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Zircon U–Pb ages of the granitic rocks in Kunisaki district, northeastern Kyushu, Southwest Japan

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Abstract The Kunisaki district in the eastern part of northern Kyushu is interpreted to be the western extension of the Ryoke belt. Zircon U–Pb ages of 8 granitoid samples from the district were obtained. Granite samples from the western part of the district are 96–100 Ma in U–Pb age and are attributed to the Ryoke belt. Granitoid samples from the eastern part of the district show relatively older ages than the western part, 108–110 Ma which is consistent with the Higo belt rather than the Ryoke belt. The granitoids in the district broadly become younger towards the northwest, from the oceanic side to continental side as well as the western side of central to northern Kyushu. Although the extension of the Ryoke belt was confirmed in the eastern side of Kyushu in this paper, the western extension of the Ryoke belt remains unclear.

Key words: granitic rocks, zircon age, Kunisaki Peninsula, Ryoke belt, Higo belt

Introduction

Kyushu is subdivided by the Matsuyama–Imari and Usuki–Yatsushiro tectonic lines into three parts: northern, central and southern Kyushu. Distribution of pre-Paleogene granitoids is restricted to northern and central Kyushu. The Kunisaki district is situated in the eastern part of northern Kyushu (Fig. 1) and has been interpreted to be the western extension of the Ryoke belt on the basis of the presence of high-*T* type metamorphic rocks and geographical continuity (e.g. Karakida *et al.*, 1969). Late Cretaceous granitoids and metamorphic rocks in central Kyushu had been also interpreted to be western extension of the Ryoke belt on the basis of mineral K–Ar and Rb–Sr ages (e.g., Nakajima et al, 1995; Sasada, 1987).

Zircon U–Pb dating has become a common method to distinguish the plutonism age of granitoids. The zircon U–Pb ages of Ryoke granitoids in the Chugoku and Shikoku regions range from *ca.* 90 to 105 Ma (Iida *et al.*, 2015; Shimooka *et al.*, 2019; Skrzypek *et al.*, 2016). The zircon U–Pb ages reveal that the granitoids in central Kyushu are much older than the Ryoke granitoids; the Higo Plutonic Complex *ca*. 108–113 Ma (Tsutsumi, 2022) and the Nioki granite in the Asaji district of *ca.* 135 Ma (Fujii *et al.*, 2008). These ages show that the granitoids in southern central Kyushu are not the western extension of the Ryoke belt in Kyusyu. Alternatively, Miyazaki *et al.* (2017) proposed that the Ryoke belt extends to the Omuta area in the Chikuhi district, northern central Kyushu.

As granitoids in the Kunisaki district may be candidates for the eastern extension of the Ryoke granitoids, newly 8 zircon U–Pb ages of granitoids in the district are studied in this paper to determine if the Ryoke belt extends to Kyushu or not.

Geological setting

Basement rocks in the Kunisaki district are found as small bodies only in the Yamakunigawa, Ajimu, Ushiyashiki, Gyojamisaki and Kurotsuzaki areas because of concealment beneath Neogene to Quaternary volcanic and pyroclastic rocks (Fig. 2). The basement rocks consist mainly of Cretaceous granitoids which are more or less associated with high-*T* type metamorphic rocks (e.g. Karakida *et al.*, 1969). Foliation of granitoids and schistose/gneissose texture of metamorphics show trend broadly E-W (Osanai *et al.*, 1993; Ishizaka, *et al.*, 2005). However, compositional features of granitoids and tex-

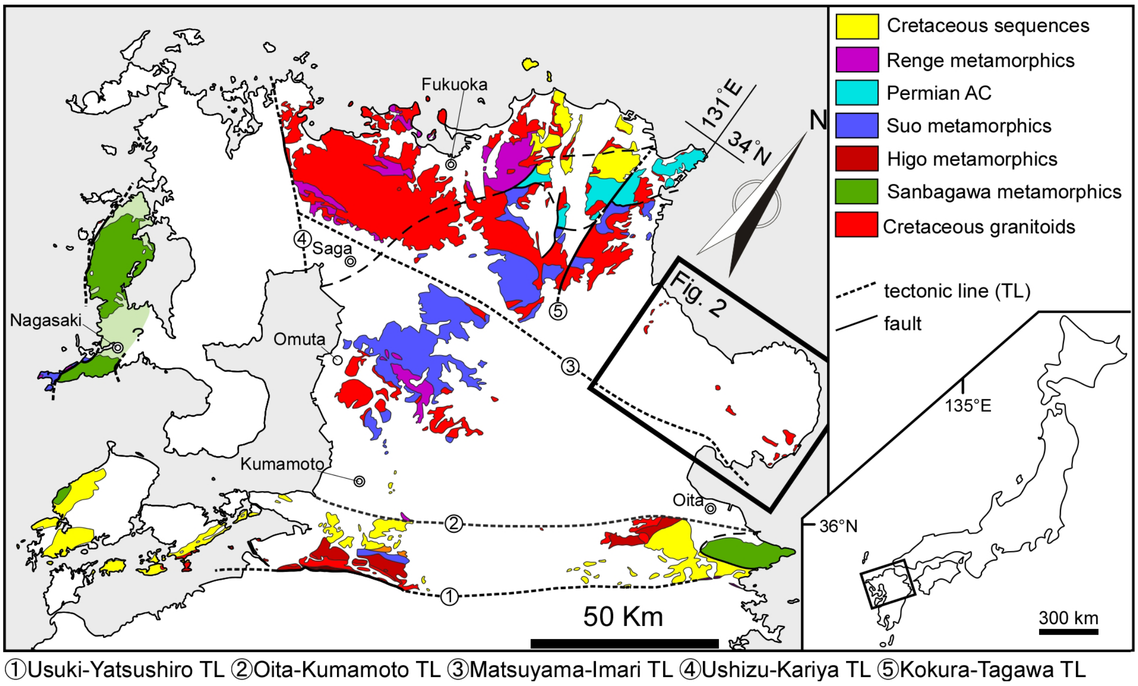

Fig. 1. Distribution map of the pre-Paleogene rocks in northern Kyushu.

tural and mineralogical features of metamorphics have NE-SW trending zonation (Murakami, 1994).

Granitoids in the Yamakunigawa area consist of tonalite, granodiorite and granite. Xenoliths of gneisses were reported in southern part of the exposure area of the granitoids (Murakami, 1994). In the Ajimu area, granitoids are subdivided into the Maruta granodiorite and Tsuru granite. The granite is accompanied by mica schist which is similar to schists in the Ryoke belt (Kasama, 1953). The biotite K–Ar age of the Maruta granodiorite is 78.2 ± 3.9 Ma (Sasada, 1987).

