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Uraninite and Thorite Ages of Around 400 Granitoids in the Japanese Islands

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Abstract. Systematic dating of around 400 granitoids in the Japanese Islands have been made on the basis of total UO_2, ThO_2 and PbO contents of uraninite and anhydrous thorite using an electron microprobe analyzer (EPMA) at the National Museum of Nature and Science, Tokyo. The ages range from ca. 5 Ma to 300 Ma. From the granitoid ages, the Japanese Islands were divided into many terranes. In northern Japan, granitoids with ages of approximately 110–120 Ma occur in the Kitakami Mountains, southwest Hokkaido and eastern Abukuma Mountains, and granitoids with ages of approximately 100–110 Ma occur at the western Abukuma Mountains and its northern extension. The granitoids that are around 90–100 Ma old occur sporadically in the Japanese Islands: mainly in the Asahi Mountains, the Nikko area, northern Shikoku and northern Kyushu. In central and northern Japan, the younger Cretaceous granitoids, partly Paleogene, with an age of around 65 Ma occur along the western part of the Asahi Mountains and Tsukuba–Nikkou area. In western Japan, granitoids that are 60–70 Ma old occur linearly along the coastal zone of the Sea of Japan. However, other granitoids with similar ages do not always show a linear or zone arrangement, but are concentrated in relatively restricted regions. These divisions by granitoid ages using uraninite and thorite are essentially similar to those determined by K–Ar ages, but the former ages are much more concentrated in each area than the latter ones.
Key words: uraninite, thorite, age, EPMA, granitoid

Introduction

Yokoyama *et al*. (2010) reconfirmed the age method for uraninite and thorite in granitoids based on the UO_2, ThO_2 and PbO contents that were obtained via an electron microprobe analyzer (EPMA). Holmes (1911) first established a method for dating minerals through normal wet chemical analyses on the basis of the assumption that inherited Pb was negligible at the time of mineral crystallization. Holmes (1931) later dealt exhaustively with the application of radioactivity to the measurement of geologic time. The method was used by many researchers and was referred to as the chemical age. After the isotope methods had been established for many minerals, the Holmes's method was not applied for uraninite and thorite until 1990. Bowles (1990) developed accurate age calculations for uraninite through EPMA analyses. Uraninite, thorianite, thorite and huttonite contain high concentrations of radiogenic Pb even in Paleogene and Neogene rocks. In most of the dating studies, the EPMA ages for these minerals were consistent with those obtained by isotopic methods (Yokoyama *et al*., 2010).

Iimori (1941) analyzed uraninite in a granitoid from Iisaka, Fukushima Prefecture, using the wet chemical method and calculated using the simple Holmes's equation. The age was 103 Ma, similar to the age obtained by the K–Ar method. Since 1965, the K–Ar method has been widely used for age analyses of granitoids in Japan (e.g. Kawano & Ueda, 1964 & 1966). Based mostly on the K–Ar method of the Kawano group, radiometric age data of granitoids in the Japanese Islands were summarized by Nozawa (1975). From the K–Ar method, it is well known that Cretaceous granitoids are the most ubiquitous in the islands, whereas Neogene granitoids occur mostly in Southwest Japan along the Pacific Ocean. Permian to Triassic granitoids occur only in the Hida Terrane, and ages of far older granitic rocks, Cambrian to Silurian, occur as small plutonic bodies.

The EPMA age method, *i.e.* U-Th-total Pb or chemical method, has attracted attention for its quickness, high spatial resolution and relatively high precision similar to isotopic methods. In this paper, we studied mainly uraninite and thorite ages of granitoids in the Japanese Islands and try to clarify age variation in each province. The age method was described in detail by Yokoyama *et al*. (2010). They demonstrated the validity of the EPMA method, which yields age results comparable to those obtained by isotopic methods such as Sensitive High Resolution Ion Microprobe (SHRIMP) and the K–Ar method. There are many methods used to obtain the ages of granitoids. Among them, SHRIMP and Laser Abration Inductively Coupled Plasma (LA-ICP-MS) are the most reliable and useful for this study because of the common presence of zircon. However, LA-ICP-MS and SHRIMP methods have, so far, only been applied to restricted samples or terranes. The present age method has a disadvantage that uraninite and thorite are not always present in the granitoids. It is, however, important to summarize the ages of the granitoids in the Japanese Islands by the same method as was performed for the K–Ar age method. In this study, the granitoid age is obtained by the same machine in the National Museum of Nature and Science and by the same analytical conditions and standards as reported by Yokoyama *et al*. (2010). Most granitoids older than the Cretaceous rarely contain uraninite and thorite. In such rocks, monazite ages are obtained by the EPMA method. Monazite ages comparing the results obtained by the same EPMA machine and isotopic ages have been reported by Santosh *et al*. (2006).

Paleomagnetic measurements showed that Southwest Japan was rotated clockwise, whereas Northeast Japan was rotated anticlockwise at the time of the opening of the Sea of Japan at around 20 Ma (e.g. Otofuji & Matsuda, 1983 & 1984). However, the boundary between the Southwest and Northeast terranes has not yet been clarified. In the Japanese Islands, Cretaceous granitoids are most common. The study of the spatial distribution of the granitoids will contribute to the reconstruction of the terranes in the islands and Prymorye, Far East Russia, before the opening of the Sea of Japan. Even if only a little, the present study will find a solution to the problem of the tectonic boundary between the Southwest and Northeast Japan.

Samples

Cretaceous and Cenozoic granitoids are widely distributed in the Japanese Islands (Fig. 1), whereas Jurassic to Permian granitoids occur only in the Hida terrane. Far older granitoids occur sporadically in the islands. Most of the granitoid samples used for this study are registered samples at the National Museum of Nature and Science. Some are preserved in storages at few universities. In total, around one thousand granitoids were crushed to check for radiogenic minerals such as uraninite, thorite and monazite. In the granitoids, uraninite (UO_2) and thorite ($ThSiO_4$) are usually rare minerals. Uraninite, if present, occurs mostly as a euhedral grain in the heavy fraction, rarely surrounded by pyrite. Although thorite was found in most of the granitoids in the Japanese Islands, it is commonly altered into hydrous thorite, especially in older granitoids. Anhydrous thorite is well preserved in

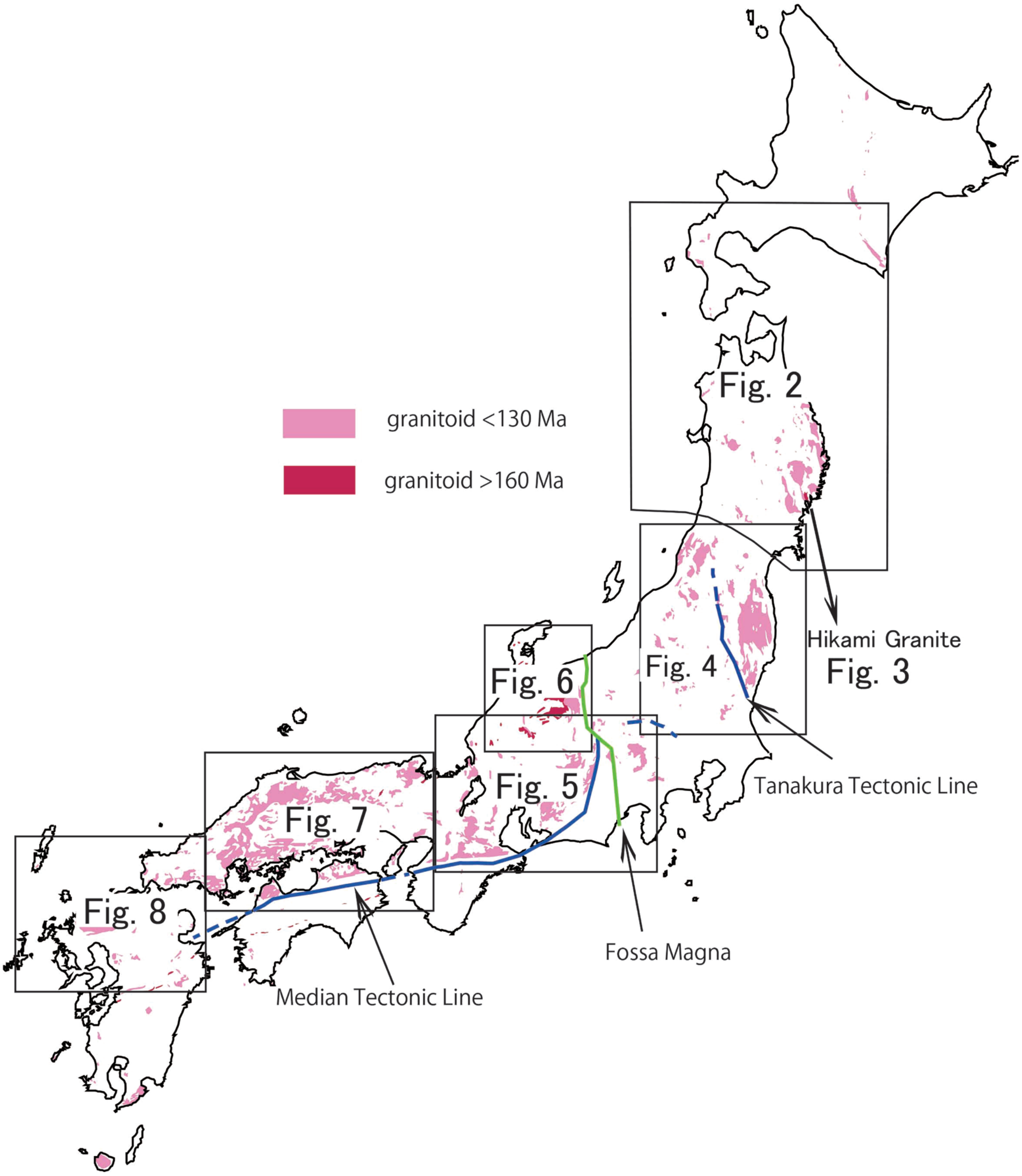

Fig. 1. Distribution of granitoids in the Japanese Islands and index map for the following figures.

the Neogene granitoids, but it is preserved partly in hydrated thorite grains in Cretaceous or older granitoids. Finally, we obtained ages from about 400 granitoid samples.

Age results

Ages of granitoids in the Japanese Islands are summarized according to the six provinces as shown in Fig. 1: southern Hokkaido–Tohoku, Asahi–Abukuma, Chubu–Kansai, Hida, Chugoku–northern Shikoku and northern Kyushu. All the

Table 1. Locality and age data of the analyzed granitoids in the Japanese Islands. The samples with registered number are stocked at the National Museum of Nature and Science.

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
Age data in Figs. 2, 3 and 4						
DN-01	granite	134109	Kenichi-onsen, Yakumo-cho, Futami-gun, Hokkaido	121.1 ± 1.7		
DN-02	granodiorite	134110	Kumaishitomarikawa, Yakumo-cho, Futami-gun, Hokkaido	119.6 ± 1.2		
DN-07	granite	134115	Pirika, Imakane-cho, Seta-gun, Hokkaido	122.2 ± 1.5		
OK-6	granodiorite	135359	Kamoishi Coast, Okushiri-cho, Okushiri-gun, Hokkaido	103.1 ± 0.6		
AO-6	granite	134279	Ohmagoe-rindo, Fukaura-machi, Nishitugaru-gun, Aomori	104.6 ± 0.7		
AO-7	granite	134280	Ohmagoe-rindo, Fukaura-machi, Nishitugaru-gun, Aomori	106.1 ± 1.6		
AO-8	granite	134281	Ohmagoe, Fukaura-machi, Nishitugaru-gun, Aomori	106.8 ± 1.7		
AO-9	granite	134282	Ohmagoe, Fukaura-machi, Nishitugaru-gun, Aomori	108.8 ± 0.9		
AO-10	aplite	134283	Ohmagoe, Fukaura-machi, Nishitugaru-gun, Aomori	107.7 ± 1.1		
AO-11	granite	134284	Ohmagoe, Fukaura-machi, Nishitugaru-gun, Aomori	92~107		
AO-14	granodiorite	134287	Ajigasawa-machi, Fukaura-machi, Nishitugaru-gun, Aomori	107.0 ± 1.0		
KTK–13	granite		Hashikami-cho, Sannohe-gun, Aomori		118.2 ± 1.7	
AK-2	granite	135408	Nibetsushinrin Museum, Akita-shi, Akita		5.0 ± 2.2	
AK-3	granite	135409	Sannai River, Kawabesannai, Akita-shi, Akita	101.9 ± 1.5		
AK-5	granite	135411	Idemaisawa, Kawabesannai, Akita-shi, Akita	101.6 ± 0.9		
AK-8	Qz diorite	135414	Kobuchigasawa, Akinomiya, Yuzawa-shi, Akita	103.0 ± 1.3		
AK-9	Qz diorite	135415	Kosawa, Akinomiya, Yuzawa-shi, Akita		23.4 ± 2.0	
TH-06	granitic rock	134472	Obonai, Tazawako, Senboku-shi, Akita			111.1 ± 7.3
TH-01	granitic rock	134464	Hondera, Genbi-cho, Ichinoseki-shi, Iwate	111.8 ± 1.2		112.2 ± 6.0
TH-02	granitic rock	134465	Yuda Dam, Nishiwaga-machi, Waga-gun, Iwate		109.1 ± 2.1	
TH-04	granitic rock	134467	Toyosawa Dam, Hanamaki-shi, Iwate	115.3 ± 1.4	112.5 ± 2.0	
TH-07	granitic rock	134470	Sawauchi, Nishiwaga-machi, Waga-gun, Iwate	109.0 ± 1.8		
TH-08	granitic rock	134471	Sawauchi, Nishiwaga-machi, Waga-gun, Iwate	108.4 ± 1.5		
AK-11	granite	135417	Koishizawa, Izawa-ku, Oshu-shi, Iwate	111.6 ± 1.2	114.4 ± 2.4	
AK-12	granite	135418	Hosoturusawa, Izawa-ku, Oshu-shi, Iwate		110.6 ± 2.2	
AK-13	granitoid	135419	Kazayodosawaguchi, Izawa-ku, Oshu-shi, Iwate	111.2 ± 2.4		
8605	granodiorite	8605	Fujikirisawa, Tsukimoshi-cho, Thono-shi, Iwate	118.4 ± 2.4	118.9 ± 4.4	
8612	granodiorite	8612	Sarugaishikawa, Tsukimoshi-cho, Thono-shi, Iwate	119.5 ± 2.3	118.0 ± 1.4	
8608	granodiorite	8608	Shimoarisu, Sumita-cho, Kesen-gun, Iwate		125.0 ± 4.0	
8609	granodiorite	8609	Sarugaishikawa, Tsukimoshi-cho, Thono-shi, Iwate		116.4 ± 4.9	
6515	granodiorite	6515	Koidenakataki, Tsukimoshi-cho, Thono-shi, Iwate		116.8 ± 2.0	
7294	adamelite	7294	Himegamidake, Tamayama-ku, Morioka-shi, Iwate		126.3 ± 4.7	
SK-1	adamelite	127853	Higashidake-toge, Hiraizumi-machi, Nishiiwai-gun, Iwate		121.9 ± 4.5	
SK-2	adamelite	127854	Nakajima, Ichinoseki-shi, Iwate		116.6 ± 4.3	
SK-5	granite	127857	Orikabe, Murone-machi, Ichinoseki-shi, Iwate		118.7 ± 4.0	
SK-19	granite	127871	Kamitubo, Takekoma-cho, Rikuzentakada-shi, Iwate		119.6 ± 4.4	
SK-32	granite	127884	Maide, Yokota-cho, Rikuzentakada-shi, Iwate		117.1 ± 1.4	
SK-14	granite	127866	Mt.Hikami, Rikuzentakada-shi, Iwate			454.8 ± 13.5
SK-16	granite	127868	Mt.Hikami, Rikuzentakada-shi, Iwate			455.7 ± 6.3
SK-18	granite	127870	Seisou-Center, Takekoma-cho, Rikuzentakada-shi, Iwate			447.6 ± 11.7
SK-25	granite	127877	Mt.Raishin, Rikuzentakada-shi, Iwate			125.1 ± 16.8
SK-29	biotite gneiss	127881	Kamitubo, Takekoma-cho, Rikuzentakada-shi, Iwate			449.4 ± 14.6
SK-30	biotite gneiss	127882	Kamitubo, Takekoma-cho, Rikuzentakada-shi, Iwate			451.9 ± 16.4
YT-5	granite	133770	Tamayamakogenr Takekoma-cho, Rikuzentakada-shi, Iwate			445.8 ± 11.7
SK-52	granite	127904	Rainai, Kamigo-cho, Thono-shi, Iwate	117.2 ± 1.9	114.4 ± 5.3	
SK-53	granite	127905	Nagaoka, Ayaori-cho, Thono-shi, Iwate	115.1 ± 1.9	117.0 ± 6.6	
SK-57	granodiorite	128618	Tahara-toge, Daito-cho, Ichinoseki-shi, Iwate	118.5 ± 2.3	118.0 ± 2.3	
SK-59	granodiorite	128620	Ogayu, Morioka-shi, Iwate		119.0 ± 2.5	
SK-61	granodiorite	128622	Takazudou, Towa-cho, Hanamaki-shi, Iwate		117.0 ± 2.7	
SK-62	granodiorite	128623	Yanagawa, Esashi-ku, Ohshu-shi, Iwate		118.0 ± 3.7	
SK-64	granodiorite	128625	Ide, Esashi-ku, Ohshu-shi, Iwate		118.0 ± 4.0	

