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Zircon U–Pb age of the granitic tectonic block between the Suo Metamorphic Belt and Nagasaki Metamorphic Complex, Nagasaki Peninsula, southwest Japan

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Abstract Small granitic bodies have been recognized in the Nagasaki Metamorphic Rocks at eastern part of the Nagasaki Peninsula. They are thought to be Paleogene intrusion or ophiolitic rock in the Suo Metamorphic Belt. Radiometric U–Pb age of zircons in the porphyritic granitoid was obtained using a Sensitive High Resolution Ion MicroProbe (SHRIMP II). The weighted mean of the zircon ages of the sample is 117.1 ± 0.4 Ma (95% conf. MSWD=0.59) which is considered to be plutonic age of the granitoid. Since any thermal effect has not been observed in surrounding rocks, the granitic bodies are thought to be tectonic blocks in the Mogi thrust and have originated from the granitoid which was simultaneously formed with the migmatite in the Higo metamorphic rocks.

Key words: zircon, U–Pb age, Early Cretaceous, Suo Metamorphic Belt, metagranite

Introduction

After several discussion about attribution of the “Nagasaki Metamorphic Rocks,” Nishimura (1998) concluded that the “Nagasaki Metamorphic Rocks” are subdivided into two different attributions: one shows relatively high metamorphic grade with Late Cretaceous ages and another shows relatively low metamorphic grade with Triassic-Jurassic age, both inferred by white mica K–Ar method. The two types of metamorphics are considered attributed to Sanbagawa and Suo belts, respectively (Fig. 1A). Now, only the younger metamorphics are called Nagasaki Metamorphic Complex (NMC), and the older metamorphics belong to a western extension of the Suo Metamorphic Belt (SMB; e.g. Miyazaki *et al.*, 2013). The tectonic boundary between the NMC and SMB is recognized in two areas, originally divided by the same thrusts: named Fukahori–Wakimisaki Thrust in the western part of the Nagasaki Peninsula and Mogi Thrust in the eastern part of the peninsula (Fig. 1B; Nishimura *et al.*, 2004). The NMC exists as a window in the SMB in the peninsula.

Small granitic bodies have been recognized in the eastern part of the Nagasaki Peninsula (Mogi area; Fig. 1C). They were considered to be Paleogene intrusions (e.g. Igi *et al.*, 1976) or ophiolitic blocks in the SMB (Nishimura *et al.*, 2004). On the other hand, Takeda et al, (2002) reported mylonites in the Fukahori–Wakimisaki Thrust. The mylonites are leucocratic granite and low –P/T type metamorphic rocks in origin and are considered to be tectonic blocks originally attributed to the Higo Belt, central Kyushu. For a tectonic reconstruction around the Nagasaki Peninsula, it is important to confirm the age of the granitic bodies, whether they belong to the Paleogene, Higo-type belt or older ophiolitic rocks. Hence in this paper, we attempted to obtain the SHRIMP zircon U–Pb ages of granite in the bodies to discuss their relationships to the geological belts in northern Kyushu.

Sample Description

The granitic bodies are recognized as a Paleogene intrusion on the basis of a biotite K–Ar age of 56 Ma (Igi *et al.*, 1976). Nishimura *et al.* (2004) pointed out that the “biotite” age is doubtful because biotite in the granitic rock has completely altered to chlorite. Thermal effect has not been confirmed in surrounding rocks. White mica K–Ar ages of the surrounding metamorphic rocks are 162 to 214 Ma