Although the granitoids in the Ushiyashiki area had been named "Ushiyashiki granite" (Karakida *et al.*, 1992; Osanai *et al.*, 1993), the granitoids are subdivided into two granitoid types: a relatively mafic and felsic, quartz diorite to tonalite and granite. Xenoliths of the former granitoids are sometimes observed in the latter granitoids. Therefore, they were re-named the "Ushiyashiki plutonic complex" (Ishizaka, *et al.*, 2005). K–Ar ages of 97 Ma and 88 Ma were reported for the granitoids in this area (Matsumoto and Narishige, 1985). The metamorphics in this area consist mainly of pelitic gneiss, quartz gneiss and amphibolite. Metamorphic grade is high, similar to the high-grade part of the Ryoke belt in the Yanai area, Yamaguchi Prefecture, (Ikeda 2004).

The granitoids in the Gyojamisaki area were named the "Gyojamisaki tonalite" (Karakida *et al.*, 1992; Osanai *et al.*, 1993). This grouping included various types of plutonic rocks; gabbro, quarts diorite, tonalite, granodiorite to granite, and two-mica granite. Therefore, they were re-named the "Gyojamisaki plutonic complex" (Ishizuka, *et al.*, 2005). K–Ar ages of white mica and biotite from the complex are reported as 94 Ma and 85.5 ± 4.3 Ma, respectively (Sasada, 1987 and references therein). The granitoids in the Kurotsuzaki area are named the "Kurotsuzaki tonalite" (Karakida *et al.*, 1992; Osanai *et al.*, 1993) and consist not only tonalite but also the other types of granitoids. K–Ar ages of biotite and hornblende from the granitoids were 91.1 ± 4.6 Ma (Sasada, 1987) and 98.7 ± 4.9 Ma (Kamei *et al.*, 2004), respectively.

K–Ar ages of granitoids in the Kunisaki district, range from 78 Ma to 97 Ma. However, the whole rock isochron (WRI) Rb–Sr age, using multiple rock samples from Gyojamisaki and Kurotsuzaki areas, was 142.2 ± 2.1 Ma (2σ, Osanai *et al.*, 1993), far older than K–Ar ages.

Analytical methods

All sample preparation and analyses were conducted at National Museum of Nature and Science,

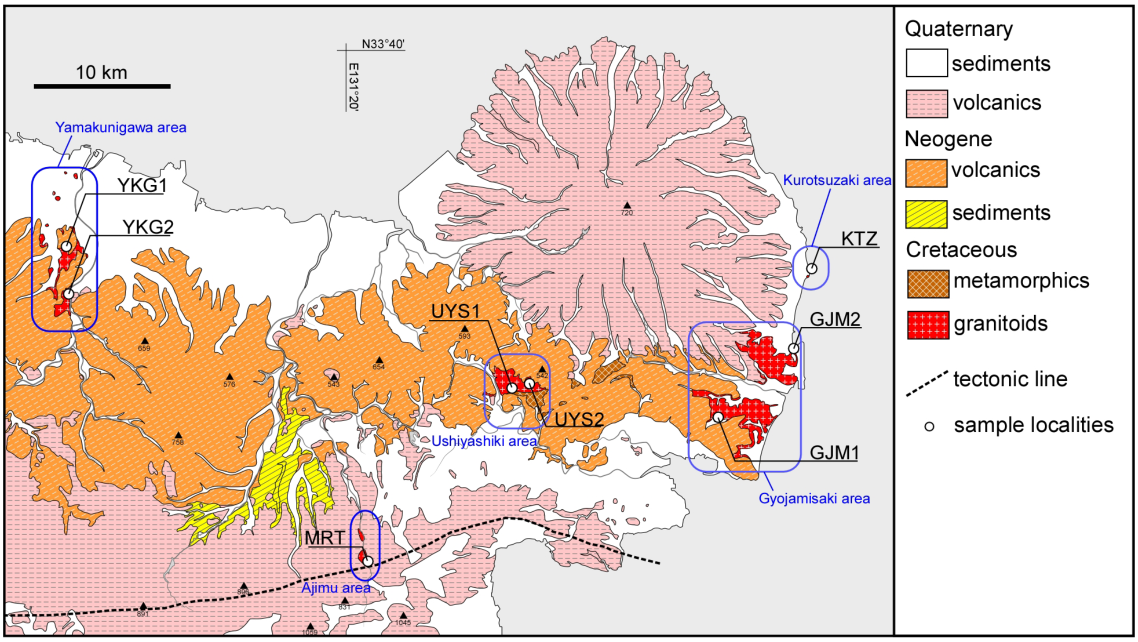

Fig. 2. Geological map of the study area showing the sampling localities, modified after Ishizuka *et al.* (2009). Gd: granodiorite, Gr. Granite.

Tsukuba, Japan. The rock samples were scrubbed and washed in an ultrasonic bath for ten minutes to avoid surface zircon contaminants as much as possible. Fragmentation of the rock samples was conducted by a high voltage pulse power selective fragmentation equipment, SELFRAG Lab (Selfrag AG). The zircon grains were handpicked from heavy fractions that were separated from heavy-liquid techniques. Zircon grains from the samples, the zircon standards TEMORA2 (416.78 Ma; Black *et al.*, 2004) and OD-3 (33 Ma; Iwano *et al.*, 2013), and the glass standard NIST SRM610 were mounted in an epoxy resin and polished till the surface was level with the center of the embedded grains. Before the mounting and polishing, secondary electron (SE) images of zircon grains are taken for morphological assessment. After mounting and polishing, backscattered electron and cathodoluminescence (CL) images of zircon grains were taken. A scanning electron microscope-cathodoluminescence equipment, JSM-6610 (JEOL) and a CL detector (SANYU electron), was used for SE and CL images. The images were used to select suitable sites for analysis. U–Pb dating of these samples was carried out using a Laser Ablation Inductively Coupled Plasma Mass Spectrometer (LA-ICP-MS) that was composed of NWR213 (Elemental Scientific Lasers) and Agilent 7700x (Agilent Technologies). The experimental conditions and the analytical procedures for the measurements were after Tsutsumi *et al.* (2012), and additional devices of buffered type stabilizer (Tunheng and Hirata, 2004) and TwoVol2 sample cell were applied. The spot size of the laser was 25 µm. A correction for common Pb was made on the basis of the measured $^{207}Pb/^{206}Pb$ ratio (^{207}Pb correction), and $^{208}Pb/^{206}Pb$ and Th/U ratios (^{208}Pb correction) (e.g. Williams, 1998) and the model for common Pb compositions proposed by Stacey and Kramers (1975). In this paper, we adopt ^{207}Pb correction for age discussion because it is effective in calculating Phanerozoic ^{238}U–$^{206}Pb^*$ age compared with ^{208}Pb correction (e.g. Williams, 1998). $^{238}U/^{206}Pb^*$ and $^{207}Pb^*/^{206}Pb^*$ ratios which corrected by ^{208}Pb correction are used for the concordia plot. Pb* indicates radiometric Pb. The pooled ages presented in this study were calculated using IsoplotR software with statistically rejection functionality enabled (Vermeesch, 2018). The data of secondary standard OD-3 zircon obtained during analysis yielded weighted mean ages of 33.5 ± 1.2 Ma (n = 10; MSWD = 0.69; when YKG1, YKG2 and MRT were analyzed), 33.2 ± 1.0 Ma (n = 12; MSWD = 1.04; when UYS1, UYS2, GJM2 and KTZ were analyzed) and 32.9 ± 1.2 Ma (n = 7; MSWD = 0.92; when GJM1 was analyzed). MSWD is acronym of mean square weighted deviation, which is calculated from square root of χ^2 value.