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
KTK–1	granite		Fujisawa-cho, Ichinoseki-shi, Iwate		116.3 ± 2.3	
KTK–5	granite		Toni-cho, Kamaishi-shi, Iwate		117.2 ± 3.7	
KTK–6	granite		Hakizaki-cho, Kamaishi-shi, Iwate		116.5 ± 2.6	
KTK–7	granite		Tashiro, Miyako-shi, Iwate	123.2 ± 0.9	118.4 ± 2.9	
KTK–9	granite		Iwaizumi-cho, Shimohei-gun, Iwate		117.4 ± 2.4	
KTK–10	granite		Fudai-mura, Shimohei-gun, Iwate		118.9 ± 2.2	
KTK–12	granite		Hirono-cho, Kunohe-gun, Iwate		120.1 ± 2.5	
KTK–14	granite		Hanamaki-shi, Iwate		114.8 ± 3.2	
KTK–15	granite		Tsukimoshi-cho, Thono-shi, Iwate		113.2 ± 2.5	
KK-4	granodiorite	127605	Ayukawa-hama, Kinkazan, Ishinomaki-shi, Miyagi		116.4 ± 3.7	
KK-16	granodiorite	127617	Ayukawa-hama, Kinkazan, Ishinomaki-shi, Miyagi		118.6 ± 5.2	
Age data in Figs. 5 and 6						
031107-4	granitoid		Jinzu-kyou, Ooe-cho, Nishimurayama-gun, Yamagata	101.5 ± 0.9		
041122-2	granitoid		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata	93.4 ± 1.4		
041122-3	granitoid		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata		92.5 ± 1.6	
050609-12	granitoid		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata	95.7 ± 1.6		
050906-3	granitoid		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata	95.5 ± 1.5		
051128-6	granitoid		Yanagawa, Ooe-machi, Nishimurayama-gun, Yamagata	102.4 ± 1.6		
051128-3	granitoid		Yanagawa, Ooe-machi, Nishimurayama-gun, Yamagata	107.9 ± 2.8		
051130-5	granitoid		Sirakura, Asahi-machi, Yamagata	97.7 ± 2.2core, 92.4 ± 1.3rim		
051130-6	granitoid		Sirakura, Asahi-machi, Yamagata	91.1 ± 1.4		
051130-7	granitoid		Yanagawa, Ooe-machi, Nishimurayama-gun, Yamagata	91.7 ± 1.1		
051130-9	granitoid		Zao-dam, Kamihosawa, Yamagata-shi, Yamagata	93.3 ± 1.3		
060426-2	granitoid		Oura-hashi, Tsuruoka-shi, Yamagata	67.9 ± 1.0	65.6 ± 1.9	
061115-1	granite		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata	95.8 ± 1.2	91.3 ± 2.6	
061115-5b	granite		Ooisawa, Nishikawa-machi, Nishimurayama-gun, Yamagata	67.3 ± 1.7	66.3 ± 2.2	
061021-19	granitoid		Asahi-kosen, Asahi-machi, Nishimurayama-gun, Yamagata	91.0 ± 1.6		
061105-1	granitoid		Oohagemoriyama, Asahi-machi, Nishimurayama-gun, Yamagata	92.5 ± 2.1		
061108-13	granitoid		Asahi-machi, Nishimurayama-gun, Yamagata	97.2 ± 1.0	97.6 ± 2.5	
070627-29	granitoid		Nishikawa-machi, Nishimurayama-gun, Yamagata		66.9 ± 3.6	
070719-2	granitoid		Oguni-machi, Nishiokitama-gun, Yamagata	80.7 ± 1.6		
070726-4	granitoid		Iide-machi, Nishiokitama-gun, Yamagata	80.2 ± 1.7 core, 68.0 ± 0.7rim	65.6 ± 4.3	
070726-11	granitoid		Teraizumi, Nagai-shi, Yamagata		63.0 ± 3.0	
061201-4	granitoid		Nakaisazawa, Nagai-shi, Yamagata	97.9 ± 1.3		
061201-5	granitoid		Urushiyama, Nanyou-shi, Yamagata	98.2 ± 1.3		
061115-8	granitoid		Nishikawa-machi, Nishimurayama-gun, Yamagata	91.0 ± 1.7		
06120-1c	granitoid		Shirataka-machi, Nishiokitama-gun, Yamagata	103.8 ± 1.4		
ER6-4	granitoid		Yamaguchi, Tendo-shi, Yamagata	101.8 ± 1.3		
111206-3	granitoid		Kamihigashiyama, Yamagata-shi, Yamagata	95.1 ± 1.4		
111207-6	granitoid		Daimon, Kaminoyama-shi, Yamagata	101.6 ± 1.3		
091022-1	granitoid		Tachiyazawa, Shonai-machi, Higashitagawa-gun, Yamagata	97.2 ± 1.0		
111012-3	granitoid		Nagaioohashi, Hinode-machi, Nagai-shi, Yamagata	97.2 ± 0.6		
Nihon-2	granite	130674	Oodai, Murayama-shi, Nigata	65.6 ± 1.3		
Nihon-3	granite	130675	Omata, Murakami-shi, Nigata	65.0 ± 1.2		
Nihon-15	granite	130686	Ganjiki, Murayama-shi, Nigata	65.5 ± 0.6		
Kita-1	diorite	129956	Nyotaisan, Nakagawa-machi, Nasu-gun, Tochigi		105.1 ± 3.7	
Ashi-6	adamelite	127850	Chyugushi, Nikko-shi, Tochigi	63.5 ± 2.5	63.6 ± 3.0	
Ashi-4	granite	127848	Ashio-machi, Nikko-shi, Tochigi	63.7 ± 2.0	65.2 ± 3.7	
Ashi-7	granite	127851	Sasamekura, Nikko-shi, Tochigi	65.1 ± 2.2	65.7 ± 3.2	
Ashi-5	granite	127849	Chyugushi, Nikko-shi, Tochigi	97.9 ± 1.8		
Ashi-3	aplite	127847	Hara, Ashio-machi, Nikko-shi, Tochigi	99.2 ± 1.7		
Ashi-2	granite	127846	Kusaki lake, Azuma-cho, Midori-shi, Gunma	99.2 ± 2.5		
ABK-7	granitoid		Yokokawa-machi, Koriyama-shi, Fukushima	103.4 ± 1.0		

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
ABK-8	granitoid		Tamura-machi, Koriyama-shi, Fukushima	124.1 ± 1.2	120.9 ± 2.6	
ABK-10	granitoid		Ono-machi, Tamura-gun, Fukushima		113.3 ± 2.4	
ABK-11	granitoid		Hirata-mura, Ishikawa-gun, Fukushima	106.5 ± 1.0		
ABK-12	granitoid		Ishikawa-machi, Ishikawa-gun, Fukushima	110.3 ± 1.5		
ABK-15	granitoid		Samekawa-mura, Higashishirakawa-gun, Fukushima	114.4 ± 1.2		
ABK-16	granitoid		Tabito-machi, Iwaki-shi, Fukushima	106.5 ± 3.0		
ABK-17	granitoid		Furudono-machi, Ishikawa-gun, Fukushima	110.3 ± 1.0		
ABK-24	granitoid		Katsurao-mura, Futaba-gun, Fukushima	110.4 ± 1.5		
ABK-25	granitoid		Tokiwa-machi, Tamura-shi, Fukushima	104.2 ± 1.0	102.5 ± 1.7	
YK24	granodiorite	127564	Mt.Takakura, Yaguki, Yotsukura-machi, Iwaki-shi, Fukushima	117.9 ± 3.5		
Yk27	granodiorite	127568	Shiosawa, Ogawa-machi, Iwaki-shi, Fukushima	115.8 ± 1.5		
K44	metaporphyry	127480	Mt.Haguro, Soma-shi, Fukushima	116.0 ± 0.05		
I-A	granite	128636	Oda, Tsukuba-shi, Ibaraki	65.1 ± 1.3		80.0 ± 7.4
I-B	granite	128637	Shiio, Makabe-cho, Sakuragawa-shi, Ibaraki	65.8 ± 1.5		
I-C	granodiorite	128638	Sakurabo, Makabe-cho, Sakuragawa-shi, Ibaraki	65.0 ± 1.2		74.7 ± 12.5
I-E	granite	128639	Inada, Kasama-shi, Ibaraki		69.5 ± 2.7	
I-4	granodiorite	128643	Iwafune, Shirosato-machi, Higashiibaraki-gun, Ibaraki			68.6 ± 1.5
I-11	granodiorite	128650	Shimokimita, Takahagi-shi, Ibaraki		105.0 ± 0.8	
I-12	granodiorite	128651	Ishioka, Nakago-cho, Kitaibaraki-shi, Ibaraki	105.2 ± 0.8		
I-14	granodiorite	128653	Takahara, Juoo-cho, Hitachi-shi, Ibaraki	106.1 ± 2.1	102 (1grain)	
Z-4	granite	128658	Inada, Kasama-shi, Ibaraki	66.5 ± 1.1	68.2 ± 1.4	
Z-6	granodiorite	128660	Iwase, Sakuragawa-shi, Ibaraki		67.2 ± 3.8	
Z-7	granite	128661	Kurusu, Kasama-shi, Ibaraki		69.3 ± 4.5	
Z-9	granite	128663	Ohirominami, Kasama-shi, Ibaraki		67.7 ± 1.0	
Z-13	granite	128667	Hojo, Tsukuba-shi, Ibaraki	64.6 ± 2.3		
Z-14	granite	128668	Usui, Tsukuba-shi, Ibaraki	68.5 ± 2.1	80.5 ± 2.2core, 67.8 ± 4.5rim	
ABK-18	granite		Oda, Tsukuba-shi, Ibaraki	65.2 ± 0.9		
ABK-20	granite		Makabe-cho, Sakurakawa-shi, Ibaraki	79.7 ± 1.4	81.0 ± 1.9	
Age data in Figs. 7 and 8						
S-1	granodiorite	128628	Mt.Eimeiji, Chino-shi, Nagano		11.5 ± 0.8	
91030804	granitoid		Kashimata, Takagi-mura, Shimoina-gun, Nagano	72.6 ± 0.9		
98031201	granitoid		Ogawa, Agematsu-machi, Kiso-gun, Nagano		71.6 ± 2.1	
YG-118	granitoid		Momiji lake, Minowa-machi, Kamiina-gun, Nagano		72.3 ± 2.7	
YG-120B	granitoid		Kuwabara fall, Kamiina-gun, Nagano	72.2 ± 1.2		
YG-121B	granitoid		Koshibu lake, Minowa-machi, Kamiina-gun, Nagano	71.6 ± 1.0		
S-2	granite	128629	Hakusyu-cho, Hokuto-shi, Yamanashi		14.1 ± 1.2	
5763	granite	5763	Taguchi, Shidara-cho, Kitashidara-gun, Aichi	101.0 ± 2.3		
E-1	granite	128626	Kerokubo, Kasagi-cho, Ena-shi, Gifu		69.4 ± 1.5	
TG-2	granite	134087	Tateishi, Tsuruga-shi, Fukui		68.6 ± 2.7	
TG-3	granite	133088	Irohama, Tsuruga-shi, Fukui		68.3 ± 2.4	
TG-4	granite	132089	Kutsu, Tsuruga-shi, Fukui		67.9 ± 2.3	
TG-5	granite	131090	Takekawa, Mihama-cho, Mikata-gun, Fukui		69.3 ± 1.9	
TG-6	granite	130091	Kurokawagawa quarry, Tsuruga-shi, Fukui		67.8 ± 2.5	
TS-3	porphyry	134453	Hachimangu, Masuya, Echizen-shi, Fukui	66 (1grain)	65.5 ± 1.5	
98031401	granitoid		Tanokami, Otsu-shi, Shiga	77.3 ± 1.0		
98031402	granitoid		Tanokami, Otsu-shi, Shiga	77.7 ± 1.1		
98031403	granitoid		Tanokami, Otsu-shi, Shiga		79.7 ± 2.1	
98031405	granitoid		Mt.Hiei, Otsu-shi, Shiga	101.1 ± 1.0	101.9 ± 1.8	
98031501	granitoid		Hira, Otsu-shi, Shiga		77.0 ± 2.1	
OG-3	granitoid		Ogi, Otsu-shi, Shiga		102.4 ± 3.8	
RZ-2	granitoid		Ryozen, Otsu-shi, Shiga		74.1 ± 2.0	
SZ-1	granitoid		Mandokoro-cho, Higashiomi-shi, Shiga		73.0 ± 2.0	
SZ-2	granitoid		Tuchiyama-cho, Koga-shi, Shiga		73.4 ± 2.5	
OM-5	granitoid		Ide-cho, Tsuzuki-gun, Kyoto		104.2 ± 2.3	
HA-4	granitoid		Hanasebetsusho-cho, Sakyou-ku, Kyoto		105.6 ± 1.9	
IN-08	granite	135895	Mie, Omiya-cho, Kyotango-shi, Kyoto		65.7 ± 4.7	
IDM-1	granitoid		Ide-cho, Tsuzuki-gun, Kyoto		90.1 ± 2.0	
KO-1	granitoid		Somada, Wazuka-cho, Soura-gun, Kyoto	98.0 ± 1.0	94.4 ± 3.3	
GY-4	granitoid		Mt.Gyoja, Kameoka-shi, Kyoto	98.8 ± 1.2		
Ik-5	granodiorite		Taishi-cho, Minamikawachi-gun, Osaka		80.9 ± 1.6	
KTN	granitoid		Kisabe, Katano-shi, Osaka		84.2 ± 1.5	

