), generally inferred for the lithospheric mantle (e.g. Zindler and Hart, 1986; Uto et al., 2004). The region was inactive after these two episodes until eruptions of mostly alkali basalt appeared at a number of small volcanic centers at southwestern end of the Goto Islands after ca. 1 Ma (Fig. 1).

Objectives of the present study are: (1) to report geochemical and isotopic characteristics of the magmatic products in the Goto Islands, the youngest in southwest Japan, (2) to interpolate and compare magmatic source compositional evolution associated with this and Hirado older (15–6 Ma) eruptive episodes, and those elsewhere in northern Kyushu, and (3) to evaluate the geodynamic relationships between tectonics and magmatic activity, and their regional implications.

2. Geology and petrography

The Shinji Folded Belt was generated in the back-arc side of the retreating Ryukyu subduction zone during opening of Japan Sea prior to the Early to Middle Miocene (Otsuka, 1939; Emery and Niino, 1968; Jolivet et al., 1994). It has generally been referred to as the Taiwan–Shinji Folded Belt (TSFB) and runs parallel to the Ryukyu trench, which propagated southward behind Western Kyushu to the land-ward side of Taiwan (Wageman et al., 1970; Le Pichon, 1997). Sub-aerial exposure of the TSFB includes Early to Middle Miocene sediments and igneous products preserved on the Islands of Ikijima, Hirado, Ikitsuki and Takushima (Fig. 1) (Kurasawa, 1967; Matsui, 1990; Matsui and Kawada, 1985; Matsui et al., 1977; Uto et al., 2004; e.g. Nakada et al., 1997; Mashima, 2009 and references therein). The age thus appears to coincide with the opening of the Japan Sea (e.g. Jolivet et al., 1994).

The Goto islands are located in the eastern side of the Fukue Basin and Tsushima Goto Fault, two major tectonic units within the TSFB (Fig. 1). The pull-apart Fukue Basin was formed during Japan Sea opening (23–15 Ma) accommodated by the Tsushima Goto