Sample descriptions and results of zircon age analysis

Table 1 lists zircon data 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, and radiometric ^{238}U–^{206}Pb* ages of the samples. All errors are 1 sigma level. All zircon grains in the samples show rhythmic oscillatory and/or sector zoning on CL images (Fig. 3), which is commonly observed in igneous zircons (e.g., Corfu *et al.*, 2003). Errors of weighted mean zircon U–Pb ages are 95% confidence interval (95% conf.). Concordia diagrams for each sample are shown in Fig. 4. The obtained weighted mean ages and sample localities are summarized in Table 2.

All rock samples are stored at the National Museum of Nature and Science. The registration number of each sample is the catalogue number of the rock specimen in the collection database of the National Museum of Nature and Science (http://db.kahaku.go.jp/webmuseum_en/).

YKG1: Yamakunigawa area

The sample was collected between Hirayamaike pond and Oike pond, northeastern part of the Koge Town, Fukuoka Prefecture (lat: N 33°33′20.1″, long: E 131°09′57.1″). This is a medium-grained weathered granite. The registration number is 138218.

Most zircon grains are partly rounded and are 140 to 270 μm in length with elongation ratios of 2.0 to 2.8. CL images of the grains are relatively bright with distinct oscillatory and/or sector zoning. 41 spots from 36 grains were analyzed and 40 data were concordant. Concordant data indicate 87–110 Ma, 188 Ma and 233 Ma. After 7 older data were excluded, the weighted mean age of 33 data indicates 95.5 ± 1.0 Ma (MSWD = 1.92; Fig. 5A).

YKG2: Yamakunigawa area

The sample was collected from west side bank of the Yamakunigawa River, southeastern part of the Koge Town, Fukuoka Prefecture (lat: N 33°31′34.0″, long: E 131°10′00.3″). This is a coarse-grained biotite granite. The major minerals of this rock are plagioclase, quartz, alkali feldspar and biotite. Plagioclase occurs as euhedral to subhedral crystals and exhibits indistinct albite twin and oscillatory zoning. Undulatory extinction is observed in quartz. Allanite and titanite are common accessory minerals. The registration number is 138219.

Most zircon grains are prismatic and are 140 to 250 μm in length with elongation ratios of 2.3 to 3.4. CL images of the grains are relatively bright with distinct oscillatory zoning. Although some darker CL cores were observed, there is no age difference beyond the error range. 41 spots from 31 grains were analyzed and 38 data are concordant. Concordant data indicate 92–107 Ma, 1786 Ma, 1866 Ma and 1879 Ma. After 7 older data were excluded, the weighted mean age of 31 data indicates 95.5 ± 1.0 Ma (MSWD = 2.46, Fig. 5B).

MRT: Maruta granodiorite, Ajimu aera

The sample was collected from west side bank of the Tsubusagawa River, southeastern part of the Ajimu Town, Oita Prefecture (lat: N 33°21′14.0″, long: E 131°23′55.9″). This is a medium-grained weathered granite. The registration number is 138220.

Most of zircon grains are partly rounded and are 140 to 230 μm in length with elongation ratios of 1.4 to 4.0. CL images of the grains are relatively bright with distinct oscillatory and/or sector zoning. 44 spots from 37 grains were analyzed and 40 data were concordant. Concordant data indicate 91–108 Ma. After 1 datum rejected by statistically rejection functionality of IsoplotR, the weighted mean age of 39 data indicates 100.4 ± 1.2 Ma (MSWD = 1.55, Fig. 5C).

UYS1: Ushiyashiki area

The sample was collected from central part of the Kitsuki City, Oita Prefecture (lat: N 33°27′59.3″, long: E 131°30′42.6″). This is a fine-grained biotite granodiorite. The major minerals of this rock are plagioclase, quartz, biotite, and alkali feldspar. Plagioclase occurs as euhedral to subhedral crystals and exhibits indistinct albite twin and oscillatory zoning. Undulatory extinction is observed in quartz. The registration number is 138241.

Most of zircon grains are prismatic and are 110 to 200 μm in length with elongation ratios of 1.5 to 2.9. CL images of the grains are relatively bright with distinct oscillatory zoning. 44 spots from 35 grains were analyzed and 40 data are concordant.

Fig. 3. Morphological secondary electron (SE) images before cement in resin and cathodoluminescence (CL) images of analyzing section of typical zircon grains from the samples. Circles on the images indicated analyzed spots by LA-ICP-MS. Spot diameter is 25 μm approx.

Concordant data indicate 107–127 Ma, 137 Ma, 163 Ma, 189 Ma, 230–265 Ma and 1874 Ma. After 17 older data were excluded, the weighted mean age of 23 data indicates 110.8 ± 1.1 Ma (MSWD = 0.50, Fig. 5D).

UYS2: Ushiyashiki area

The sample was collected from central part of the Kitsuki City, Oita Prefecture (lat: N 33°28′12.1″, long: E 131°31′26.1″). This is a medium-grained two-mica granite. The major minerals of this rock are quartz, plagioclase, alkali feldspar, biotite, and muscovite. Plagioclase occurs as euhedral to subhedral crystals and exhibits indistinct albite twin and oscillatory zoning. Undulatory extinction is observed in quartz. The registration number is 138243.