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
98031502	granitoid		Ibaraki-shi, Osaka		80.9 ± 1.9	
98031503	granitoid		Ibaraki-shi, Osaka		82.2 ± 1.8	
98031504	granitoid		Ibaraki-shi, Osaka		81.5 ± 2.7	
Ik-1	granite	129930	Kitasanjyoguchi-station, Heguri-cho, Ikoma-shi, Nara	86.7 ± 0.9		
Ik-2	granite	129931	Ichihara tunnel, Heguri-cho, Ikoma-shi, Nara	86.0 ± 0.6		
Ik-3	granite	129932	Kitasanjyoguchi-station, Heguri-cho, Ikoma-shi, Nara	86.6 ± 0.5		
IK-9	granite	129938	Hondo, Sango-cho, Ikoma-gun, Nara	81.2 ± 2.2		
Ik-11	qz diorite	129940	Kyuanji, Heguri-cho, Ikoma-shi, Nara		86.0 ± 1.4	
SK-02	granitoid		Nakatani, Sakurai-shi, Nara	89.0 ± 1.7		
SK-03	granitoid		Kasa, Sakurai-shi, Nara	89.3 ± 1.4		
SK-04	granitoid		Kasa, Sakurai-shi, Nara	74.7 ± 1.3		
S-3	granite	128630	Kamiobina-cho, Kofu-shi, Yamanashi		15.8 ± 1.7	
S-4	granite	128631	Yoshizawa, Kai-shi, Yamanashi		16.9 ± 2.1	
S-5	granodiorite	128632	Yanagidaira, Makioka-cho, Yamanashi-shi, Yamanashi		4.1 ± 0.8	
S-6	granodiorite	128633	Kanazakura shrine, Makioka-cho, Yamanashi-shi, Yamanashi		4.8 ± 1.2	
S-8	granodiorite	128635	Narusawa, Makioka-cho, Yamanashi-shi, Yamanashi		12.8 ± 1.2	
S-9	granodiorite	134085	Kaiyamato statim, Yamato-cho, Kosyu-shi, Yamanashi		12.1 ± 1.5	
Age data in Figs. 9 and 10						
98031301	granite		Niho power station, Yatsuo-machi, Toyama-shi, Toyama	195.5 ± 3.2		
98052212	granite		Iori, Kamiichi-machi, Nakaniikawa-gun, Toyama	66.8 ± 2.0	67.1 ± 3.1	
98052217	granite		Iori, Kamiichi-machi, Nakaniikawa-gun, Toyama	198.7 ± 2.5		
98112501	granite		Minamimata vally, Sanga, Uozu-shi, Toyama	232.4 ± 4.4		
98112504	granite		Minamimata, Sanga, Uozu-shi, Toyama	236.3 ± 5.5		
99040905	granite		Mt.Shiridaka, Kamiichi-machi, Nakashinkawa-gun, Toyama	241.0 ± 3.6		
99042210	granite		Kufusu river, Kiritani, Yatsuo-machi, Toyama-shi, Toyama	189.9 ± 3.2		
99082802	aplite		Shona river, Tateyama-machi, Nakashinkawa-gun, Toyama	198.1 ± 3.0		195.4 ± 6.5
99100705	granite		Otozawa, Unazuki-machi, Kurobe-shi, Toyama	255.8 ± 2.9		
99100707	granite		Unazuki-machi, Kurobe-shi, Toyama	core:241.1 ± 4.2, sec:191.8 + 5.9		
5760	granite	5760	Aimoto, Unazuki-machi, Kurobe-shi, Toyama	95.9 ± 2.4		
98112201	granite		Isurugiyama, Nakanoto-machi, Kashima-gun, Ishikawa	183.5 ± 3.7		
99042801	granite		Mt.Hotatu, Hakui-shi, Ishikawa			188.5 ± 7.1
99042805	granite		Mt.Hotatu, Hakui-shi, Ishikawa	234.3 ± 2.8		
99091807	granite		Notokongo, Shika-machi, Hakui-gun, Ishikawa		189.2 ± 7.0	
99111304	granite		Metuke vally, Aratani, Hakusan-shi, Ishikawa	188.9 ± 3.1		
99111305	granite		Metuke vally, Aratani, Hakusan-shi, Ishikawa	161.1 ± 4.5		215.2 ± 13.6
99111306	granite		Metuke vally, Aratani, Hakusan-shi, Ishikawa			196.5 ± 9.8
98092905	granite		Horatani, Miyagawa-cho, Hida-shi, Gifu			198.3 ± 4.1
98092906	granite		Horatani, Miyagawa-cho, Hida-shi, Gifu			196.5 ± 3.8
98092907	granite	129249	Horatani, Miyagawa-cho, Hida-shi, Gifu		245.2 ± 5.0core, 196.7 ± 7.4rim	
98092908	granite		Horatani, Miyagawa-cho, Hida-shi, Gifu	206.8 ± 2.4		
98092910	granite	129248	Utsubo, Miyagawa-cho, Hida-shi, Gifu	204.4 ± 4.3		
98092911	granite		Utsubo, Miyagawa-cho, Hida-shi, Gifu	208.5 ± 2.5		
98092913	granite		Utsubo, Miyagawa-cho, Hida-shi, Gifu	189.6 ± 3.6		
98100304	granite	129250	Azukizawa, Miyagawa-cho, Hida-shi, Gifu	189.6 ± 4.0		
98100308	granite		Hongo, Kamitakara-cho, Takayama-shi, Gifu	201.7 ± 2.8		
98100309	granite		Shimosatani, Kamitakara-cho, Takayama-shi, Gifu	198.8 ± 3.5		
98100310	granite		Shimosatani, Kamitakara-cho, Takayama-shi, Gifu	191.5 ± 2.9		
98100311	granite		Kuzuyama, Kamitakara-cho, Takayama-shi, Gifu	194.2 ± 3.3		
99042103	granite	129252	Morimo, Kamioka-cho, Hida-shi, Gifu	198.9 ± 2.6		
99042106	granite		Sugoroku river, Kamitakara-cho, Takayama-shi, Gifu			205.4 ± 7.8
99042107	granite		Kasatani, Kamitakara-cho, Takayama-shi, Gifu	205.2 ± 3.6		
99042108	granite		Kamitakara-cho, Takayama-shi, Gifu			267.8 ± 10.1
99082901	granite		Kagasawa, Utubo, Miyakawa-cho, Hida-shi, Gifu	190.2 ± 4.0		193.4 ± 4.9
99093003	granite		Osaka-toge, Furukawa-maci, Hida-shi, Gifu			215.2 ± 13.6
99093004	granite		Furukawa-cho, Hida-shi, Gifu			196.1 ± 11.9

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
HD31	granite		Asoya, Kamioka-cho, Hida-shi, Gifu	201.6 ± 3.1		
KM133	granite		Mannami river, Miyagawa-cho, Hida-shi, Gifu	233.4 ± 3.4core, 191.4 ± 1.8rim		
Age data in Figs. 11 and 12						
D2000408	granitoid		Aioi, Aioi-shi, Hyogo		86.8 ± 2.4	
GY-05	granitoid		Okuyane, Tanto-cho, Toyooka-shi, Hyogo		66.2 ± 2.6	
GY-06	granitoid		Tanto-cho, Toyooka-shi, Hyogo		67.4 ± 2.3	
TSHY-60	granitoid		Nada-ku, Kobe-shi, Hyogo		81.6 ± 2.5	
9803170313	granitoid		Kita-ku, Kobe-shi, Hyogo		79.3 ± 2.0	
98031702	granitoid		Mt.Rokko, Higashinada-ku, Kobe-shi, Hyogo		81.6 ± 1.1	
MIKAGE	qz-diorite		Mt.Rokko, Higashinada-ku, Kobe-shi, Hyogo		82.2 ± 1.0	
TSHYG-42	granitoid		Mt.Rokko, Higashinada-ku, Kobe-shi, Hyogo		81.6 ± 2.5	
Akou	granitoid		Tenwa, Akou-shi, Hyogo		88.2 ± 1.7	
Tatsuno-1	granitoid		Shinmiya-cho, Tatsuno-shi, Hyogo		87.6 ± 2.0	
TSTAU-1	granitoid		Shiosaki, Miya, Ienaga-cho, Himeji-shi, Hyogo		85.4 ± 2.0	
TSTAU-7	granitoid		Hishinohana, Ienaga-cho, Himeji-shi, Hyogo		85.8 ± 1.8	
NGM-2	granitoid		Nojima-Hirabayashi, Awaji-shi, Hyogo	82.9 ± 1.6	86.1 ± 1.7	
AW-58c	granitoid		Oomachi, Awaji-shi, Hyogo		87.0 ± 3.0	
SZUKI-1	granitoid		Shio, Awaji-shi, Hyogo	84.0 ± 0.7		
YG-41	granitoid		Iwaya, Shinmura, Awaji-shi, Hyogo	84.8 ± 1.8	87.3 ± 2.5	
YG-43	granitoid		Iwaya, Shinmura, Awaji-shi, Hyogo		81.2 ± 2.1	
YG-58	granitoid		Takenokuchi, Sumoto-shi, Hyogo	85.4 ± 1.2	85.8 ± 2.1	
YG-59	granitoid		Shio, Awaji-shi, Hyogo	84.3 ± 1.4		
YG-81	granite		Shio, Awaji-shi, Hyogo	88.1 ± 0.5		
YG-87	granitoid		Iwaya, Shinmura, Awaji-shi, Hyogo	81.2 ± 1.1	81.7 ± 1.2	
YG-88	granitoid		Nojima Hikinoura, Awaji-shi, Hyogo	81.9 ± 0.9		
YG-89	granitoid		Higashiyama, Shinmura, Awaji-shi, Hyogo	82.8 ± 2.1	87.8 ± 3.3	
GY-02	granitoid		Shimonomiya, Toyooka-shi, Hyogo		66.4 ± 1.5	
GY-03	granitoid		Hokkeiji, Toyooka-shi, Hyogo		74.8 ± 2.5	
GY-05	granitoid		Okuyane, Tanto-cho, Toyooka-shi, Hyogo		66.2 ± 2.6	
GY-06	granitoid		Okuyane, Tanto-cho, Toyooka-shi, Hyogo		67.4 ± 2.3	
Mannari	granite		Mannai, Kita-ku, Okayama		87.8 ± 1.9	
GY-12	granitoid		Kamisaibara, Kagami-cho, Tomata-gun, Okayama	72.6 ± 2.6		
GY30-2	granitoid		Ushiroyama, Mimasaka-shi, Okayaam		65.9 ± 3.0	
GY-65	granitoid		Hiruzen-Nishikayabe, Maniwa-shi, Okayama	64.3 ± 1.3		
GY-86	granitoid		Fujimori, Maniwa-shi, Okayama	68.0 ± 1.2		
YG-07	granitoid		Kashino, Ushimado-cho, Setouchi-shi, Okayama		83.9 ± 2.3	
YG-08	granitoid		Yomogisaki, Ushimado-cho, Setouchi-shi, Okayama		86.6 ± 2.6	
YG-09	granitoid		Oka, Ushimado-cho, Setouchi-shi, Okayama		88.7 ± 1.8	
YG10-1	granitoid		Kashino, Ushimado-cho, Setouchi-shi, Okayama		85.8 ± 1.2	
YG-12	granitoid		Tamahara, Tamano-shi, Okayama	87.5 ± 1.1	85.1 ± 2.1	
YG-17	granitoid		Miyaura, Minami-ku, Okayama-shi, Okayama	87.2 ± 1.6	87.8 ± 2.4	
YG-18	granitoid		Mt.Hachijyoiwa, Minami-ku, Okayama-shi, Okayama	84.8 ± 0.9		
YG-19	granitoid		Hase lake, Kamiyamasaka, Tamano-shi, Okayama		87.0 ± 1.7	
YG-20	granitoid		Kamo-cho, Tsuyama-shi, Okayama	73.4 ± 1.1		
YG-105	granite		Kamisaibara, Kagami-cho, Tomata-gun, Okayama	63.8 ± 1.5		
YG-106	granite		Kamisaibara, Kagami-cho, Tomata-gun, Okayama	64.5 ± 1.5		
YG-130	granitoid		Okutsu, Kagamino-cho, Tomata-gun, Okayama	71.6 ± 0.9	71.6 ± 0.8	
YG-132	granitoid		Okutsu, Kagamino-cho, Tomata-gun, Okayama	72.4 ± 1.0	71.9 ± 2.1	
YG-135	granitoid		Okutsu, Kagamino-cho, Tomata-gun, Okayama	72.2 ± 1.2	72.4 ± 2.1	
YG-137	granitoid		Okutsu, Kagamino-cho, Tomata-gun, Okayama		72.7 ± 2.0	
YG-138	granitoid		Okutsu, Kagamino-cho, Tomata-gun, Okayama		75.3 ± 3.7	
YG-139	granitoid		Kamisaibara, Kagami-cho, Tomata-gun, Okayama	72.5 ± 1.0		
84101601	granitoid		Kaita-cho, Aki-gun, Hiroshima		89.5 ± 1.9	
84101804	granitoid		Jhoge-cho, Fuchu-shi, Hiroshima		94.7 ± 2.3	
84102702	granitoid		Fukutomi-cho, Higashihiroshima-shi, Hiroshima		94.8 ± 1.8	
84102901	granitoid		Higashihiroshima-shi, Hiroshima	92.9 ± 1.1		
GY-21-3	granite		Iwamoto, Iwami-cho, Iwami-gun, Tottori	32.4 ± 0.8		
GY-53	granitoid		Yamaguchi, Mochigase-cho, Toori-shi, Tottori	86.3 ± 2.3		
GY-56-1	granite		Tanigawa, Hoki-cho, Saihaku-gun, Tottori	89.9 ± 2.8	88.0 ± 2.0	
GY-58	granite		Asakane, Aimi-cho, Saihaku-gun, Tottori	65.4 ± 1.1		
GY-59	granite		Ikeno, Aimi-cho, Saihaku-gun, Tottori	65.0 ± 1.0		
GY-61	granite		Neubara, Hoki-cho, Saihaku-gun, Tottori	66.1 ± 0.7		
GY-62	granite		Kakibara, Kofu-cho, Hino-gun, Tottori	68.2 ± 0.8	71.2 ± 2.0	
GY-63	granite		Furuyashiki, Kofu-cho, Hino-gun, Tottori		65.0 ± 1.8	