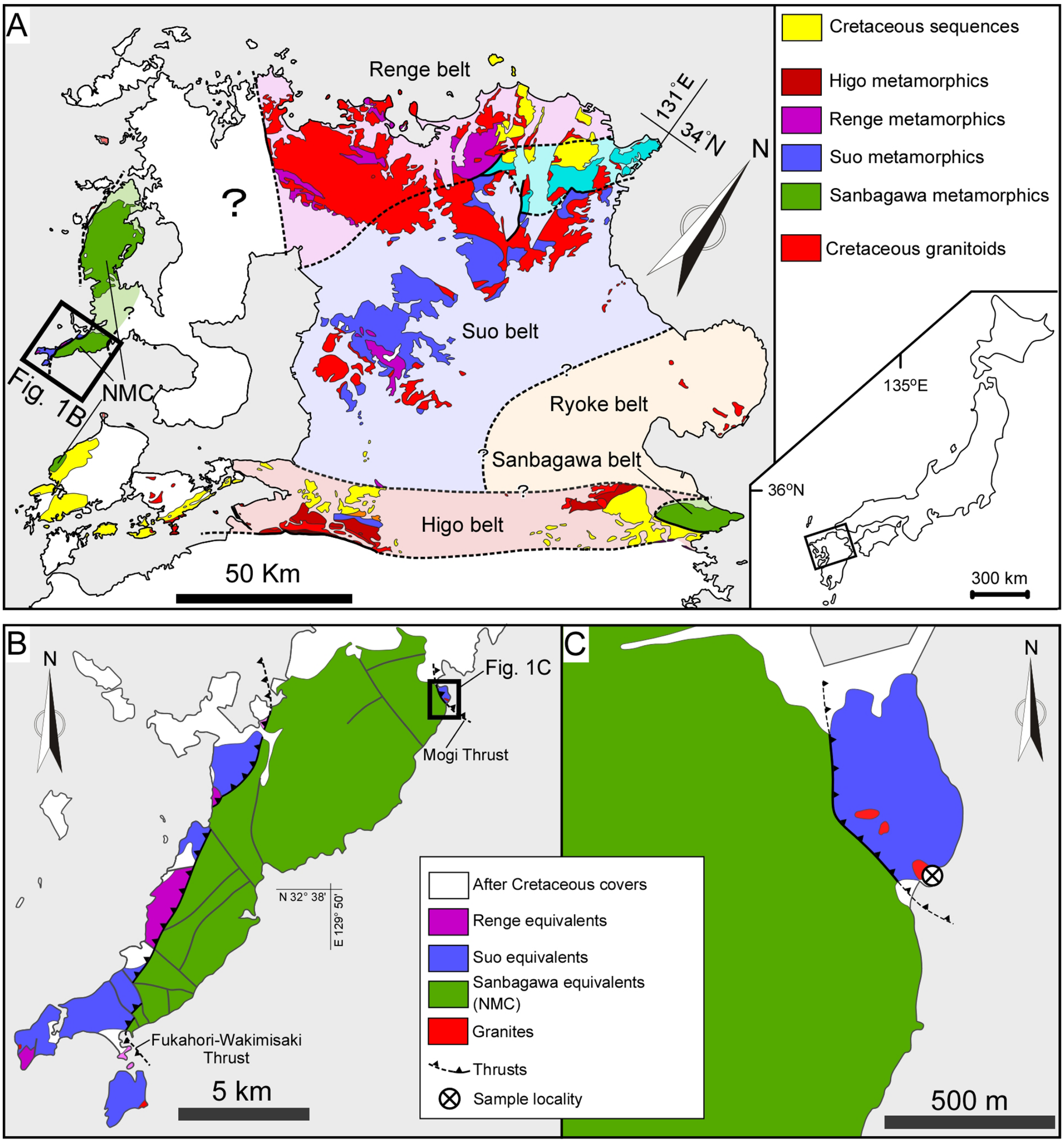

Fig. 1. A: Distribution map of the pre-Paleogene rocks in northern Kyushu. B: Geological map of Nagasaki Peninsula modified after Geological Survey of Japan (2015), Nishimura (1998) and Nishimura *et al.* (2004). C: Geological map of Mogi area modified after Nishimura *et al.* (2004).

(Nishimura *et al.*, 2004). The granitic rock has been stored in the National Museum of Nature and Science, Tsukuba, Japan with the registration number of NSM-R-134628.