Most of zircon grains are prismatic and are 150 to 420 μm in length with elongation ratios of 1.2 to 5.3. CL images of the grains are relatively bright with distinct oscillatory zoning. 44 spots from 37 grains were analyzed and 41 data are concordant. Concordant data indicate 90–106 Ma, 112–116 Ma and 1842 Ma. After 7 older data were excluded and 1 datum rejected by statistically rejection functionality of IsoplotR, the weighted mean age of 33 data

Table 1. LA-ICP-MS U–Pb data and calculated ages of zircons in the samples.

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)	^{238}U-$^{206}Pb^*$ age (2) (Ma)	$^{207}Pb^*/^{206}Pb^*$ age (1) (Ma)	Disc(3) (%)	Remarks
YKG1_01.1	0.03	127	103	0.83	73.47 ± 2.54	0.0439 ± 0.0134	87.1 ± 3.0	87.2 ± 2.7			
YKG1_02.1	0.00	1019	681	0.69	27.16 ± 0.39	0.0521 ± 0.0014	233.1 ± 3.3	232.7 ± 3.3			N
YKG1_02.2	1.82	402	41	0.11	68.66 ± 1.57	0.0465 ± 0.0048	93.2 ± 2.1	93.4 ± 2.1			
YKG1_03.1	0.00	914	171	0.19	66.91 ± 1.21	0.0499 ± 0.0024	95.6 ± 1.7	95.4 ± 1.7			
YKG1_04.1	0.00	338	124	0.38	64.64 ± 1.47	0.0459 ± 0.0034	99.0 ± 2.2	99.0 ± 2.2			
YKG1_05.1	0.00	610	185	0.31	69.41 ± 1.51	0.0491 ± 0.0027	92.2 ± 2.0	92.1 ± 2.0			
YKG1_06.1	0.16	1158	366	0.32	68.28 ± 1.15	0.0466 ± 0.0023	93.7 ± 1.6	93.9 ± 1.6			
YKG1_07.1	0.00	70	38	0.56	61.40 ± 3.14	0.0376 ± 0.0111	104.1 ± 5.3	104.1 ± 5.3			N
YKG1_07.2	0.30	519	137	0.27	67.88 ± 1.57	0.0473 ± 0.0045	94.3 ± 2.2	94.4 ± 2.2			
YKG1_08.1	0.00	596	293	0.51	65.26 ± 1.29	0.0478 ± 0.0028	98.0 ± 1.9	98.0 ± 1.9			
YKG1_09.1	0.00	1000	305	0.31	59.89 ± 1.13	0.0489 ± 0.0020	106.7 ± 2.0	106.6 ± 2.0			N
YKG1_09.2	0.00	1242	401	0.33	64.46 ± 1.05	0.0499 ± 0.0021	99.2 ± 1.6	99.0 ± 1.6			
YKG1_10.1	0.72	1244	542	0.45	69.07 ± 1.10	0.0492 ± 0.0033	92.7 ± 1.5	92.5 ± 1.4			
YKG1_11.1	0.00	376	68	0.19	65.07 ± 1.50	0.0477 ± 0.0035	98.3 ± 2.2	98.3 ± 2.2			
YKG1_12.1	0.00	434	122	0.29	68.04 ± 1.64	0.0563 ± 0.0034	94.1 ± 2.3	93.1 ± 2.3			D, N
YKG1_13.1	0.00	1499	718	0.49	66.74 ± 1.08	0.0478 ± 0.0016	95.9 ± 1.5	95.9 ± 1.5			
YKG1_14.1	0.00	934	359	0.39	66.82 ± 1.15	0.0489 ± 0.0023	95.8 ± 1.6	95.6 ± 1.7			
YKG1_15.1	0.00	451	146	0.33	67.53 ± 1.39	0.0486 ± 0.0031	94.8 ± 1.9	94.7 ± 2.0			
YKG1_17.2	0.02	570	82	0.15	64.71 ± 1.33	0.0464 ± 0.0032	98.9 ± 2.0	98.9 ± 2.0			
YKG1_18.1	1.06	166	129	0.79	69.75 ± 2.40	0.0446 ± 0.0113	91.8 ± 3.1	92.1 ± 3.0			
YKG1_19.1	0.00	261	212	0.83	69.38 ± 1.56	0.0462 ± 0.0039	92.3 ± 2.1	92.3 ± 2.1			
YKG1_20.1	0.00	402	68	0.17	67.25 ± 1.38	0.0488 ± 0.0032	95.2 ± 1.9	95.0 ± 2.0			
YKG1_21.1	0.86	986	168	0.17	33.82 ± 0.56	0.0487 ± 0.0021	187.8 ± 3.1	188.1 ± 3.1			N
YKG1_21.2	0.33	419	65	0.16	67.04 ± 1.66	0.0509 ± 0.0043	95.5 ± 2.4	95.1 ± 2.4			
YKG1_22.1	0.00	66	57	0.89	63.39 ± 2.48	0.0453 ± 0.0080	100.9 ± 3.9	100.9 ± 3.9			
YKG1_23.1	1.21	124	73	0.61	65.42 ± 2.33	0.0263 ± 0.0117	97.8 ± 3.5	99.0 ± 3.3			
YKG1_24.1	0.00	576	158	0.28	65.47 ± 1.30	0.0483 ± 0.0024	97.7 ± 1.9	97.7 ± 2.0			
YKG1_25.1	0.09	225	26	0.12	65.74 ± 1.84	0.0431 ± 0.0049	97.3 ± 2.7	97.4 ± 2.7			
YKG1_26.1	0.00	91	56	0.63	60.63 ± 2.20	0.0383 ± 0.0053	105.5 ± 3.8	105.5 ± 3.8			N
YKG1_28.1	0.00	365	151	0.42	63.06 ± 1.17	0.0447 ± 0.0029	101.4 ± 1.9	101.4 ± 1.9			
YKG1_28.2	0.03	811	99	0.13	64.77 ± 1.15	0.0473 ± 0.0031	98.8 ± 1.7	98.8 ± 1.7			
YKG1_29.1	0.00	172	75	0.45	58.18 ± 1.71	0.0420 ± 0.0055	109.9 ± 3.2	109.9 ± 3.2			N
YKG1_30.1	0.00	76	44	0.60	68.37 ± 3.02	0.0431 ± 0.0082	93.6 ± 4.1	93.6 ± 4.1			
YKG1_31.1	0.00	825	191	0.24	68.37 ± 1.13	0.0490 ± 0.0023	93.6 ± 1.5	93.5 ± 1.6			
YKG1_32.1	0.00	528	143	0.28	64.87 ± 1.39	0.0547 ± 0.0038	98.6 ± 2.1	97.8 ± 2.1			
YKG1_33.1	0.00	70	54	0.79	68.84 ± 2.87	0.0313 ± 0.0097	93.0 ± 3.8	93.0 ± 3.8			
YKG1_34.1	0.00	583	126	0.22	68.97 ± 1.30	0.0508 ± 0.0031	92.8 ± 1.7	92.5 ± 1.8			
YKG1_35.1	0.00	721	330	0.47	59.81 ± 1.12	0.0449 ± 0.0018	106.9 ± 2.0	106.9 ± 2.0			N
YKG1_36.2	0.23	716	159	0.23	67.57 ± 1.26	0.0498 ± 0.0036	94.7 ± 1.8	94.5 ± 1.8			
YKG1_37.1	0.95	71	39	0.57	68.56 ± 3.17	0.0207 ± 0.0159	93.4 ± 4.3	94.2 ± 4.0			