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
GY-64	granite		Sukesawa, Kofu-cho, Hino-gun, Tottori		66.6 ± 3.2	
GY-85	granite		Yamaguchi, Sekikane-cho, Kurayoshi-shi, Tottori	64.1 ± 1.3		
YG93-1	granite		Kuro pass, Okumoto, Chizu-cho, Yazu-gun, Tottori		90.2 ± 1.4	
YG93-2	granite		Kuro pass, Okumoto, Chizu-cho, Yazu-gun, Tottori		87.7 ± 2.6	
YG-95	granite		Hazi, Chizu-cho, Yazu-gun, Tottori	83.3 ± 1.3		
YG-96	granite		Kuchiunami, Chizu-cho, Yazu-gun, Tottori	83.0 ± 1.3		
YG-98	granite		Kuchiunami, Chizu-cho, Yazu-gun, Tottori	83.0 ± 1.5		
YG-104	granite		Oshikakei, Misasa-cho, Tohaku-gun, Tottori	64.6 ± 0.9		
YG-141	granite		Kijiyama, Misasa-cho, Tohaku-gun, Tottori		42.1 ± 2.3	
YG-142	granite		Kijiyama, Misasa-cho, Tohaku-gun, Tottori		43.7 ± 2.0	
YG-143	granite		Misasa-cho, Tohaku-gun, Tottori	65,6 ± 0.8		
YG-144	granite		Simonishidani, Misasa-cho, Tohaku-gun, Tottori	66.5 ± 1.0		
YG-145	granite		Shimohata, Misasa-cho, Tohaku-gun, Tottori	70.2 ± 0.7		
YG-146	granite		Fukumoto, Misasa-cho, Tohaku-gun, Tottori	66.9 ± 1.1		
92072301	granite		Hirao-cho, Kumage-gun, Yamaguchi	94.2 ± 1.1		
92072403	granite		Totu, Iwakuni-shi, Yamaguchi	92.9 ± 1.1		
95101802	granite		Suoshima-cho, Ooshima-gun, Yamaguchi	94.5 ± 1.8		
Do-2	granite	130691	Fuse, Okinoshima-cho, Oki-gun, Shimane	18.7 ± 2.0		
YG-21	granitoid		Kinosho, Shodoshima-cho, Shozu-gun, Kagawa	86.5 ± 1.2	85.6 ± 2.4	
YG-22-1	granitoid		Yoshino, Shodoshima-cho, Shozu-gun, Kagawa	84.9 ± 2.9		
YG-22-2	granitoid		Yoshino, Shodoshima-cho, Shozu-gun, Kagawa	87.7 ± 1.3		
YG-23	granitoid		Kamano, Shodoshima-cho, Shozu-gun, Kagawa	93.0 ± 1.6, 88.6 ± 1.6		
YG-24	granitoid		Futaomote, Shodoshima-cho, Shozu-gun, Kagawa	92.0 ± 1.7		
YG-26-2	granitoid		Un-misaki, Furuo, Shodoshima-cho, Shozu-gun, Kagawa	90.1 ± 2.1	92.2 ± 1.8	
YG-27	granitoid		Sakate, Shodoshima-cho, Shozu-gun, Kagawa	92.2 ± 2.4		
YG-28	granitoid		Tachibana, Shodoshima-cho, Shozu-gun, Kagawa	94.2 ± 1.1		
YG-29	granitoid		Tachibana, Shodoshima-cho, Shozu-gun, Kagawa	104.4 ± 2.2		
YG-30	granitoid		Tachibana, Shodoshima-cho, Shozu-gun, Kagawa	105.6 ± 1.7		
YG-31	granitoid		Tachibana, Shodoshima-cho, Shozu-gun, Kagawa		92.5 ± 2.5	
YG-33-2	granitoid		Fukuda, Shodoshima-cho, Shozu-gun, Kagawa		84.3 ± 1.6	
YG-53	granitoid		Sue, Sanuki-shi, Kagawa	92.4 ± 1.5		
YG-54	granitoid		Shido, Sanuki-shi, Kagawa	90.8 ± 1.2	90.2 ± 1.5	
YG-55	granitoid		Shirotori, Higashikagawa-shi, Kagawa	90.1 ± 1.0		
YG-56	granitoid		Nyunoyama, Higashikagawa-shi, Kagawa	89.1 ± 0.9		
87S34B	granitoid		Matsuyama-shi, Ehime	100.5 ± 2.4		
87S36A	granitoid		Matsuyama-shi, Ehime	99.0 ± 2.0		
87S36B	granitoid		Matsuyama-shi, Ehime	96.8 ± 2.0		
YG-61	granitoid		Takabe, Imabari-shi, Ehime	95.6 ± 2.4		
YG62-1	granitoid		Namikata, Namikata-cho, Imabari-shi, Ehime	92.9 ± 1.9	91.1 ± 2.2	
YG-65	granitoid		Moriue, Namikata-cho, Imabari, Ehime	95.3 ± 1.0		
YG-68	granitoid		Kugawa, Matsuyama-shi, Ehime	97.0 ± 1.3	96.2 ± 4.4	
6415	aplite	6415	Ashizurimisaki, Tosashimizu-shi, Kochi		13.7 ± 1.9	
KK-11	sheard granite	130794	Heimiyaganaro, Niyodogawa-cho, Agawa-gun, Kochi			465.8 ± 15.8
Ko-16	gneiss	130709	Umanohara, Sagawa-cho, Takaoka-gun, Kochi			456.5 ± 17.1
Age data in Figs. 13 and 14						
YG-04	granite	135813	Onihara, Hekishimo, Nagata-shi, Yamaguchi		87.3 ± 4.6	
Kyu-1	granitoid	133730	Isozaki, Nijofukui, Itoshima-shi, Fukuoka		101.5 ± 3.0	99.4 ± 6.8
Kyu-5	granitoid	133734	Mikasa, Dazaifu-shi, Fukuoka			87.8 ± 4.4
Kyu-7	granitoid	133736	Kakishita, Kawara-machi, Tagawa-gun, Fukuoka	103.0 ± 1.8		
09-3-01	pegmatite	134200	Imajuku-Nagataru, Nishi-ku, Fukuoka-shi, Fukuoka	93.9 ± 1.1		105.8 ± 5.3
09-3-02	pegmatite	134201	Hakoshima, Nijohamakubo, Itoshima-shi, Fukuoka	105.5 ± 1.2		
09-3-03	granite	134202	Nijomatusue, Itoshima-shi, Fukuoka		95.2 ± 1.2	100.5 ± 7.6
09-3-04	aplite	134204	Nijyoufukui, Itoshima-shi, Fukuoka	98.5 ± 1.0	105.5 ± 1.8	
09-3-06	granite	134205	Haisaki, Nijofukui, Itoshima-shi, Fukuoka	107.2 ± 1.1	106.0 ± 2.7	
09-3-07	pegmatite	134206	Haisaki, Nijofukui, Itoshima-shi, Fukuoka	107.7 ± 2.8		
09-3-08	granite	134207	Kushisaki, Nijoshikaka, Itoshima-shi, Fukuoka			98.0 ± 6.7
09-3-09	pegmatite	134208	Kushisaki, Nijoshikaka, Itoshima-shi, Fukuoka			106.8 ± 8.9
09-3-16	granite	134215	Kankake pass, Tanushimaru-machi, Kurume-shi, Fukuoka			87.2 ± 15.0
09-8-01	granite	134217	Tsufune, Itoshima, Nishi-ku, Fukuoka-shi, Fukuoka	95.0 ± 1.4		
09-8-02	granite	134218	Tsugami, Itoshima, Nishi-ku, Fukuoka-shi, Fukuoka		106.3 ± 2.4	
09-8-05	qz diorite	134221	Masaki, Kawasaki-machi, Tagawa-gun, Fukuoka	97.9 ± 1.4	97.6 ± 2.4	

Table 1. (continued)