Granitic rock from the Mogi area

The sample (lat: N32°41′50.2″, long: E129° 54′53.1″) was collected from eastern side of the Mogi thrust (Fig. 1; Nishimura *et al.*, 2004). The major minerals of this rock are plagioclase, alkali feldspar, quartz, chlorite with greenish color and epidote. Plagioclase occurs as subhedral crystal and exhibits indistinct albite twin. Fine grained clinozoisite and sericite are included in plagioclase. The granitic rock shows porphyritic texture (Fig. 2B). Alkali feldspar appears as a phenocryst with 1 cm in size (Fig. 2B). Undulatory extinction is observed in quartz that also occurs as a phenocryst with rounded shape. Pseudomorph after biotite is composed totally of chlorite (Fig. 2C and D) whereas pseudomorph after amphibole is chlorite with epidote core (Fig. 2E and F). Zircon and opaque mineral are

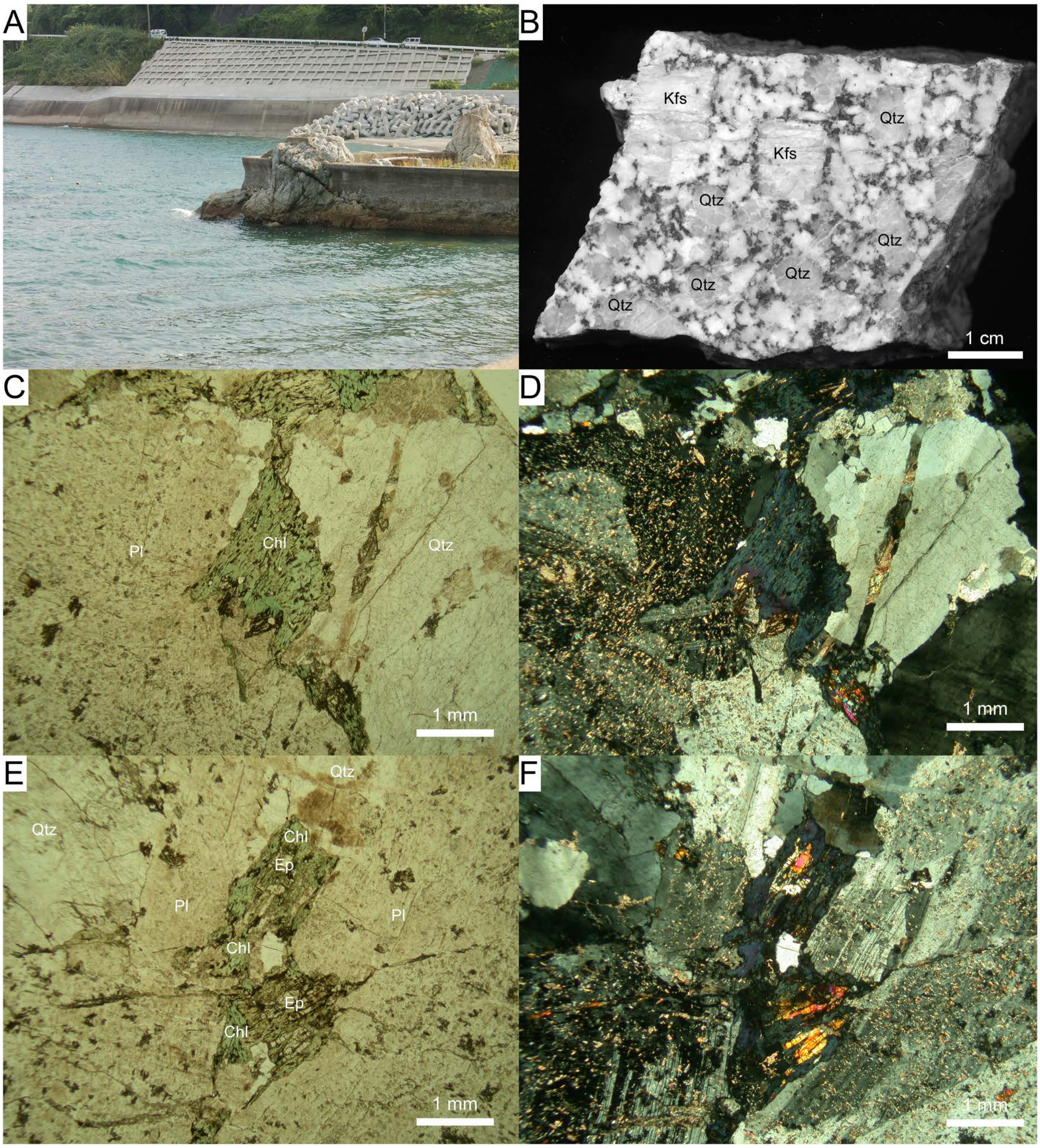

Fig. 2. A: Local outcrop of the granitic body. B: Polished section of the granitic rock including K-feldspar (Kfs) and quartz (Qtz) phenocrysts. C and D: Photomicrographs of biotite pseudomorph which was displaced by chlorite. Open and cross polar, respectively. E and F: Photomicrographs of amphibole pseudomorph which was displaced by chlorite with epidote core. Open and cross polar, respectively.

common accessory minerals. Calcite occurs as vein.

Experimental Procedure

The zircon grains for the SHRIMP analysis were handpicked from heavy fractions that were separated from the rock samples by standard crushing and heavy-liquid techniques. Zircon grains from the samples and the zircon standard AS3 ($^{206}Pb/^{238}U$ = 0.1859; Paces and Miller, 1993) were mounted in an epoxy resin and polished until the surface was flattened and the center of the embedded grains was exposed. Images of both the backscattered electron and cathodoluminescence were used for selecting the sites for the SHRIMP