YKG1_38.1	0.26	1056	305	0.30	66.98 ± 1.06	0.0484 ± 0.0028	95.5 ± 1.5	95.5 ± 1.5			
YKG2_01.1	1.71	212	77	0.37	67.57 ± 2.32	0.0513 ± 0.0087	94.7 ± 3.2	94.3 ± 3.2			
YKG2_02.1	0.00	522	160	0.31	67.79 ± 1.14	0.0543 ± 0.0026	94.4 ± 1.6	93.6 ± 1.6			D, N
YKG2_04.1	0.00	491	164	0.34	65.82 ± 1.20	0.0510 ± 0.0028	97.2 ± 1.8	96.8 ± 1.8			
YKG2_05.1	0.00	690	213	0.32	66.12 ± 1.11	0.0472 ± 0.0023	96.8 ± 1.6	96.8 ± 1.6			
YKG2_06.1	0.32	605	197	0.33	66.71 ± 1.00	0.0525 ± 0.0041	95.9 ± 1.4	95.4 ± 1.4			
YKG2_07.1	0.00	549	245	0.46	68.60 ± 1.13	0.0462 ± 0.0029	93.3 ± 1.5	93.3 ± 1.5			
YKG2_08.1	0.00	728	320	0.45	67.96 ± 1.14	0.0441 ± 0.0019	94.2 ± 1.6	94.2 ± 1.6			
YKG2_08.2	0.28	450	133	0.30	65.79 ± 1.19	0.0476 ± 0.0043	97.2 ± 1.7	97.3 ± 1.7			
YKG2_09.1	0.54	767	207	0.28	59.89 ± 0.94	0.0429 ± 0.0031	106.7 ± 1.7	107.3 ± 1.6			N
YKG2_09.2	0.00	363	93	0.26	69.72 ± 1.34	0.0490 ± 0.0030	91.8 ± 1.7	91.7 ± 1.8			
YKG2_10.1	0.00	342	94	0.28	3.11 ± 0.04	0.1149 ± 0.0013	1795.8 ± 18.1	1786.6 ± 18.1	1879 ± 20	4.4	N
YKG2_10.2	0.01	357	76	0.22	67.11 ± 1.36	0.0485 ± 0.0042	95.3 ± 1.9	95.3 ± 1.9			
YKG2_11.1	0.00	515	144	0.29	65.37 ± 1.24	0.0477 ± 0.0027	97.9 ± 1.8	97.9 ± 1.8			
YKG2_12.1	0.40	140	60	0.44	67.16 ± 2.12	0.0480 ± 0.0089	95.3 ± 3.0	95.3 ± 3.0			
YKG2_12.2	0.00	335	90	0.27	67.94 ± 1.40	0.0474 ± 0.0034	94.2 ± 1.9	94.2 ± 1.9			
YKG2_13.1	0.00	810	202	0.26	61.70 ± 0.99	0.0486 ± 0.0022	103.6 ± 1.6	103.6 ± 1.7			N
YKG2_14.1	0.00	975	369	0.39	69.56 ± 1.10	0.0488 ± 0.0021	92.0 ± 1.4	91.9 ± 1.5			
YKG2_15.1	0.00	641	288	0.46	68.82 ± 1.19	0.0482 ± 0.0025	93.0 ± 1.6	93.0 ± 1.6			
YKG2_16.1	0.00	95	38	0.41	60.66 ± 2.19	0.0448 ± 0.0062	105.4 ± 3.8	105.4 ± 3.8			N
YKG2_17.1	0.00	205	88	0.44	60.89 ± 1.66	0.0448 ± 0.0039	105.0 ± 2.8	105.0 ± 2.8			N
YKG2_17.2	0.00	721	503	0.72	64.05 ± 1.11	0.0511 ± 0.0024	99.9 ± 1.7	99.5 ± 1.7			
YKG2_18.1	0.00	70	42	0.62	67.98 ± 2.93	0.0600 ± 0.0100	94.1 ± 4.0	92.7 ± 4.1			
YKG2_18.2	0.00	398	133	0.34	68.52 ± 1.36	0.0539 ± 0.0033	93.4 ± 1.8	92.7 ± 1.9			
YKG2_19.1	1.55	90	63	0.71	72.43 ± 2.91	0.0169 ± 0.0140	88.4 ± 3.5	89.8 ± 3.4			D, N
YKG2_19.2	0.38	1355	364	0.28	69.51 ± 1.10	0.0453 ± 0.0025	92.1 ± 1.4	92.4 ± 1.4			
YKG2_20.1	0.78	619	410	0.68	3.67 ± 0.05	0.1091 ± 0.0017	1552.3 ± 19.4	1532.5 ± 19.2	1786 ± 28	13.1	N
YKG2_20.2	0.57	446	98	0.22	64.98 ± 1.26	0.0455 ± 0.0041	98.5 ± 1.9	98.8 ± 1.9			
YKG2_21.1	0.00	748	372	0.51	64.35 ± 1.13	0.0488 ± 0.0023	99.4 ± 1.7	99.3 ± 1.8			
YKG2_23.1	0.00	212	21	0.10	66.07 ± 1.68	0.0465 ± 0.0048	96.8 ± 2.4	96.8 ± 2.4			
YKG2_24.1	0.00	164	130	0.81	61.06 ± 1.84	0.0654 ± 0.0055	104.7 ± 3.1	102.5 ± 3.2			D, N
YKG2_24.2	0.00	531	134	0.26	65.97 ± 1.13	0.0482 ± 0.0028	97.0 ± 1.6	96.9 ± 1.7			
YKG2_25.1	0.09	729	312	0.44	66.76 ± 1.10	0.0510 ± 0.0037	95.8 ± 1.6	95.5 ± 1.5			
YKG2_26.1	0.00	517	159	0.32	63.48 ± 1.10	0.0456 ± 0.0027	100.8 ± 1.7	100.8 ± 1.7			
YKG2_27.1	0.00	325	57	0.18	3.58 ± 0.05	0.1140 ± 0.0015	1588.0 ± 19.2	1561.9 ± 19.0	1866 ± 23	14.9	N
YKG2_27.2	0.30	504	201	0.41	69.55 ± 1.38	0.0511 ± 0.0046	92.0 ± 1.8	91.7 ± 1.8			
YKG2_28.1	0.10	529	179	0.35	68.89 ± 1.35	0.0465 ± 0.0039	92.9 ± 1.8	93.0 ± 1.8			
YKG2_29.1	0.00	972	401	0.42	65.07 ± 0.96	0.0467 ± 0.0019	98.3 ± 1.4	98.3 ± 1.4			
YKG2_30.1	0.00	318	94	0.30	67.72 ± 1.50	0.0512 ± 0.0037	94.5 ± 2.1	94.1 ± 2.1			
YKG2_31.1	0.20	839	321	0.39	68.92 ± 1.12	0.0492 ± 0.0037	92.9 ± 1.5	92.7 ± 1.5			
YKG2_32.1	0.09	735	67	0.09	63.76 ± 0.99	0.0513 ± 0.0029	100.3 ± 1.5	99.9 ± 1.6			
YKG2_33.1	0.00	758	263	0.36	65.91 ± 1.23	0.0470 ± 0.0022	97.1 ± 1.8	97.1 ± 1.8			
MRT_01.1	0.00	162	104	0.66	61.32 ± 1.70	0.0440 ± 0.0055	104.3 ± 2.9	104.3 ± 2.9			
MRT_01.2	0.00	109	59	0.55	66.84 ± 2.51	0.0640 ± 0.0070	95.7 ± 3.6	93.8 ± 3.6			D, N
MRT_02.1	0.00	135	57	0.43	61.96 ± 1.75	0.0393 ± 0.0046	103.2 ± 2.9	103.2 ± 2.9			
MRT_03.1	1.24	230	183	0.82	65.36 ± 1.58	0.0394 ± 0.0092	97.9 ± 2.3	98.9 ± 2.3			
MRT_05.1	0.00	242	173	0.73	63.92 ± 1.48	0.0496 ± 0.0045	100.1 ± 2.3	99.9 ± 2.4			