sample No	rock	reg. No	locality	Uraninite	Thorite	Monazite
09-8-06	qz diorite	134222	Naiju-kyo, Naiju, Iisuka-shi, Fukuoka	94.9 ± 1.2		97.2 ± 5.6
09-8-07	granite	134223	Mt. Sangun, Yusubaru, Chikushino-shi, Fukuoka			94.0 ± 4.8
09-10-04	granite	134227	Kitashima, Itoshima, Nishi-ku, Fukuoka-shi, Fukuoka		111.9 ± 1.7	
09-10-05	granite	134228	Tsugami, Itoshima, Nishi-ku, Fukuoka-shi, Fukuoka	112.9 ± 1.9	107.9 ± 3.0	
09-10-07	granite	134230	Karadomari, Itoshima, Nishi-ku, Fukuoka-shi, Fukuoka	112.6 ± 0.9		
09-10-08	aplite	134231	Kafuri, Itoshiro-shi, Fukuoka	107.5 ± 1.6		110.7 ± 6.3
09-10-09	granodiorite	134232	Kafuri, Itoshiro-shi, Fukuoka		105.86 ± 1.5	
09-10-10	aplite	134233	Nijohamakubo, Itoshima-shi, Fukuoka			111.6 ± 9.7
09-10-11	granite	134234	Nijohamakubo, Itoshima-shi, Fukuoka	106.9 ± 1.4	105.6 ± 2.8	
09-10-12	granite	134235	Nijomatusue, Itoshio-shi, Fukuoka			107.0 ± 6.0
09-10-13	aplite	134236	Nijofukui, Itoshiro-shi, Fukuoka			108.2 ± 7.9
09-10-14	granodiorite	134237	Nijyoufukui, Itoshima-shi, Fukuoka		104.4 ± 2.9	
09-10-16	aplite	134238	Maeda, Nijofukui, Itoshima-shi, Fukuoka	103.5 ± 1.0	104.6 ± 5.2	
09-10-17	pegmatite	134241	Haisaki, Nijofukui, Itoshima-shi, Fukuoka			100.1 ± 4.7
09-10-19	granite	134242	Ishikama, Sagara-ku, Fukuoka-shi, Fukuoka			95.7 ± 13.3
09-10-26	granite	134249	Kamihoman, Hondoji, Chikushio-shi, Fukuoka			98.2 ± 9.7
09-10-27	granite	134250	Hondoji, Chikushio-shi, Fukuoka			92.7 ± 6.5
09-10-28	granite	134251	Anraku temple, Hondoji, Chikushio-shi, Fukuoka			103.2 ± 10.1
09-10-29	granite	134252	Kitaya dam, Kitaya, Dazaifu-shi, Fukuoka			92.3 ± 10.3
09-10-30	granite	134253	Byobu, Shioji, Usami-machi, Kasuya-gun, Fukuoka	95.1 ± 2.8		90.8 ± 0.11.7
09-11-01	granite	134254	Mt. Ganjaku, Soeda-machi, Tagawa-gun, Fukuoka	100.5 ± 1.7		
09-11-02	pegmatite	134255	Aburagi dam, Soeda-machi, Tagawa-gun, Fukuoka			102.2 ± 7.6
09-11-03	granite	134256	Tsuno, Soeda-machi, Tagawa-gun, Fukuoka	102.1 ± 0.7		
09-11-04	granite	134257	Jinya dam, Soeda-machi, Tagawa-gun, Fukuoka			10.16 ± 12.0
09-11-05	granite	134258	Jinya dam, Soeda-machi, Tagawa-gun, Fukuoka	99.6 ± 0.8		
09-11-06	granite	134259	Jinya dam, Soeda-machi, Tagawa-gun, Fukuoka	102.1 ± 1.8		97.6 ± 6.0
09-11-07	granite	134260	Chugenji, Soeda-machi, Tagawa-gun, Fukuoka	98.1 ± 1.3	98.8 ± 1.2	
09-11-08	granodiorite	134261	Toya-natural park, Kawsaki-machi, Tagawa-gun, Fukuoka	99.4 ± 2.2		
09-11-09	granodiorite	134262	Amagi, Kawasaki-machi, Tagawa-gun, Fukuoka		99.2 ± 1.7	
09-11-10	granite	134263	Amagi, Kawasaki-machi, Tagawa-gun, Fukuoka	99.0 ± 1.2		
09-11-11	granite	134264	Amagi, Kawasaki-machi, Tagawa-gun, Fukuoka	98.5 ± 1.2		
09-11-12	granite	134265	Tateishi-toge, Aka-mura, Tagawa-gun, Fukuoka	99.8 ± 1.3		101.1 ± 9.0
09-11-13	granite	134266	Yusubaru station, Aka-mura, Tagawa-gun, Fukuoka		99.1 ± .2.0	100.2 ± 7.8
09-11-15	granite	134268	Mt. Toshiro, Aka-mura, Tagaw-gun, Fukuoka	100.3 ± 0.9	97.1 ± 0.6	
09-11-16	granodiorite	134269	Uchida, Aka-mura, Tagawa-gun, Fukuoka		99.2 ± 2.8	
09-11-17	granite	134270	Uchida, Aka-mura, Tagawa-gun, Fukuoka	100.3 ± 1.3		
09-12-01	granite	134271	Inokuni, Kawsaki-machi, Tagawa-gun, Fukuoka	102.1 ± 1.3		95.4 ± 6.8
09-12-02	granite	134272	Amagi, Kawasaki-machi, Tagawa-gun, Fukuoka			93.4 ± 6.3
Kyu-3	granitoid	133732	Mitsuse, Mitsuse-mura, Saga-shi, Saga			98.3 ± 7.7
09-3–11	granite	134210	Mt. Kurosaki, Ura, Karatsu-shi, Saga			86 ± 17
09-10-21	granite	134244	Mitsuse, Mitsuse-mura, Saga-shi, Saga			109.7 ± 7.2
09-10-22	pegmatite	134245	Mitsuse, Mitsuse-mura, Saga-shi, Saga			94.4 ± 8.9
QK-1	granitoid		Hinokage-cho, Nishiusuki-gun, Miyazaki	14.7 ± 0.6		
QK-5	granitoid		Kitakata-cho, Nishiusuki-gun, Miyazaki		15.6 ± 1.7	
QK-6	granitoid		Kitakata-cho, Nishiusuki-gun, Miyazaki		15.6 ± 1.5	
QK-7	granitoid		Kitakata-cho, Nishiusuki-gun, Miyazaki		15.5 ± 1.9	
QK-8	granitoid		Hinokage-cho, Nishiusuki-gun, Miyazaki		15.7 ± 1.6	
QK-9	granitoid		Hinokage-cho, Nishiusuki-gun, Miyazaki		15.0 ± 1.6	
1574	granitoid	1574	Kiurakozan, Ume, Saiki-shi, Oita		14.4 ± 3.0	
6396	granite	6396	Kitamura, Yamagashi-shi, Kumamoto	113.4 ± 1.2		116 ± 6
TSM-17	granite	135872	Uchiyama, Izuhara-machi, Tsushima-shi, Nagasaki	15.5 ± 0.5	15.5 ± 1.4	
Age data out of the figures						
6644	granite	6644	Kosugidani, Yakushima-cho, Kumage-gun, Kagoshima	14.9 ± 0.3		
3624	granite	3624	Kinko-cho, Kimotsuki-gun, Kagoshima		16.3 ± 1.5	
H-7	granite	128038	Idenohana, Ashikita-machi, Ashikita-gun, Kumamoto			426.3 ± 14.8

data in the granitoids were summarized as an average and standard deviation. The standard deviation is usually 1 sigma calculated from a Gaussian distribution in probability theory. The age data and localities of about 400 granitoids are summarized in Table 1. Age data and their histograms in each province are plotted in Figs. 2 to 16.

Uraninite and thorite ages obtained from the Japanese Islands range from ca. 5 to 300 Ma. In some granitoids, monazite age determined by EPMA analyses and zircon age determined by LA-ICP-MS are used. Their analytical methods were presented by Santosh *et al*. (2006) and Tsutsumi *et al.* (2010), respectively. In the present study, the standard deviations of uraninites are found to be around 4 Ma at around 200 Ma, 1 Ma at around 70 Ma, and less than 1 Ma at around 5 Ma, which is comparable to those obtained by isotopic methods. The standard deviation for thorite is roughly double that for uraninite. In some samples, bimodal age distributions were obtained due to a later stage thermal event as found by Yokoyama *et al*. (2010).

Southern Hokkaido and Tohoku Province: Granitoids in Southern Hokkaido and Tohoku Province are mostly Lower Cretaceous in age (Figs. 2 & 3). Neogene granitoids and Ordovician granitoids rarely occur. The Cretaceous and Neogene ages were obtained using uraninite and thorite whereas ages of the Ordovician granitoids in the Hikami Area (Fig. 4) were obtained by monazite analyses. The age of one diorite dyke rock at the Shimokita Peninsula, Aomori prefecture, was obtained by LA-ICP-MS because of the absence of both uraninite and anhydrous thorite. Except for Neogene and Ordovician granitoids, the Lower Cretaceous granitoids are divided into two terranes based on age: the Kitakami Mountains area and the western Tohoku area. The former granitoids exceed 110 Ma and the latter is less than 110 Ma. The boundary between them extends in a N–S direction along the middle of the Ou Mountains. The age range of the western part of Tohoku is from 101 Ma to 109 Ma. Cretaceous granitoids younger than 101 Ma were not found in the area. As far as age is concerned, granitoids with ages > 110 Ma extend to southern Hokkaido except for Okushiri Island. In southern Hokkaido, the boundary between the two types is present between Esashi and the Okushiri Island. The oldest Cretaceous granitoid was found in the Himegami body in the Kitakami Mountains and is 126 Ma. The age histogram by uraninite is different from that by thorite as shown in Fig. 3. This is due to the strong alteration of thorite in the granitoids from the western part of Tohoku.

Many K–Ar ages were obtained from Southern Hokkaido and from Tohoku Province. In the Kitakami Mountains, K–Ar ages of granitoids range from 89 to 128 Ma (Kawano & Ueda, 1965a). Although their oldest age is similar to present results, about 30% of the ages are less than 110 Ma, which corresponds to the western part of the Tohoku group of granitoids. K–Ar ages in the western part of Tohoku are also variable ranging from ca. 80 Ma to 110 Ma, which is different from present results that are concentrated well in a narrow range: 101 Ma to 109 Ma. The variable range is because the Cretaceous granitoids suffered from a late stage thermal event or alteration that caused younger results due to Ar loss. The division of the area by uraninite and thorite ages will be important when we discuss the extension of the terrane or comparison of the granitoids in Primorye, Far East Russia, because the Japanese Islands were a part of the Eurasia continent and were in contact with Primorye before the opening of the Sea of Japan during the early Neogene.

Granitoid ages at Hikami Mountain were obtained only by studying the monazite (Fig. 4), even though thorite was commonly present. The thorite was completely altered into a hydrous state making it unsuitable for age dating. The monazite age is 451 ± 4 Ma, which is almost consistent with the SHRIMP age of 442.5 ± 3.5 Ma determined by Watanabe *et al*. (1995). Cambrian granitoids were found as a small block from the Isawa and Nagasaka areas, Iwate Prefecture (Isozaki *et al*., 2015), in the terrane with an age

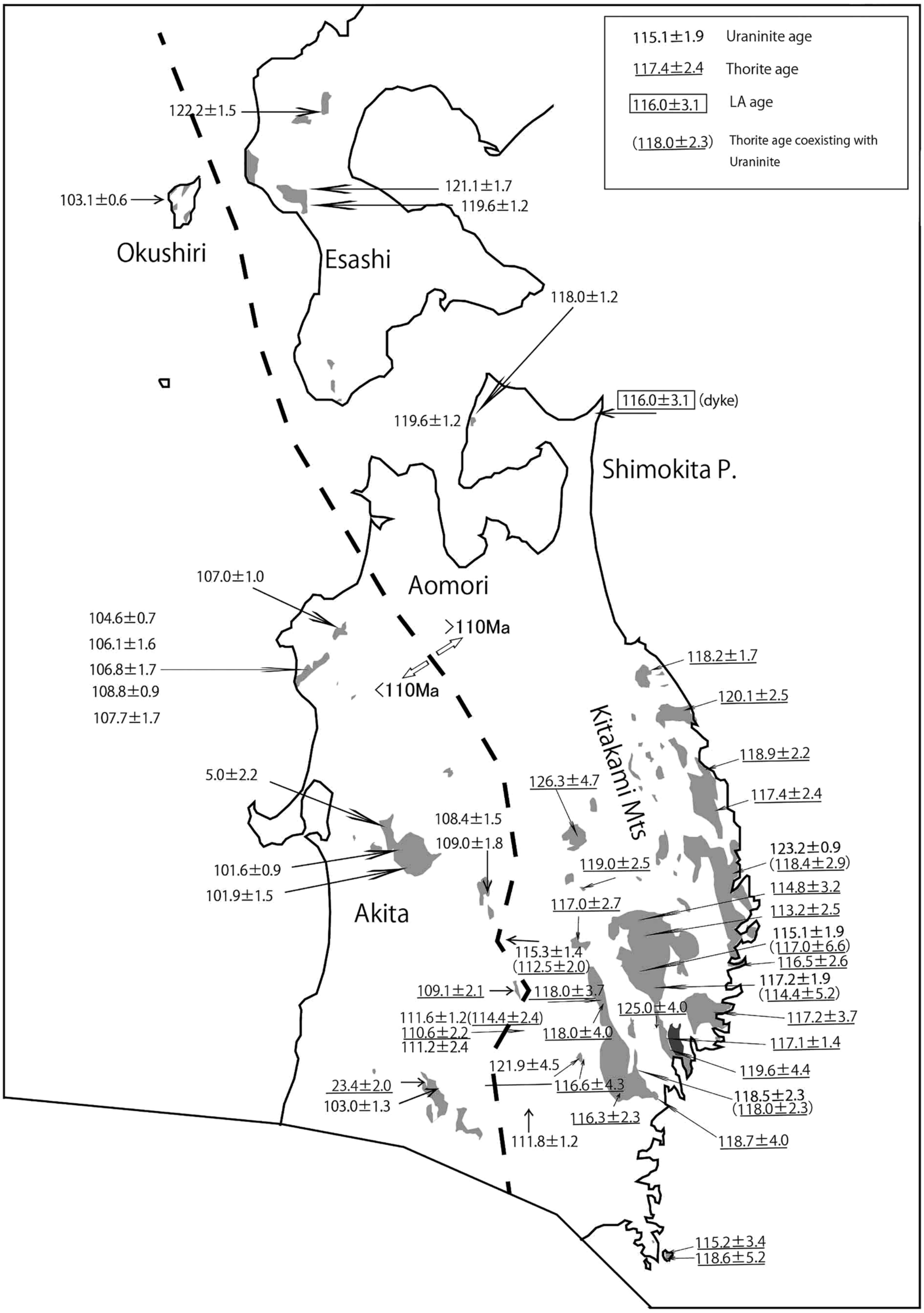

Fig. 2. Sample localities of the studied granitoids in the southern Hokkaido and Tohoku Province. Numbers are age data of granitoids. Most of the ages are obtained by EPMA analyses of uraninite and thorite. Zircon age in one sample is obtained by LA-ICP-MS method.

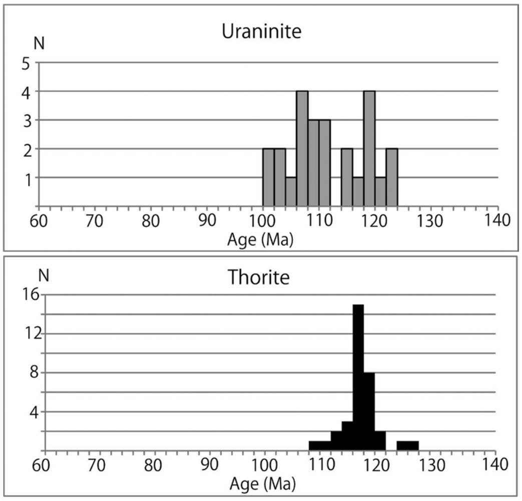

Fig. 3. Histograms of the uraninite and thorite ages from the granitoids in southern Hokkaido and Tohoku Province.

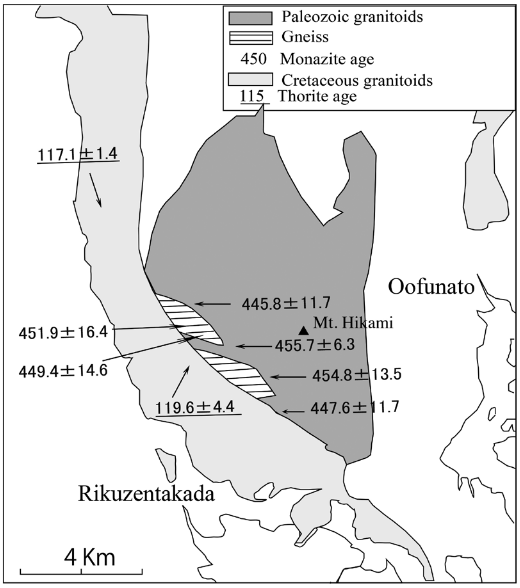

Fig. 4. Monazite ages of the Hikami granitoids and associated metamorphic rocks. Average age of the rocks are 451 Ma with a standard deviation of 4 Ma as one sigma.

>110 Ma as well as the Hikami Granitoids. Although the geological relations of the old granitoids are unknown, such old granitoids occur sporadically in the Japanese Islands such as in the Maizuru, Hitachi areas and Kurosegawa Belt (e.g. Tsutsumi *et al*., 2012; Tagiri *et al*., 2010; Isozaki *et al*., 2015). Isozaki *et al.* (2015) discussed such Early Paleozoic granitoids as remnants of the arc plutonic belt from the Early Paleozoic Japan that developed near the continental margin.