analysis. The U–Pb dating of these samples was carried out using SHRIMP II installed at the National Institute of Polar Research (NIPR), Japan. The experimental conditions and the procedures for the measurements followed Williams (1998). The spot size of the primary ion beam was approximately 20 μm. The U–Pb data were reduced in a manner similar to that described by Williams (1998) using the SQUID Excel macro written by Ludwig (2001). A correction for common Pb was made on the basis of the measured ^{204}Pb and the model for common Pb compositions proposed by Stacey and Kramers (1975). For age data of granitoid samples, the pooled ages presented in this study were calculated using the Isoplot/Ex software (Ludwig, 2003). The uncertainties in the mean ^{206}Pb*/^{238}U ages are within the 95% confidence limits (95% conf.) and include the uncertainty in the Pb/U calibration for each analytical session.

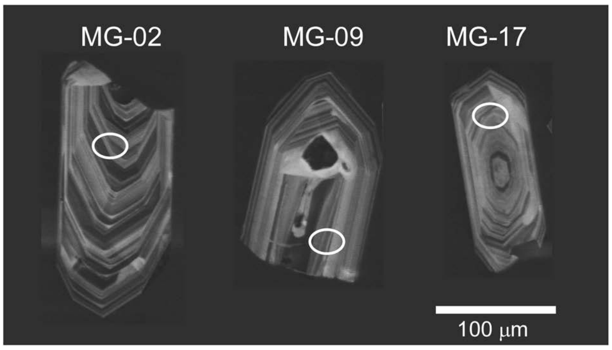

Fig. 3. Cathodoluminescence (CL) image of typical zircon grains. Ellipses on the images indicate the analyzed spots by SHRIMP.

Result

Table 1 lists zircon data of the metagranite sample in terms of the fraction of common ^{206}Pb, U, and Th concentrations, Th/U, ^{238}U/^{206}Pb*, and ^{207}Pb*/^{206}Pb* ratios, radiometric ^{238}U/^{206}Pb* ages. All errors are 1 sigma level. Figure 4A shows Tera–Wasserberg concordia diagrams for all analyzed spots. All zircons in the sample show rhythmic oscillatory zoning on backscattered electron and/or cathodoluminescence images (Fig. 3) which is commonly observed in igneous zircons (Corfu *et al.* 2003), and their higher Th/U ratios (>0.1) also support that they are igneous in origin (Williams and Claesson, 1987; Schiøtte *et al.*, 1988; Kinny *et al.*, 1990; Hoskin and Black, 2000). The weighted mean of the zircon ages of the sample (Fig. 4B) is 117.1 ± 0.4 Ma (95% conf. MSWD = 0.59).