Table 1. Continued.

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)	^{238}U-$^{206}Pb^*$ age (2) (Ma)	$^{207}Pb^*/^{206}Pb^*$ age (1) (Ma)	Disc (3) (%)	Remarks
MRT_05.2	0.06	216	74	0.35	64.89 ± 1.79	0.0509 ± 0.0067	98.6 ± 2.7	98.2 ± 2.7			
MRT_06.1	0.00	163	92	0.58	60.39 ± 1.76	0.0439 ± 0.0046	105.9 ± 3.1	105.9 ± 3.1			
MRT_07.1	0.00	91	44	0.50	62.21 ± 2.15	0.0434 ± 0.0074	102.8 ± 3.5	102.8 ± 3.5			
MRT_08.1	0.00	202	260	1.32	64.15 ± 1.74	0.0514 ± 0.0050	99.7 ± 2.7	99.3 ± 2.7			
MRT_08.2	0.00	122	104	0.87	62.01 ± 2.18	0.0685 ± 0.0076	103.1 ± 3.6	100.5 ± 3.6			D, N
MRT_09.1	1.13	241	172	0.73	67.05 ± 1.72	0.0548 ± 0.0083	95.4 ± 2.4	94.6 ± 2.3			
MRT_09.2	0.20	164	58	0.36	63.53 ± 2.06	0.0581 ± 0.0082	100.7 ± 3.2	99.4 ± 3.2			
MRT_10.1	0.11	165	63	0.40	65.01 ± 1.79	0.0471 ± 0.0074	98.4 ± 2.7	98.5 ± 2.6			
MRT_11.1	0.00	158	103	0.67	62.98 ± 1.84	0.0484 ± 0.0045	101.6 ± 2.9	101.5 ± 3.0			
MRT_12.1	0.00	99	35	0.36	66.21 ± 2.48	0.0742 ± 0.0084	96.6 ± 3.6	93.5 ± 3.6			D, N
MRT_13.1	0.00	112	64	0.58	64.59 ± 2.02	0.0620 ± 0.0070	99.0 ± 3.1	97.3 ± 3.1			
MRT_14.1	2.20	165	111	0.69	62.24 ± 1.84	0.0416 ± 0.0111	102.7 ± 3.0	103.6 ± 2.9			
MRT_15.1	0.67	277	224	0.83	63.01 ± 1.84	0.0617 ± 0.0103	101.5 ± 2.9	99.8 ± 2.7			
MRT_15.2	0.72	218	83	0.39	62.98 ± 1.54	0.0487 ± 0.0073	101.6 ± 2.5	101.5 ± 2.4			
MRT_16.1	0.00	137	25	0.19	60.47 ± 1.73	0.0446 ± 0.0056	105.7 ± 3.0	105.7 ± 3.0			
MRT_17.1	1.17	149	82	0.57	59.64 ± 2.07	0.0389 ± 0.0098	107.2 ± 3.7	108.4 ± 3.6			
MRT_18.1	0.00	175	94	0.55	66.71 ± 1.91	0.0453 ± 0.0046	95.9 ± 2.7	95.9 ± 2.7			
MRT_19.1	0.97	188	122	0.66	66.72 ± 1.84	0.0451 ± 0.0104	95.9 ± 2.6	96.3 ± 2.5			
MRT_20.1	0.00	81	43	0.54	58.44 ± 1.99	0.0576 ± 0.0076	109.4 ± 3.7	108.1 ± 3.8			
MRT_21.1	0.12	158	84	0.55	62.72 ± 2.08	0.0506 ± 0.0089	102.0 ± 3.4	101.6 ± 3.3			
MRT_22.1	0.00	385	381	1.01	64.15 ± 1.56	0.0539 ± 0.0035	99.7 ± 2.4	99.0 ± 2.4			
MRT_22.2	3.20	228	130	0.58	59.78 ± 1.50	0.0518 ± 0.0103	106.9 ± 2.7	106.5 ± 2.6			
MRT_23.1	0.00	141	63	0.46	62.54 ± 1.60	0.0409 ± 0.0045	102.3 ± 2.6	102.3 ± 2.6			
MRT_24.1	0.00	190	92	0.50	64.65 ± 1.82	0.0444 ± 0.0040	98.9 ± 2.8	98.9 ± 2.8			
MRT_25.1	0.00	132	74	0.58	60.63 ± 2.07	0.0496 ± 0.0053	105.5 ± 3.6	105.3 ± 3.6			
MRT_26.1	1.63	86	44	0.52	65.66 ± 2.83	0.0256 ± 0.0129	97.4 ± 4.2	99.0 ± 4.1			
MRT_27.1	0.00	147	76	0.53	61.44 ± 1.94	0.0438 ± 0.0050	104.1 ± 3.3	104.1 ± 3.3			
MRT_28.1	0.00	192	101	0.54	61.24 ± 1.61	0.0460 ± 0.0047	104.4 ± 2.7	104.4 ± 2.7			
MRT_28.2	0.84	115	57	0.51	63.31 ± 2.49	0.0297 ± 0.0117	101.0 ± 3.9	101.9 ± 3.8			
MRT_29.1	0.00	175	100	0.58	62.96 ± 1.69	0.0554 ± 0.0048	101.6 ± 2.7	100.7 ± 2.8			
MRT_30.1	0.00	230	134	0.60	65.29 ± 1.41	0.0574 ± 0.0047	98.0 ± 2.1	96.8 ± 2.2			D, N
MRT_31.1	0.00	185	85	0.48	65.03 ± 1.91	0.0448 ± 0.0046	98.4 ± 2.9	98.4 ± 2.9			
MRT_32.1	0.00	213	158	0.76	70.03 ± 1.77	0.0495 ± 0.0038	91.4 ± 2.3	91.2 ± 2.3			N
MRT_33.1	0.00	178	69	0.40	64.45 ± 1.83	0.0531 ± 0.0050	99.2 ± 2.8	98.6 ± 2.8			
MRT_34.1	1.17	106	47	0.45	69.25 ± 2.60	0.0361 ± 0.0112	92.4 ± 3.4	93.5 ± 3.4			
MRT_35.1	0.39	150	82	0.56	64.01 ± 1.93	0.0487 ± 0.0089	99.9 ± 3.0	99.8 ± 3.0			
MRT_36.1	0.00	186	106	0.59	68.40 ± 2.02	0.0488 ± 0.0041	93.6 ± 2.7	93.5 ± 2.8			
MRT_37.1	0.28	191	69	0.37	65.16 ± 2.00	0.0491 ± 0.0078	98.2 ± 3.0	98.0 ± 3.0			
MRT_38.1	0.00	87	26	0.30	61.66 ± 2.56	0.0588 ± 0.0081	103.7 ± 4.3	102.3 ± 4.3			
UYS1_01.1	0.09	180	94	0.53	58.50 ± 1.48	0.0424 ± 0.0073	109.3 ± 2.7	109.4 ± 2.6			
UYS1_02.1	0.00	354	68	0.20	3.13 ± 0.04	0.1146 ± 0.0012	1786.3 ± 20.7	1776.7 ± 20.7	1874 ± 19	4.7	N
UYS1_03.1	0.00	102	76	0.77	59.36 ± 1.78	0.0687 ± 0.0079	107.7 ± 3.2	104.9 ± 3.3			D, N
UYS1_03.2	0.00	266	112	0.43	52.87 ± 1.22	0.0455 ± 0.0030	120.8 ± 2.8	120.8 ± 2.8			N
