Zircon U-Pb ages and whole-rock geochemistry from the Hida granites: implications for the geotectonic history and the origin of Mesozoic granites in the Hida belt, Japan

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The Hida granites, classified into the pre–Jurassic and Jurassic plutons in this study, are important components of the Hida belt, which is a Paleozoic–Mesozoic basement of the Japan arc and underwent Permian to Triassic metamorphism during the collision between the North and South China blocks. This study performed zircon U-Pb dating and whole-rock geochemical analyses for the Hida granites from the major plutonic bodies to reveal the geotectonic history and the origin of the Hida belt. Obtained 238U-206Pb weighted mean ages exhibit 239.1–238.3 Ma for the Katakaigawa body (augen granite) and 200.5–180.9 Ma for the other bodies (non-deformed granitoids), and these ages can be correlated to the pre–Jurassic and Jurassic plutons, respectively. Geochronological results suggest that the mylonitization forming augen granites of the pre–Jurassic plutons occurred during its intrusion and indicate that the Jurassic plutons are distributed widely in the Japan Sea side of the Hida belt. Meanwhile, geochemical characteristics of whole–rock major and trace element compositions indicate that the pre–Jurassic and Jurassic plutons seem difficult to distinguished geochemically and suggest that both of them are adakitic and non-adakitic granites generated in subduction zone.

Keywords: Hida belt, Hida granites, Zircon U-Pb age, Whole-rock geochemistry, Adakite

INTRODUCTION

The Hida belt in the back–arc side of the Southwest Japan is a Paleozoic–Mesozoic basement unit composed of granitoids and various metamorphic rocks. The Hida belt is thought to be a fragment of the eastern Asian continent such as the North China block (Omori and Isezaki, 2011; Horie et al., 2018) or the South China block (Wallis et al., 2020), however, its origin is one of the unsolved major issues related to the proto-Japan. Hence, the detailed understanding of the Hida belt is of great significance to understand the geotectonic history of the eastern Asian continent and processes of continental growth. Especially, igneous rocks such as the Mesozoic Hida granites (Takahashi et al., 2010) are important key to reveal igneous history and processes of the eastern Asia. However, previous geochronological and geochemical studies have targeted only a few main plutonic bodies of the Hida granites (e.g., Katakaigawa and Funatsu bodies; Fig. 1). Considering these situations, we obtained U-Pb ages and whole-rock geochemical compositions of the Hida granites from major plutonic bodies of the entire Hida belt. This study performed zircon U-Pb ages and whole-rock geochemical analyses for them and provide key information on the origin of the Hida belt.
The Hida belt consists of the Hida metamorphic rocks, the Unazuki metamorphic rocks, and the Hida granites (Fig. 1; Takahashi et al., 2010). The Hida metamorphic rocks are composed of shelf sediment-derived paragneisses and marbles with amphibolites and orthogneisses that were formed mainly by low P/T metamorphism in 250–235 Ma, and the metamorphic grade reached from amphibolite to granulite facies (Sohma and Kunugiza, 1993; Takahashi et al., 2018; Wallis et al., 2020). The Hida granites consist of the Triassic Hida older granites and the Jurassic Hida younger granites (Takahashi et al., 2010). Takahashi et al. (2018) discussed that the Hida older and younger granites were formed in 250–235 and 200–190 Ma, respectively and inferred that the magmatism prior to main metamorphism of the Hida belt (250–235 Ma) occurred at 330, 274, 266, and 255 Ma. Additionally, based on geochronological and geochemical characteristics, Takahashi et al. (2010) suggested that the Hida older and younger granites are distributed in the Japan Sea side and the Pacific Ocean side in the Hida belt, respectively, as shown in Figure 1.

We collected granitoid samples from the Hida granites following the subdivision of plutonic bodies mainly by Kan-no (1990) and classified samples into the pre-Jurassic and Jurassic plutons based on recent geochronological studies (Takahashi et al., 2010, 2018; Horie et al., 2018; Takehara and Horie, 2019; Koizumi and Otoh, 2020; this study) as shown in Tables 1 and 2. Collected samples of the pre-Jurassic plutons can be distinguished petrographically into two groups: granite mylonite with megacrysts of alkali feldspar (augen granite) and non-deformed granitoids composed mainly of Bt granite and Bt diorite. The Jurassic plutons on the other hand is composed only of non-deformed granitoids (e.g., Bt granite and Bt quartz diorite).