Neogene granitoid occurs sporadically in Hokkaido and in Tohoku Province. Only two Neogene granitoids were analyzed. Their uraninite ages are 23 and 5 Ma. They are probably related with the opening of the Sea of Japan and later stage igneous events, respectively, but regional study is necessary to discuss their origin.

Asahi Mountains, Abukuma Mountains and Tsukuba–Nikko area: Fig. 5 shows the ages of granitoids in the Asahi Mountains, the Abukuma Mountains and the Tsukuba–Nikko area. A histogram of the Cretaceous age is shown in Fig. 6. In this area, the Tanakura Tectonic Line (Fig. 1) runs along the western margin of the Abukuma Mountains. The tectonic line divides the Japanese Islands into two blocks. It was confirmed that the two blocks moved in different ways at the time of the opening of the Japan Sea (e.g. Otofuji & Matsuda, 1983 & 1984). Even though the line is important, its northern extension has not been clarified. In this area, we can divide the area into several terranes based on uraninite and thorite age. In the Asahi Mountains, the western part is composed of granitoids younger than 70 Ma, between 65 and 68 Ma, whereas granitoids in the eastern part are between 90 Ma and 98 Ma with one exception at 103 Ma. Two granitoids with an age around 80 Ma occur near the younger granitoid terrane mentioned above.

Granitoids in the Abukuma Mountains are roughly classified into two groups based only on the uraninite and thorite ages: 100–107 Ma and 110–124 Ma, with one exception at 301 Ma from the Soma area (Tsutsumi *et al*., 2012). The latter older granitoid was further analysed and the age was confirmed by the LA-ICM-MA method (Tsutsumi *et al*., 2012). If this division is available, the western part of the Abukuma Mountains is consistent with those from the western part of

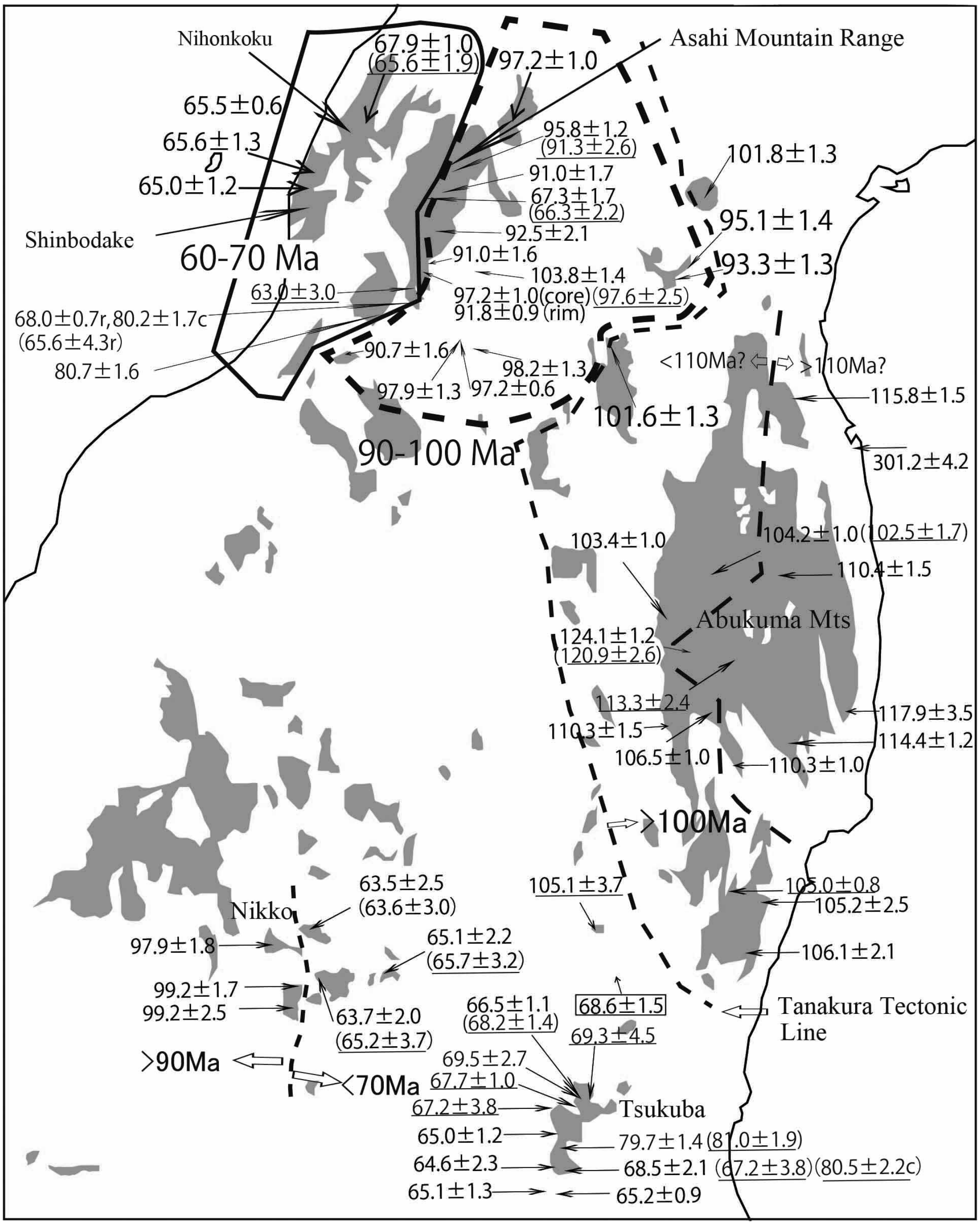

Fig. 5. Age data of granitoids in the Asahi Mountains, Abukuma Mountains and Nikko–Tsukuba area. Explanation of the age data is shown in Fig. 2.

Tohoku in Fig. 2, whereas the eastern part of the Abukuma Mountains corresponds to the Kitakami Mountains and its northern extension.

In addition to the K–Ar ages for the granitoids determined by Kawano & Ueda (1965b), there are many studies about the granitoid ages in the

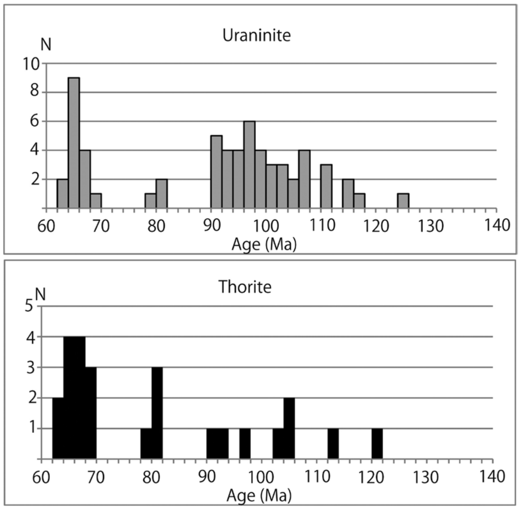

Fig. 6. Histograms of the uraninite and thorite ages from the granitoids in the Asahi Mountains, Abukuma Mountains, and Nikko–Tsukuba area.

Abukuma Mountains determined via zircon analyses by recent LA-ICM-MA and SHRIMP methods (Tagiri *et al*., 2010; Kon & Tagiri, 2012; Kon *et al*., 2015; Ishihara & Orihashi, 2015). Tagiri *et al*. (2010) reported a Cambrian metagranitoid from the Hitachi metamorphic terrane at the southern end of the Abukuma Mountains with an age of around 500 Ma. Many other papers presented Cretaceous granitoid ages from the central part of the Abukuma Mountains (Kon & Tagiri, 2012; Kon *et al*., 2015; Ishihara & Orihashi, 2015). The Cretaceous age ranges from 97 Ma to 121 Ma similar to our results of 100–124 Ma. However, they reported a younger age from the eastern part of the mountains where the uraninite and thorite ages are 110–124 Ma. Kon *et al*. (2015) concluded that the spatial distribution of hornblende-biotite granitoids had no correlation with their intrusive ages. In contrast, the leucocratic granitoids with an age of around 110 Ma were located at the eastern part of the Abukuma Mountains, whereas those with an age around 100 Ma were at the western part. Our results may be comparable with the leucocratic granitoids.

In the Tsukuba area (Fig. 5), at the southern end of the Yamizo Mountains, granitoids have ages ranging from 65 Ma to 70 Ma with the exception of two samples that had ages of 80 Ma. Granitoids in the Yamizo Mountains were studied using the K–Ar method by Shibata *et al*. (1973). The K–Ar ages are similar to uraninite and thorite ages, i.e. mostly less than 70 Ma. Two samples in this study were found to have an age of 80 Ma, which was found to be a relict age. The combination with 65–70 Ma and 80 Ma may be correlated with granitoids from the western part of the Asahi Mountains. One granitoid that had an age of 105 Ma occurs at the eastern part of the Yamizo Mountains, close to the Tanakura Tectonic Line. Although the age shows correlation with those in the Abukuma Mountains, it is clearly different because the Yamizo Mountains belonged to western Japan at the time of the opening of the Sea of Japan, whereas the Abukuma Mountains were in eastern Japan.

In the western part of the Nikko area, granitoids have an age of 99 Ma, whereas in the eastern part the ages are around 64 Ma. These age data show that the western part of the Nikko corresponds to the Asahi Mountain, whereas eastern Nikko, including the Tsukuba area, corresponds to the western part of the Asahi Mountains. It is well accepted that metamorphic rocks in the Tsukuba area belong to the Ryoke belt and its extension is the Nihonkoku area of northern Niigata Prefecture; western part of the Asahi Mountains (Fig. 5). Hence, it will be reasonable to conclude that the Tsukuba and Nihonkoku will be formed as the same igneous province. Granitoids that are 80 Ma in both areas will be treated same.

Many granitoids in this area have not been analyzed yet, especially in the region between Nikko and the Asahi Mountains (Fig. 5). Analyses of such granitoids will be important to study the spatial distribution between the Nikko and Asahi Mountains granitoids.

Chubu and Kansai provinces: Fig. 7 shows the ages of granitoids in the Chubu and Kansai provinces. Histogram of the Cretaceous age is shown in Fig. 8. In this area, the granitoid age ranges from 4 Ma to 106 Ma. The youngest granitoids occur along the Fossa Magna region, Yamanashi

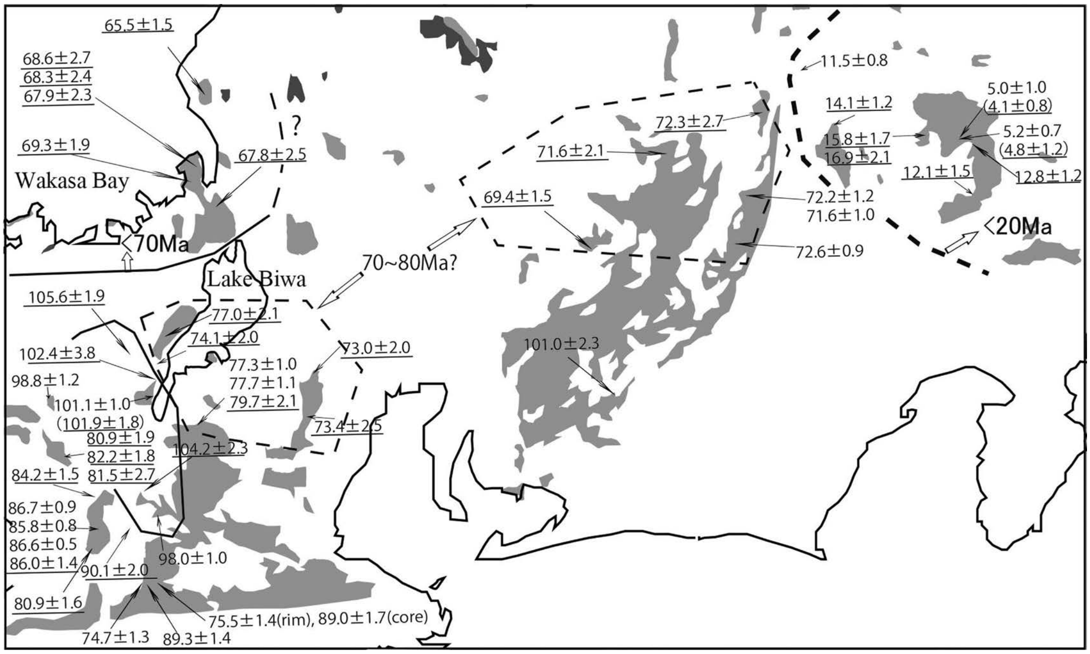

Fig. 7. Age data of granitoids in Chubu and Kansai provinces. Explanation of the age data is shown in Fig. 2.

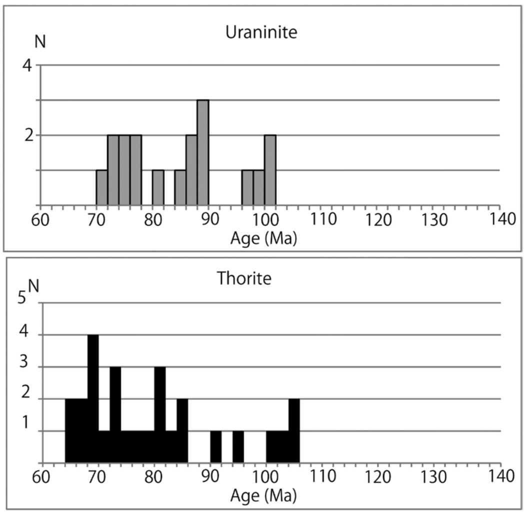

Fig. 8. Histograms of the uraninite and thorite ages from the granitoids in the Chubu and Kansai provinces.