UYS1_04.1	0.23	132	62	0.48	56.42 ± 1.69	0.0573 ± 0.0090	113.3 ± 3.4	112.0 ± 3.3			
UYS1_05.1	0.42	133	104	0.80	56.88 ± 1.65	0.0454 ± 0.0105	112.4 ± 3.2	112.8 ± 3.1			
UYS1_06.1	0.00	109	103	0.97	33.63 ± 0.84	0.0455 ± 0.0039	188.9 ± 4.7	188.9 ± 4.7			N
UYS1_07.1	0.00	1261	472	0.38	27.41 ± 0.32	0.0490 ± 0.0011	231.0 ± 2.7	231.0 ± 2.7			N
UYS1_07.2	0.00	355	175	0.51	56.34 ± 1.09	0.0507 ± 0.0031	113.4 ± 2.2	113.1 ± 2.2			
UYS1_08.1	0.00	134	74	0.57	58.09 ± 1.62	0.0495 ± 0.0054	110.0 ± 3.0	109.9 ± 3.1			
UYS1_08.2	0.00	468	101	0.22	58.80 ± 0.99	0.0441 ± 0.0023	108.7 ± 1.8	108.7 ± 1.8			
UYS1_09.1	0.00	103	56	0.56	55.99 ± 1.75	0.0308 ± 0.0043	114.1 ± 3.5	114.1 ± 3.5			D, N
UYS1_09.2	0.00	369	121	0.34	51.88 ± 1.01	0.0510 ± 0.0027	123.1 ± 2.4	122.7 ± 2.4			N
UYS1_10.1	0.59	122	87	0.73	56.10 ± 1.78	0.0565 ± 0.0117	113.9 ± 3.6	112.7 ± 3.4			
UYS1_10.2	0.68	517	181	0.36	58.99 ± 1.03	0.0445 ± 0.0039	108.4 ± 1.9	108.9 ± 1.9			
UYS1_11.1	0.00	167	74	0.46	46.47 ± 1.29	0.0433 ± 0.0041	137.3 ± 3.8	137.3 ± 3.8			N
UYS1_12.1	2.26	150	127	0.86	59.03 ± 1.87	0.0347 ± 0.0135	108.3 ± 3.4	110.1 ± 3.2			
UYS1_12.2	0.81	631	160	0.26	57.87 ± 1.11	0.0511 ± 0.0048	110.4 ± 2.1	110.0 ± 2.1			
UYS1_13.1	1.37	109	63	0.59	60.02 ± 2.21	0.0309 ± 0.0118	106.5 ± 3.9	108.0 ± 3.7			
UYS1_14.1	0.00	93	67	0.74	57.65 ± 1.86	0.0426 ± 0.0070	110.9 ± 3.5	110.9 ± 3.5			
UYS1_15.1	1.14	359	280	0.80	26.30 ± 0.42	0.0481 ± 0.0046	240.6 ± 3.8	241.4 ± 3.7			N
UYS1_15.2	0.00	282	136	0.49	59.88 ± 1.36	0.0580 ± 0.0041	106.8 ± 2.4	105.5 ± 2.4			D, N
UYS1_16.1	0.00	469	366	0.80	56.60 ± 1.07	0.0547 ± 0.0032	112.9 ± 2.1	112.0 ± 2.2			D, N
UYS1_17.1	2.02	111	74	0.69	59.25 ± 2.23	0.0252 ± 0.0122	107.9 ± 4.0	110.1 ± 3.9			
UYS1_18.1	0.46	103	54	0.54	58.22 ± 2.01	0.0485 ± 0.0116	109.8 ± 3.8	109.8 ± 3.6			
UYS1_19.1	0.00	96	56	0.60	59.06 ± 2.15	0.0551 ± 0.0071	108.2 ± 3.9	107.3 ± 4.0			
UYS1_19.2	0.22	640	224	0.36	57.71 ± 1.02	0.0429 ± 0.0031	110.8 ± 1.9	111.0 ± 1.9			
UYS1_20.1	0.04	161	101	0.64	56.83 ± 1.57	0.0453 ± 0.0080	112.4 ± 3.1	112.5 ± 2.9			
UYS1_21.1	0.00	226	105	0.48	57.10 ± 1.32	0.0519 ± 0.0035	111.9 ± 2.6	111.4 ± 2.6			
UYS1_22.1	0.48	115	88	0.79	55.24 ± 2.09	0.0414 ± 0.0130	115.7 ± 4.3	116.2 ± 4.1			N
UYS1_23.1	0.04	283	148	0.54	56.93 ± 1.22	0.0485 ± 0.0063	112.3 ± 2.4	112.2 ± 2.3			
UYS1_24.1	0.00	181	87	0.49	28.20 ± 0.55	0.0525 ± 0.0029	224.6 ± 4.3	224.1 ± 4.4			N
UYS1_25.1	0.00	153	105	0.70	52.53 ± 1.47	0.0445 ± 0.0048	121.6 ± 3.4	121.6 ± 3.4			N
UYS1_25.2	0.00	119	73	0.63	52.67 ± 1.65	0.0508 ± 0.0054	121.2 ± 3.8	120.9 ± 3.8			N
UYS1_26.1	0.00	606	165	0.28	56.13 ± 0.99	0.0438 ± 0.0024	113.8 ± 2.0	113.8 ± 2.0			
UYS1_27.1	0.00	97	57	0.60	52.45 ± 1.67	0.0518 ± 0.0067	121.7 ± 3.8	121.2 ± 3.9			N
UYS1_29.1	3.26	114	67	0.61	59.04 ± 2.17	0.0231 ± 0.0126	108.3 ± 3.9	111.7 ± 3.9			
UYS1_30.1	0.81	311	111	0.37	58.40 ± 1.39	0.0521 ± 0.0061	109.5 ± 2.6	108.9 ± 2.6			
UYS1_31.1	0.00	154	48	0.32	38.87 ± 1.04	0.0505 ± 0.0041	163.7 ± 4.3	163.5 ± 4.4			N
UYS1_32.1	0.00	260	128	0.51	52.98 ± 1.12	0.0425 ± 0.0031	120.5 ± 2.5	120.5 ± 2.5			N
UYS1_33.1	0.49	245	127	0.53	54.55 ± 1.33	0.0461 ± 0.0063	117.1 ± 2.8	117.4 ± 2.8			N
UYS1_34.1	0.76	259	120	0.48	56.43 ± 1.50	0.0438 ± 0.0066	113.2 ± 3.0	113.9 ± 2.9			
UYS1_35.1	1.46	163	133	0.83	24.01 ± 0.58	0.0424 ± 0.0078	263.0 ± 6.3	266.0 ± 6.1			N
UYS1_36.1	0.00	292	116	0.41	50.14 ± 0.93	0.0499 ± 0.0032	127.3 ± 2.3	127.1 ± 2.4			N
UYS2_01.1	0.03	808	146	0.18	54.59 ± 1.08	0.0535 ± 0.0027	117.0 ± 2.3	116.3 ± 2.3			N
UYS2_01.2	0.00	88	36	0.43	60.14 ± 2.52	0.0679 ± 0.0095	106.3 ± 4.4	103.7 ± 4.5			D, N
UYS2_02.1	0.07	248	74	0.31	63.27 ± 1.64	0.0539 ± 0.0059	101.1 ± 2.6	100.3 ± 2.6			
UYS2_02.2	2.66	114	64	0.58	66.22 ± 2.36	0.0200 ± 0.0141	96.6 ± 3.4	99.2 ± 3.2			