METHOD

Zircon grains were separated from each sample at National Museum of Nature and Science (Tsukuba, Japan). Zircon dating was performed by using a Nu Plasma II (Nu instruments, U.K.) Multi-collector-ICP-MS coupled to CARBIDE femtosecond laser-ablation system (Light Conversion, USA) at the University of Tokyo. Detailed analytical condition is described in Sawaki et al. (2020). Monitored uranium isotope was \(^{238}\text{U}\) for samples (HD07, 10, 17, 28, 37m, 38, and 39) and \(^{235}\text{U}\) for samples (HD26, 28, and 43). Analytes of \(^{202}\text{Hg}, \text{^{204} (Pb + Hg)}, \text{^{206}Pb}, \text{^{207}Pb}, \text{^{208}Pb}, \text{^{232}Th}\) were commonly monitored for all samples. Analytical uncertainties were combined with counting statistics of signal intensities, and the reproducibility of the standard analyses (NIST SRM610 and Nancy 91500 zircon) was added in quadrature (Wiedenbeck et al., 1995; Jochum et al., 2005). During the analytical sessions, we measured GJ-1 zircon as a secondary standard (Jackson et al., 2004). The results of the secondary standards were weighted mean \(^{206}\text{Pb}/^{238}\text{U}\) age of 592.6 ± 5.2 Ma (n = 28), which is coincident with
previously reported values within the analytical errors throughout the analysis.

Whole-rock major element compositions were determined by X-ray fluoresces (XRF) spectrometry with a Rigaku RIX 3000 at Niigata University. The XRF analysis was performed through glass bead method following the analytical procedures by Takahashi and Shuto (1997). Whole-rock trace element concentrations were determined by using Agilent 7500a quadrupole ICP-MS at Niigata University. Sample preparation was conducted following alkali fusion after acid digestion (AFAD) method by Senda et al. (2014), and analytical procedures by Neo et al. (2006) were followed. Trace element concentrations of BHVO-2 USGS standard material obtained during the analytical session were consistent with its reference values (Eggins et al., 1997; Makishita and Nakamura, 2006).

RESULT

Concordia diagrams with cathodoluminescence images of typical zircon grains. Solid circles in CL images are showing analyzed locations of diameter of 15 µm.

Table 1. Collected samples for zircon U-Pb dating and/or whole-rock geochemical analyses

| Plutonic body        | Subdivision in this study | Sample no. |
|----------------------|---------------------------|-------------|
| Jurassic plutons of the Hida granites (this study) | | |
| Funatsu              | B                         | HD13, 14, 17, 18, 56 |
| Hirose               | B                         | HD24        |
| Hodatsusan           | A                         | HD39        |
| Moriyasu             | B                         | HD26, 27    |
| Nagatogawa           | A                         | HD54        |
| Sekidosan            | A                         | HD42, 43    |
| Shimboramachi        | A                         | HD51        |
| Shimonomoto          | B                         | HD20, 55    |
| Shokawa              | A                         | HD36, 37, 37m |
| Togi                 | A                         | HD40        |
| Utsubo               | B                         | HD28, 29, 30, 31 |
| Yatazodani           | B                         | HD57, 58    |
| Yatsuho              | A                         | HD01, 38, 59 |

Pre-Jurassic plutons of the Hida granites (this study)

| A                           | B                         |
|-----------------------------|----------------------------|
| Amo                         | HD89                       |
| Asuwagawa                   | HD47                       |
| Ehieji                      | HD50                       |
| Iori                        | HD09                       |
| Katakagawa                  | HD06, 07, 10               |
| Mekkodani                   | HD53                       |
| Mugishima                   | HD60                       |
| Murakuniyama                | HD45, 45m                  |
| Nakayoro                    | HD48                       |
| Noguchi                     | HD11, 12, 21, 22, 23       |
| Shimowakago                 | HD49                       |
| Taiheizan                   | HD68, 69                   |
| Unazuki                     | HD04                       |
| Yokone                      | HD44                       |

A. Hida older granites; B, Hida younger granites.
Ma (Fig. 2) and Th/U ratio between 0.2 and 2.0. Those zircons show U and Th concentrations between 100 and 1000 ppm except for some with higher concentration from HD28. Weighted mean ages (Table 2) were calculated <3% discordance and >0.1 Th/U ratio.