Prefecture. Their ages range from 4.1 Ma to 16.9 Ma, which is comparable to the K–Ar data of 4.5–13.0 Ma by Shibata *et al*. (1984) and Uchiumi *et al*. (1990). Cretaceous granitoids are variable in age, but they are divided roughly into four groups: >70 Ma, 70–80 Ma, 80–90 Ma and 98–106 Ma. The granitoids with ages younger than 70 Ma occur around the Wakasa Bay. Granitoids that are 70–80 Ma occur at the Ina district, around Lake Biwa and at the Suzuka Mountains. Granitoids that are 80–90 Ma are found around the Ikoma Mountains where SHRIMP analyses by Watanabe *et al*. (2000) presented similar ages. Granitoids with ages of 98–106 Ma occur southeast of Lake Biwa. Suzuki & Adachi (1998) obtained granitoid ages in the Ryoke metamorphic belt analyzing monazite by EPMA. Their ages range from 67 Ma to 95 Ma, which is mostly much older than the K–Ar age. They thought that the difference was due to the cooling rate due to the difference of closure temperature of monazite and mica. As presented by Suzuki and Adachi, there is younger granitoid terrane in the Ryoke belt than in the present data. Although more age data were necessary in the other areas to confirm the regional differences, we tentatively divide the granitoids only by means of the present age data.

In the western part of the Chubu and Kansai areas shown in Fig. 7, it is expected that the granitoid age will be getting younger northwards. In the inner zone of southwest Japan, granitoids are generally divided into three zones: the Ryoke belt, the Sanyo belt and the Sanin belt from south to north as discussed later. Generally speaking, age of granitoids becomes younger from south to north. However, granitoids with ages over 98 Ma occur surrounded by young granitoid regions such as 73 Ma to 80 Ma and 80–87 Ma. Such relatively old granitoids, 102–107 Ma, were reported from the same area by Imaoka *et al.* (2014). The complex spatial distribution of the granitoids shows that igneous activity is not consistent with the geological belts such as the Ryoke metamorphic belt and Mino Jurassic Belt. Apparently the older granitoids, 98–106 Ma, occur locally and were surrounded by younger granitoids that are 70–80 Ma and 80–90 Ma.

Hida terrane: There were many studies about the age of granitoids in the Hida terrane. Ota & Itaya (1989) summarized age data of K–Ar, Rb–Sr, U–Pb and other methods in the terrane. Fig. 9 shows uraninite, thorite and monazite ages of granitoids in the Hida terane. The histogram of the age data is shown in Fig. 10. In this analysis, we found that the granitoids are older than 180 Ma except for a local intrusion of Cretaceous granitoids with an age of around 60–70 Ma and 100 Ma. Uraninite and thorite ages in four granitoids from the Hida terrane were reconfirmed by SHRIMP analyses (Yokoyama *et al.*, 2010). In the Hida terrane, two granitoid types were recognized based on the geological relations. They are the Funatsu and Simonomoto types. Ota & Itaya (1989) concluded that Funatsu type is 170–180 Ma in age, whereas the Shimonomoto type is around 190 Ma. Our study could not confirm a granitoid younger than 180 Ma except for a granitoid that is 160 Ma, which is much younger than the other age data. Because the granitoid with a uraninite age of 160 Ma has monazite ages of 215 ± 15 Ma, the uraninite age will be due to resetting by a later stage thermal event different from the main metamorphic or igneous events in the Hida terrane.

Histogram in Fig. 10 shows a roughly bimodal distribution: 180–210 Ma and 230–260 Ma. The

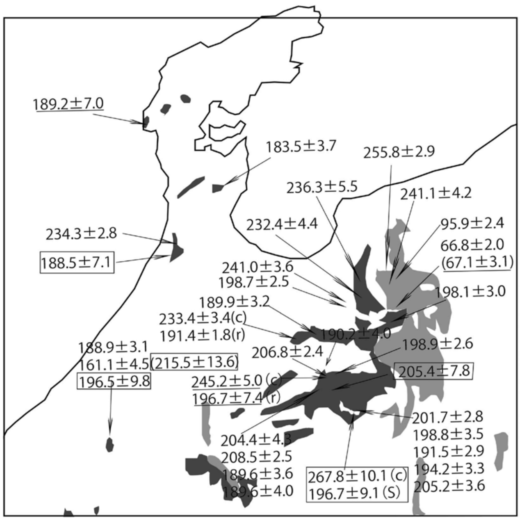

Fig. 9. Age data of granitoids in the Hida area. Explanation of the age data is shown in Fig. 2. The number in the box shows ages obtained from monazite by EPMA analyses.

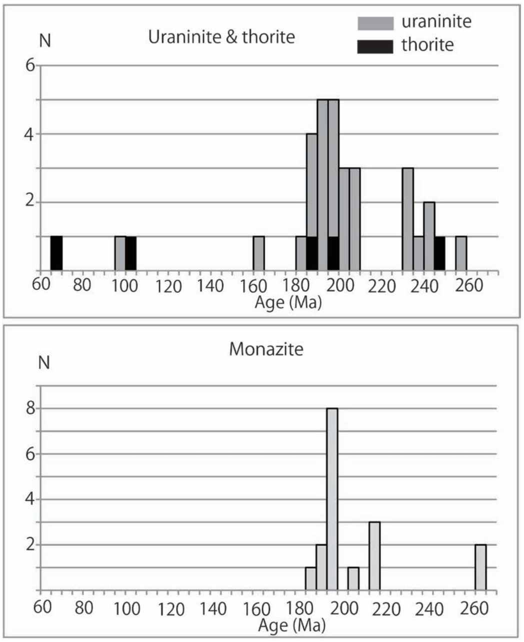

Fig. 10. Histograms of the uraninite, thorite and monazite ages from the granitoids in the Hida area.

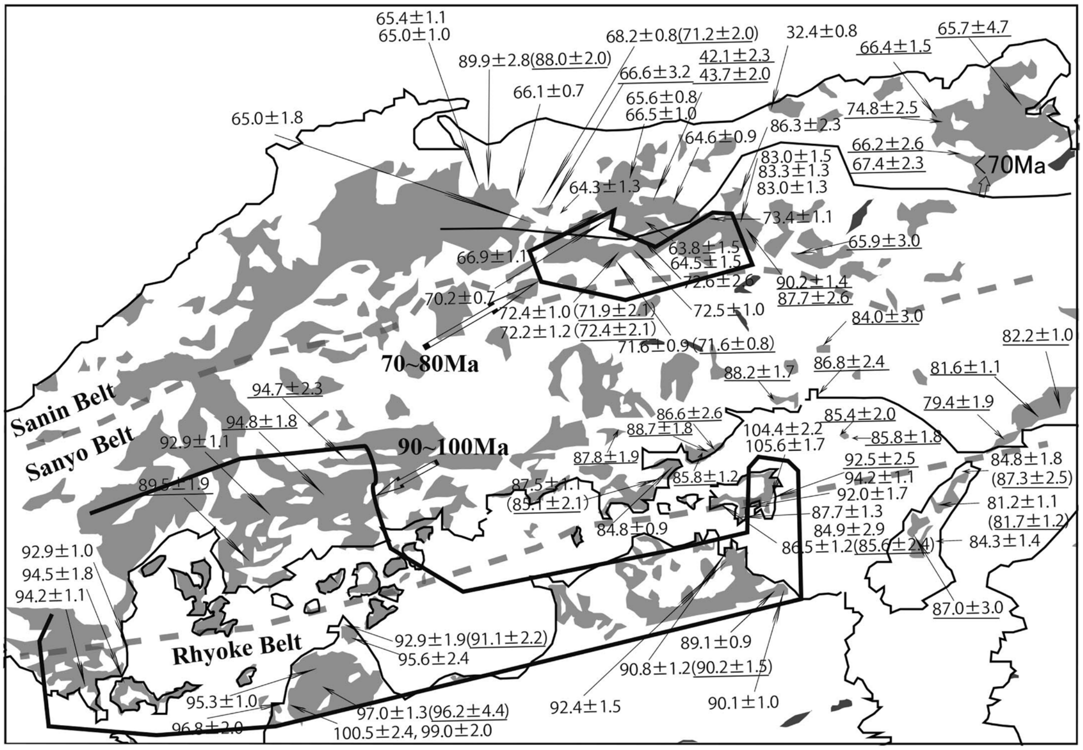

Fig. 11. Age data of granitoids in the Chugoku and northern Shikoku provinces. Explanation of the age data is shown in Fig. 2.

two age groups are confirmed often by the core and rim relationships in the uraninite and thorite grains (Fig. 9 and Yokoyama *et al.*, 2010). There is no areal distinction between the two groups in the map. It is difficult from the uraninite and thorite ages to conclude whether early stage igneous activity occurred in all the areas or only at the local level. These data will be important for future age studies or for determining the tectonic setting of the Hida terrane.

Chugoku and northern Shikoku provinces: Fig. 11 shows the granitoid ages in the Chugoku and northern Shikoku provinces. A histogram of the granitoid ages is shown in Fig. 12. The inner zone of Southwest Japan is geologically divided into three belts: Ryoke, Sanyo and Sanin from the south to north. Even though there are many age data in the Ryoke and Sanyo belts, a reliable correlation with age has not been obtained. On the other hand, in the Sanin belt, Imaoka *et al.*

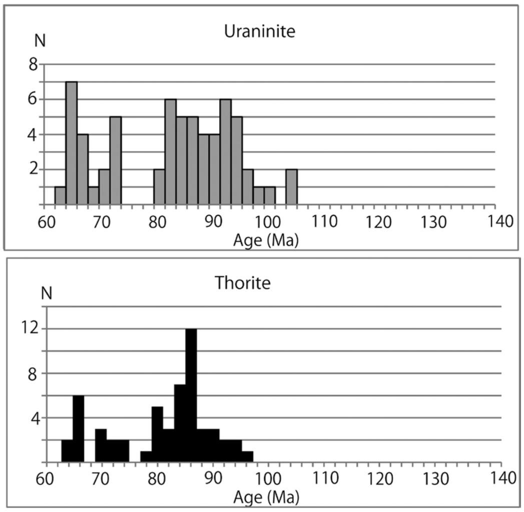

Fig. 12. Histograms of the uraninite and thorite ages from the granitoids in the Chugoku and northern Shikoku provinces.

(2011) obtained detailed ages of the Eocene–Oligocene granitoids by the K–Ar method and roughly found their linear arrangement as well as the granitoids that are 60–70 Ma. In the present analyses, granitoids younger than 70 Ma develop along the coast of the Sea of Japan. Except for a few granitoids that have ages of 30–45 Ma and 73–83 Ma in the Sanin Belt, the area almost overlaps with those of the Eocene–Oligocene granitoids by Imaoka *et al*. (2011). As far as the granitoid that is 60–70 Ma is concerned, the belt will continue to the 60–70 Ma granitoid region around Wakasa Bay in Fig. 7. Imaoka *et al*. (2011) concluded that the lineation of the granitoids that are 30–45 Ma was related to the plate subduction at the time of formation of the Shimanto Belt running parallel to the Pacific Ocean. The granitoids that are 30–45 Ma occur only in the rather restricted area of the Sanin Belt, which is different from the elongation of the Shimanto Belt that continues from Okinawa to the Boso Peninsula, Kanto Province. Distribution of such granitoids is too local to deduce a close correlation with the Shimanto Belt.

In contrast to the Sanin Belt, it is hard to find a linear arrangement on the basis of the granitoid age in the Ryoke and Sanyo belts. Murakami (1987) summarized K–Ar ages of the granitoids in the belts: 75–95 Ma in the Ryoke Belt and 70–115 Ma in the Sanyo Belt. There is no spatial distribution about the age in both the belts as shown in Fig. 11. The Ryoke Belt has uraninite and thorite ages from 90 to 105 Ma except for granitoids from Awaji Island. The oldest age observed is 106 Ma from the northeastern part of Shodo Island. Only granitoids with an age of around 80–85 Ma continue eastwards: Ikoma Mountains in Fig. 9. In the Sanyo Belt, most of the age data are from 70 to 95 Ma and there are three areas that collect together based on granitoid age. The oldest area is at the western part of Hiroshima and most of the granitoids are older than 90 Ma. The youngest are with 70–73 Ma, and they occur in a narrow area of the Sanin Mountain, close to the Sanin Belt. In the other area, granitoid ages are mostly 80–90 Ma, similar to the Awaji Island of the Ryoke Belt. Linear arrangement of the granitoids simply by uraninite and thorite age is not recognized in both the Ryoke and Sanyo belts, but it seems that granitoids with similar ages have concentrated in restricted areas.

Northern Kyushu Province: Fig. 13 shows ages of granitoids in northern Kyushu. A histogram of the granitoids is shown in Fig. 14. Most of Cretaceous granitoids in northern Kyushu have a narrow age range determined by uraninite and thorite from 95 Ma to 108 Ma. A few granitoids have ages around 113 Ma. Karakida (1992) summarized K–Ar ages of granitoids in northern Kyushu. The range of the K–Ar age was from 75 to 115 Ma. As found in the other terranes, the oldest age obtained by the K–Ar age in each terrane is similar to that of the uraninite or thorite age, which is probably because a fresh granitoid gives a reasonable age for K–Ar dating. As far as the age is concerned, this terrane will be one igneous province similar to the western part of the Ryoke belt (Fig. 11) and the Abukuma Mountains. The granitoids younger than 20 Ma concentrate in the Okueyama Mountains. Such young granitoids occur at the Osumi Peninsula and in Yakushima Island (Table 1), Kagoshima Prefecture, as well as granitoids in the Shimanto belt, namely along the Pacific coast. In addition to the young granitoids from the Fossa Magna region (Fig. 7), they were formed after or during the opening of the Sea of Japan.

Other granitoid ages: Most of the age data are plotted in Figs. 2–13. Some granitoids analyzed in this study are not included in the figures. They are younger than 20 Ma and occur at the southern parts of Kyushu, Shikoku and the Kii Peninsula. Furthermore, some old granitoids occurring in the Maizuru and Kurosegawa belts are not presented in the figures. Their ages were obtained by monazite or LA-ICP-MS. The granitoids from the Maizuru belt were reported by Tsutsumi *et al*. (2014). The other age data are shown in Table 1.