Discussion

According to the zircon U–Pb age, the formation age of the granitic block is inferred 117.1 ± 0.4 Ma (95% conf.). If the granitic blocks in the Mogi area were ophiolitic blocks in the SMB, the age of the granitic block would be older than accretionary and metamorphism age of the SMB in this area. But the formation age of the granitic rock is far younger

Table 1. SHRIMP U–Pb data and calculated ages

Labels	$^{206}Pb_c$ $^{(1)}$ (%)	U (ppm)	Th (ppm)	Th/U	^{238}U/^{206}Pb*$^{(1)}$	^{207}Pb*/^{206}Pb*$^{(1)}$	^{238}U/^{206}Pb* age$^{(1)}$ (Ma)
MG-01.1	0.26	427	106	0.26	54.70 ± 0.48	0.04830 ± 0.00159	116.8 ± 1.0
MG-02.1	0.00	914	242	0.27	54.38 ± 0.37	0.04884 ± 0.00080	117.5 ± 0.8
MG-03.1	0.18	338	123	0.38	55.11 ± 0.52	0.04820 ± 0.00185	115.9 ± 1.1
MG-04.1	0.13	1974	357	0.19	54.37 ± 0.35	0.04830 ± 0.00052	117.5 ± 0.8
MG-05.1	0.14	833	296	0.37	54.14 ± 0.37	0.04881 ± 0.00095	118.0 ± 0.8
MG-06.1	0.21	203	88	0.45	54.66 ± 0.48	0.04860 ± 0.00131	116.9 ± 1.0
MG-07.1	1.18	192	57	0.31	55.59 ± 0.60	0.04120 ± 0.00507	115.1 ± 1.2
MG-09.1	0.13	521	204	0.40	54.44 ± 0.39	0.04947 ± 0.00067	117.4 ± 0.8
MG-10.1	0.30	436	245	0.58	54.65 ± 0.61	0.04700 ± 0.00228	116.9 ± 1.3
MG-11.1	0.08	419	114	0.28	54.92 ± 0.42	0.04870 ± 0.00156	116.3 ± 0.9
MG-12.1	0.05	2276	524	0.24	54.19 ± 0.35	0.04887 ± 0.00044	117.9 ± 0.8
MG-13.1	0.06	1262	355	0.29	54.27 ± 0.36	0.04862 ± 0.00055	117.7 ± 0.8
MG-14.1	0.26	335	102	0.32	54.59 ± 0.43	0.04836 ± 0.00100	117.0 ± 0.9
MG-15.1	0.11	2071	593	0.30	54.52 ± 0.35	0.04722 ± 0.00043	117.2 ± 0.7
MG-17.1	0.15	408	254	0.64	54.43 ± 0.41	0.04880 ± 0.00114	117.4 ± 0.9
MG-18.1	0.16	451	143	0.33	54.63 ± 0.41	0.04790 ± 0.00107	117.0 ± 0.9
MG-19.1	0.20	712	257	0.37	54.95 ± 0.39	0.04770 ± 0.00112	116.3 ± 0.8
MG-20.1	0.20	329	207	0.65	54.94 ± 0.87	0.04800 ± 0.00168	116.3 ± 1.8
MG-21.1	0.06	321	154	0.50	54.24 ± 0.42	0.04870 ± 0.00128	117.8 ± 0.9

Errors are 1-sigma; Pb_c and Pb* indicate the common and radiogenic portions, respectively.
(1) Common Pb corrected using measured ^{204}Pb