Geochemical characteristics using compositional variation plots, discrimination diagrams, and trace element patterns of the pre–Jurassic and Jurassic plutons are shown in Figure 3. Both of the pre–Jurassic and Jurassic plutons show similar chemical compositions as they exhibit transitional composition between alkaline and subalkaline series and I–type granitic trends in SiO₂–ASI [aluminum saturation index; Al₂O₃/(CaO + Na₂O + K₂O) mol] diagram. Moreover, the most samples of them are plotted in areas of volcanic arc granite. It is one of remarkable points that some samples of the pre–Jurassic and Jurassic plutons have adakitic composition and indicate similar trace element patterns.

Table 2. Sampling locations, petrographic descriptions and ²³⁸U–²⁰⁶Pb weighted mean ages of dated samples

| Sample no. | Locality          | Rock body                  | Main mineral assemblage⁹/rocks type                  | Mean age (Ma) | MSWD | Probability |
|------------|-------------------|----------------------------|------------------------------------------------------|---------------|------|-------------|
| HD07       | N36°43'32.29", E137°31'14.57" | Katakaiwaga                | Afs Qz Pł Bt Ep Spn Ms/ Mylonitized Granite          | 238.3 ± 2.4   | 1.7  | 0.021       |
|            |                   |                            | Afs Qz Bt Ep Spn Ms/ Mylonitized Granite             | (n = 23)      |      |             |
| HD10       | N36°38'58.09", E137°32'32.07" | Katakaiwaga                | Afs Qz Bt Ep Spn Ms/ Mylonitized Granite             | 239.1 ± 1.9   | 2.4  | 0.001       |
|            |                   |                            | Afs Qz Ep Spn/ Mylonitized Granite                   | (n = 19)      |      |             |
| HD17       | N36°17'56.64", E137°22'27.50" | Funatsu                     | Afs Qz Ep Spn/ Massive Granite                      | 194.4 ± 2.4   | 2.7  | 0.000       |
|            |                   |                            | Afs Qz Ep Spn/ Massive Granite                      | (n = 19)      |      |             |
| HD26       | N36°19'54.34", E137°08'21.80" | Moriyasu                    | Afs Qz Ep Hbl Ep Spn/ Massive Granite               | 200.5 ± 5.5   | 4.7  | 0.000       |
|            |                   |                            | Afs Qz Ep Hbl Ep Spn/ Massive Granite               | (n = 9)       |      |             |
| HD28       | N36°22'26.34", E137°11'32.94" | Utsubo                      | Afs Qz Ep Hbl Ep Spn/ Massive Granite               | 190.3 ± 3.6   | 3.0  | 0.007       |
|            |                   |                            | Afs Qz Ep Hbl Ep Spn/ Massive Granite               | (n = 7)       |      |             |
| HD37m      | N36°29'15.17", E136°58'58.68" | Shokawa                     | Pl Qz Ep Afs Bt Hbl Spn/ Massive Quartz diorite     | 189.7 ± 3.9   | 4.0  | 0.000       |
|            |                   |                            | Pl Qz Ep Afs Bt Hbl Spn/ Massive Quartz diorite     | (n = 8)       |      |             |
| HD38       | N36°29'45.96", E137°08'03.00" | Yatsuo                      | Pl Afs Bt Hbl Qz/ Foliated Diorite                  | 187.5 ± 1.7   | 1.8  | 0.027       |
|            |                   |                            | Pl Afs Bt Hbl Qz/ Foliated Diorite                  | (n = 17)      |      |             |
| HD39       | N36°45'49.09", E136°46'29.50" | Hodatsusan                  | Afs Qz Ep Bt Hbl Spn/ Massive Granite               | 180.9 ± 1.1   | 2.2  | 0.001       |
|            |                   |                            | Afs Qz Ep Bt Hbl Spn/ Massive Granite               | (n = 25)      |      |             |
| HD43       | N36°58'15.07", E136°56'21.63" | Sekidosan                   | Afs Qz Ep Bt Hbl Spn/ Massive Granite               | 189.9 ± 0.9   | 1.5  | 0.032       |
|            |                   |                            | Afs Qz Ep Bt Hbl Spn/ Massive Granite               | (n = 30)      |      |             |

* Mineral abbreviations are after Whitney and Evans (2010).

Ma (Fig. 2) and Th/U ratio between 0.2 and 2.0. Those zircons show U and Th concentrations between 100 and 1000 ppm except for some with higher concentration from HD28. Weighted mean ages (Table 2) were calculated <3% discordance and >0.1 Th/U ratio.