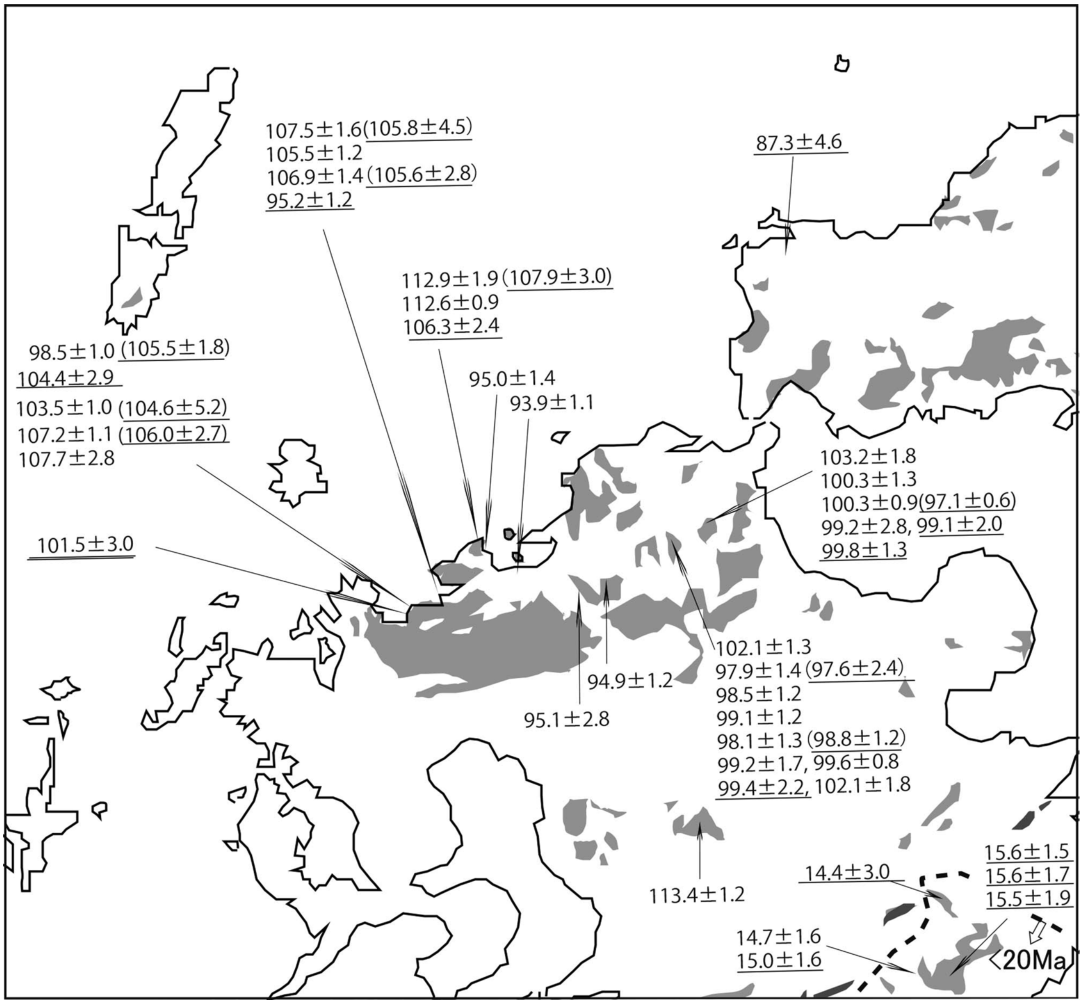

Fig. 13. Age data of granitoids in the northern Kyushu Province. Explanation of the age data is shown in Fig. 2.

Discussions

Ages of about 400 granitoids in the Japanese Islands were obtained through EPMA analyses of uraninite and thorite. Although the age data are not enough to discuss a spatial distribution of granitoids in the islands, the present study is important because the ages of the granitoids are obtained by the same method and machine throughout this study. Age data obtained by LA-ICP-MS or SHRIMP will be available. But so far it is difficult to compare their age data with present data because of differences in method, standard, machine and other experimental differences. In the near future, it will be best to use a common mineral in granitoids such as zircon when we summarize more detailed distributions in the islands by a more reliable method such as LA-ICP-MS or SHRIMP. Among the obtained data, it is concluded that the uraninite and thorite ages are much more concentrated in each province than by ages obtained by the K–Ar method. The K–Ar method involves a few problems. One is the Ar loss during later stage thermal events and alteration. The others are an age difference among minerals used for the age analyses and low closure temperature. Uraninite and thorite ages also have a closure temperature problem as

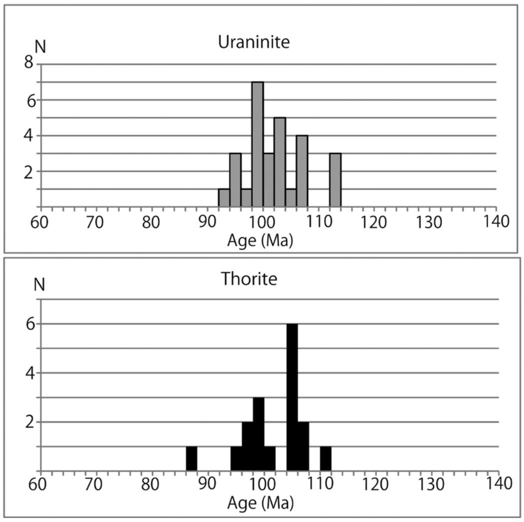

Fig. 14. Histograms of the uraninite and thorite ages from the granitoids in the northern Kyushu Province.

shown by Yokoyama *et al*. (2010). Uraninite and thorite are lower in closure temperature than zircon and monazite, but higher than micaceous minerals. For the other problem, uraninite and anhydrous thorite are usually rare and are not always present in the granitoids. In spite of these problems, the ages obtained by EPMA analyses of uraninite and thorite are available because of equivalent results to the SHRIMP age or K–Ar age for Neogene granitoids (Yokoyama *et al*., 2010). Therefore, we try to discuss the spatial distribution of the granitoids only through uraninite and thorite ages.

Devonian and Cambrian granitoids occur only sporadically in the islands and were summarized by Isozaki *et al*. (2015). The other younger granitoids in the Japanese Islands are roughly summarized by the present study mainly using the uraninite and thorite ages and are divided into several terranes. Spatial distribution by granitoid ages in the islands is summarized in Fig. 15. It will be probable that the age boundaries are eventually more ambiguous and the zones with similar ages may overlap more or less with each other. The oldest terrane is the well-known Hida terrane that has an age older than 180 Ma. The terrane will be further divided into two events: 180–220 Ma and 230–260 Ma (Fig. 10). As presented in the histograms (Figs. 10 and 16), it will be noteworthy that the granitoids with ages from 126 Ma to 180 Ma are absent in the Japanese Islands. Cretaceous granitoids that also partly include Paleogene in age are widely distributed throughout the islands. Their ages range from 60 Ma to 126 Ma that appears almost continuous in the summarized data (Fig. 16), indicating almost continuous igneous activity including volcanism in the islands. The Kitakami granitoids with 110–126 Ma show a zone from southern Hokkaido to the eastern Abukuma Mountains. Ages older than 110 Ma are only and locally found in northern Kyushu, though there may be no continuous relation with the Kitakami granitoids. Granitoids with ages of 100–110 Ma roughly form a zone from the Okushiri Island, Hokkaido, to the western Abukuma Mountains through the Akita area. Similar granitoids that are 100–110 Ma occur sporadically along the Median Tectonic Line and in a restricted area at the southwest part of Lake Biwa. Similar granitoids are well concentrated in northern Kyushu. Granitoids that are 90–100 Ma are found in several areas: the Asahi Mountains, Nikko and sporadically across southwest Japan along the Median Tectonic Line. So far, clear zonation has not been recognized among them.

Granitoids that are 80–90 Ma occur mostly in the Chugoku to Kinki provinces and may be grouped as the same igneous province. Granitoids that are 70–80 Ma occur in two areas: Shinshu on the northern side of the Median Tectonic Line, and the central part of the Sanin Province. Granitoids that are 60–70 Ma in age are well concentrated along the coast of the Sea of Japan and in the Tsukuba–Nikko area.

Igneous activity including volcanism in the Japanese Islands and along the continental margin of Asia has been treated as a result of subduction of the oceanic plate as an analogue of the present plate tectonics (e.g. Imaoka *et al*., 2015; Kon *et al*., 2015). Spatial distribution of granitoids with similar ages, especially Cretaceous

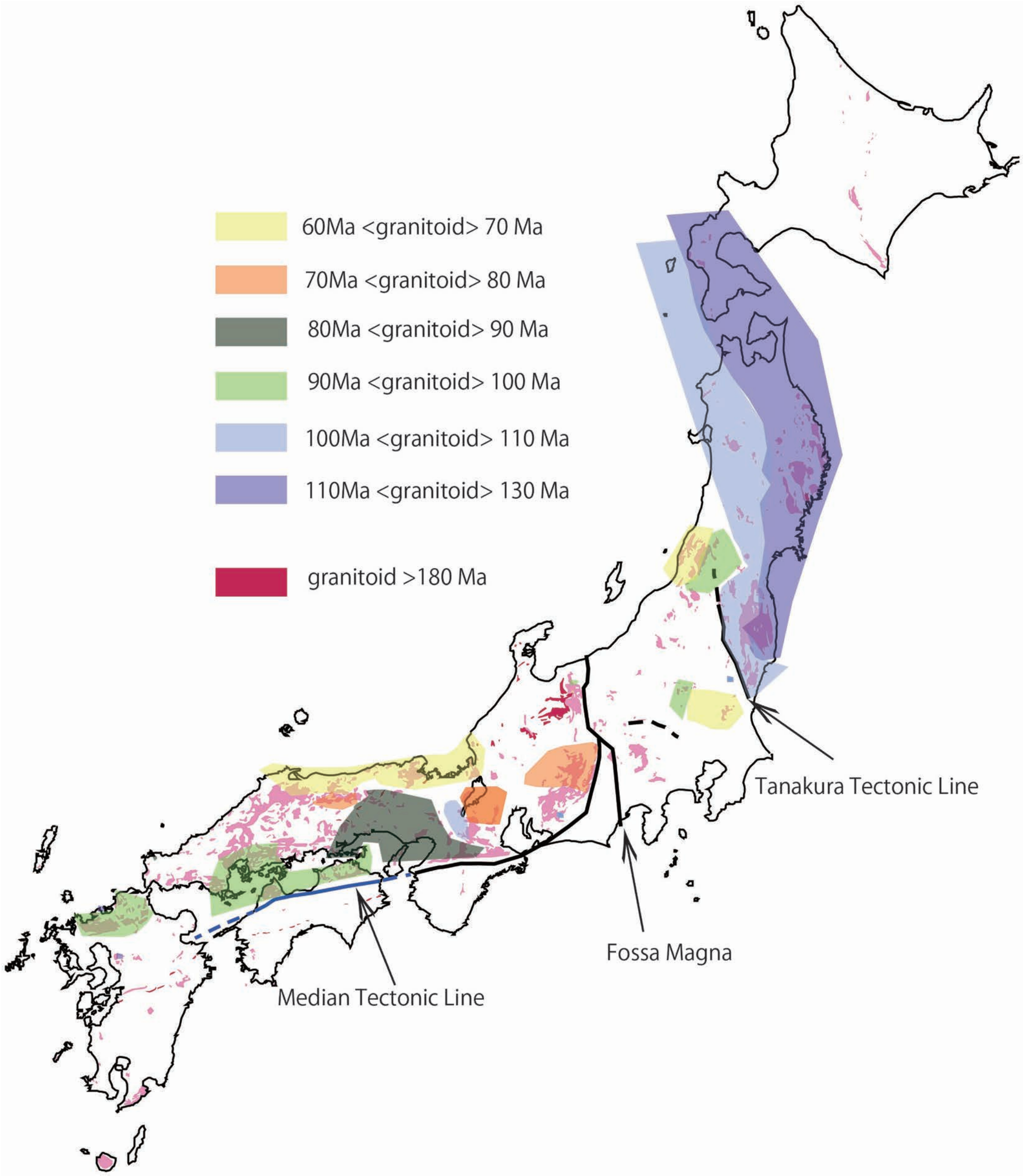

Fig. 15. Spatial distribution of granitoids summarized by uraninite and thorite ages in the Japanese Islands.

ones, does not always show a linear arrangement and is not related with the geological province. Hence, the correlation with subduction has not been solved yet. The youngest granitoids occur along the Pacific coast of western Japan and along the Fossa Magna zone and are related to the events that occurred after the opening of the Sea of Japan. Unfortunately, we could not develop a clear model for the youngest granitoids. This study of the spatial distribution of granitoids in the Japanese Islands is still on the way and will be refined or reconfirmed by LA-ICP-MS, SHRIMP and/or new age techniques. The present data will be available as a prelimi-

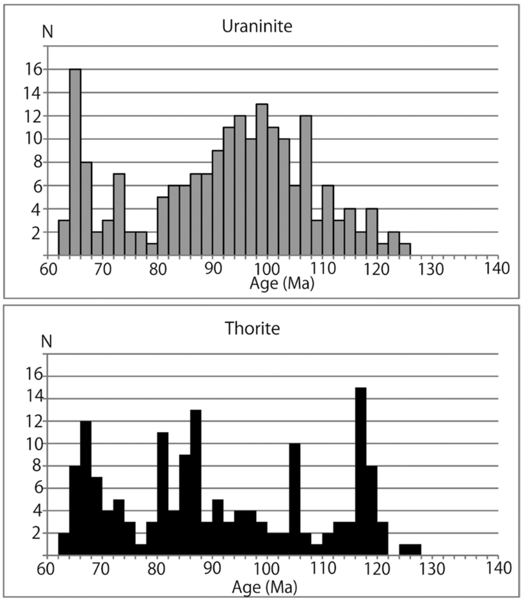

Fig. 16. Histograms of the uraninite and thorite ages from the granitoids in the Japanese Islands.

nary study for the compilation of the granitoids in the Japanese Islands in the near future.

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日本列島の花崗岩質岩400資料の閃ウラン鉱とトールによる年代測定

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日本列島の花崗岩質岩400資料が閃ウラン鉱とトールのEPMA分析により年代測定された．年代は，5百万年から3億年の範囲で，狭い年代の範囲で地域ごとに纏められた．日本の北部では，海溝沿いに年代が並ぶ地域があるが，西南日本では，一部を除き，帯状配列は見られず，点状に分布する年代地域があることが判明した．これらの年代データは，日本海対岸の花崗岩質岩の年代との比較で古地理の復元に利用されるものである．