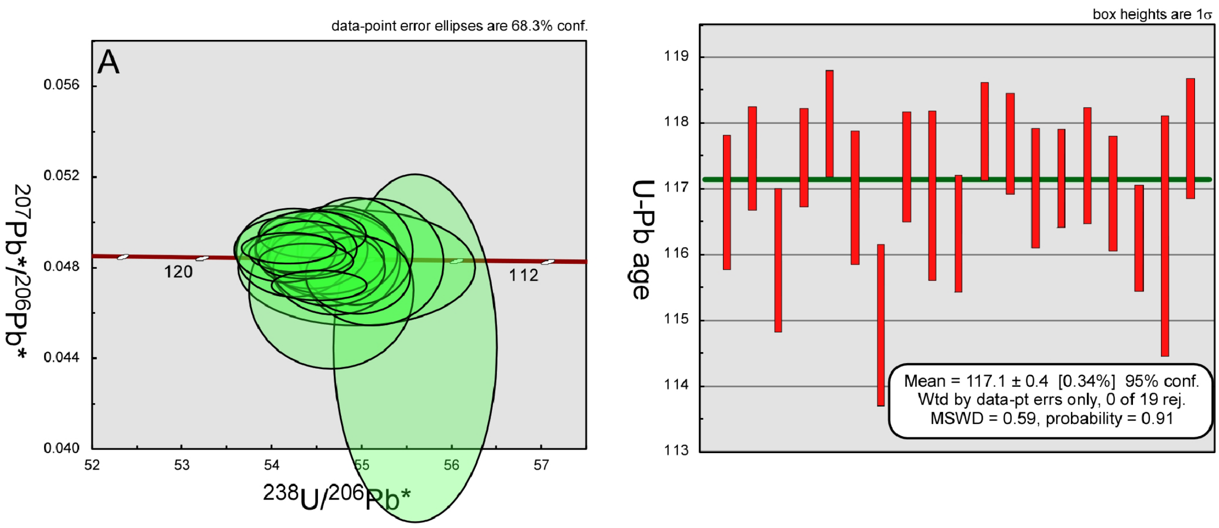

Fig. 4. A: Tera–Wasserburg U–Pb concordia diagrams of zircons and age distribution plot of zircon in the sample. ^{207}Pb* and ^{206}Pb* indicate radiometric ^{207}Pb and ^{206}Pb, respectively. Common Pb is corrected using measured ^{204}Pb. Solid curve indicates the concordia curve. B: Age distribution plot of zircon with calculated weighted mean age of the sample. Common Pb is corrected using measured ^{204}Pb.

than the white mica K–Ar ages reported from the SMB of this area. Moreover, the surrounding rocks have not been suffered from thermal effect by the granite bodies (Nishimura *et al.*, 2004). Hence, it is concluded that the granitic blocks are tectonic blocks in the Mogi thrust and were incorporated after their initial formation.

Takeda *et al.* (2002) reported a mylonite along the Fukahori–Wakimisaki Thrust in the Nagasaki Peninsula (Joyama mylonite). It consists of leucocratic granite and low –P/T type metamorphic rocks in origin. They considered that the rocks are attributed to the Higo Belt on the basis of the rock assemblage. There is a possibility that the granitic block in the Mogi area have an origin different from the present Higo granitoids. K–Ar ages of garnet-two mica schist in the Joyama mylonites are 84 and 92 Ma (white mica), whereas Amakusa mylonite indicate 96–101 Ma (white mica and biotite; Takeda *et al.*, 2002). Zircon U–Pb ages of migmatitic rock in the Amakusa mylonites indicate 113.7 ± 1.6 Ma, which is thought to be the age of the granulite facies metamorphism (Miyazaki *et al.*, 2013). An amphibolite mylonite from the Karasaki Mylonite thrusts on the Sanbagawa Belt in western Shikoku indicates 107.1 ± 3.4 Ma (2σ; Sakashima *et al.*, 2000), similar to the age of granitoids in the Higo Belt, ca. 110 Ma (e.g. Sakashima *et al.*, 2003). Moreover, the Joyama, Amakusa and Karasaki mylonites occupy tectonically an upper part of Sanbagawa metamorphic rocks including NMC.

Based on age data and tectonic consideration, the mylonites are thought to attribute to the Higo belt, but the formation age of 117 Ma of the granite in the Mogi thrust is slightly older than Higo granitoids. Maki *et al.* (2014) reported zircon U–Pb ages of 116 Ma and 110 Ma from two types of migmatites in the Higo Metamorphic Rocks, respectively. It is probable that the age of the granite in this study correspond to the age of the older migmatite (116 Ma) whereas the age of Higo granitoids correspond to the age of the younger migmatite (110 Ma). Hence, it is considered that the granitic block is a remnant of the heat source which produced the older migmatite.

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