Geochemical characteristics using compositional variation plots, discrimination diagrams, and trace element patterns of the pre–Jurassic and Jurassic plutons are shown in Figure 3. Both of the pre–Jurassic and Jurassic plutons show similar chemical compositions as they exhibit transitional composition between alkaline and subalkaline series and I–type granitic trends in SiO₂–ASI [aluminum saturation index; Al₂O₃/(CaO + Na₂O + K₂O) mol] diagram. Moreover, the most samples of them are plotted in areas of volcanic arc granite. It is one of remarkable points that some samples of the pre–Jurassic and Jurassic plutons have adakitic composition and indicate similar trace element patterns.
DISCUSSION

The present samples of the Katakaigawa body show mean ages of 239–238 Ma, whereas Takahashi et al. (2010, 2018) suggested igneous age of ~250–240 Ma for the Hida older granites and metamorphic ages of ~250–235 Ma (main metamorphism of the Hida metamorphic rocks) and 215–211 Ma (recrystallization by mylonitization). As the present dated zircons show igneous textures such as oscillatory zoning and 0.2–2.0 of Th/U ratio, the mean ages of 239–238 Ma (Table 2) also can be regarded as its igneous age of the host rocks. In the Katakaigawa-Hayatsukigawa-Joganjigawa area, at least two generations of deformed granitoid were described by Kano (1983); one is augen granite of the Katakaigawa body mylonitized along the adjacent simultaneous Iori body, and the other is mylonitized orthogneiss (augen gneiss) of the Hida metamorphic rocks. The present samples were collected from the augen granite of the Katakaigawa body, and the igneous age by Takahashi et al. (2010, 2018) indicates older deformed granite such as the augen gneiss. These results suggest continuous emplacement and subsequent deformation of granitic bodies in the Katakaigawa-Hayatsukigawa-Joganjigawa area during 250–240 Ma.

Zircon U-Pb age from the Funatsu body (194.4 ± 2.4 Ma) obtained in this study is consistent with previously reported igneous age of 199.1 ± 1.7 Ma by Takehara and Horie (2019). The present study for the first time reports zircon U-Pb ages by LA-ICP-MS and exhibited ages of 190–180 Ma from the other plutonic bodies (Table 2), except for the Moriyasu body (200.5 ± 5.5 Ma). These results indicate that the Jurassic plutons, which can be correlated to the Hida younger granites are distributed widely in the Japan Sea side of the Hida belt (Fig. 1 and Table 1). However, some dated plutos include mylonitazed facies, possibly expected older age like the Katakaigawa body, and indicate characteristic Sr-Nd isotopic compositions (Arakawa, 1988, 1990; Arakawa and Shimamura, 1995). Although the previous idea that the Hida older and younger granites are distributed in the Japan Sea and Pacific sides of the Hida belt, respectively (Takahashi et al., 2010), should be partly reconsidered, more geochronological data from those plutons is required to reveal age zoning in them. Additionally, the present results suggest that granitic magmatism forming the Jurassic plutons had continued until 180 Ma. Combined with age range (200–190 Ma) of the Hida younger granites by Takahashi et al. (2018), it can be assumed that the magmatic activity forming the Jurassic plutons took place in 200–180 Ma.

Negative anomalies of Nb and Ta in whole-rock trace element patterns (Fig. 3f), as well as discrimination diagrams of trace element concentration (Figs. 3d and 3e), suggest that the origins of both the pre-Jurassic and Jurassic plutons are produced through subduction zone magmatism rather than related to the continental collision between the North and South China blocks as previously thought (e.g., Sohmi and Kunugiza, 1993). This supports discussion on the petrogenesis of metagabbro from the Hida belt, proposing that protolith of the metagabbro was generated also in subduction zone (Kamitomo et al., 2011). Additionally, adakitic geochemical features such as high Sr/Y ratio and low Y concentration and I-type granitic trends in SiO$_2$-ASI diagram of the present samples are consistent with the previous analyses of the Hida granites (Arakawa and Shimamura, 1995; Ishihara, 2005). This study further shows that the pre-Jurassic and Jurassic plutons cannot be distinguished easily by whole-rock major and trace element compositions contrary to the expectations by previous studies (Arakawa and Shimamura, 1995; Takahashi et al., 2010), even though Arakawa (1988, 1990) and Arakawa and Shimamura (1995) described two contracting types of the Hida granites based on Sr-Nd isotopes. The present results indicate that both adakitic and non-adakitic arc magmatism had occurred intermittently between 240 and 180 Ma along the active margin of the eastern Asian continent to form the Hida granite.

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