Table 1. Continued.

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)	^{238}U-$^{206}Pb^*$ age (2) (Ma)	$^{207}Pb^*/^{206}Pb^*$ age (1) (Ma)	Disc(3) (%)	Remarks
UYS2_03.1	0.41	76	69	0.94	61.12 ± 2.90	0.0237 ± 0.0184	104.6 ± 4.9	105.0 ± 4.4			
UYS2_04.1	0.00	585	299	0.52	66.20 ± 1.24	0.0509 ± 0.0030	96.7 ± 1.8	96.3 ± 1.8			
UYS2_05.1	0.00	171	242	1.45	68.19 ± 1.98	0.0509 ± 0.0048	93.8 ± 2.7	93.5 ± 2.8			
UYS2_06.1	0.00	170	169	1.02	63.81 ± 2.24	0.0442 ± 0.0054	100.2 ± 3.5	100.2 ± 3.5			
UYS2_07.1	0.00	104	95	0.94	61.89 ± 2.41	0.0378 ± 0.0060	103.3 ± 4.0	103.3 ± 4.0			
UYS2_08.1	0.00	600	149	0.25	62.79 ± 1.28	0.0579 ± 0.0029	101.9 ± 2.1	100.6 ± 2.1			D, N
UYS2_08.2	0.00	53	44	0.86	62.84 ± 3.00	0.0396 ± 0.0105	101.8 ± 4.8	101.8 ± 4.8			
UYS2_09.1	0.04	189	61	0.33	63.78 ± 1.86	0.0430 ± 0.0062	100.3 ± 2.9	100.3 ± 2.8			
UYS2_10.1	0.00	102	89	0.89	66.68 ± 2.43	0.0369 ± 0.0067	96.0 ± 3.5	96.0 ± 3.5			
UYS2_11.1	0.42	191	46	0.25	64.84 ± 1.85	0.0482 ± 0.0072	98.7 ± 2.8	98.6 ± 2.8			
UYS2_12.1	0.50	169	83	0.50	68.82 ± 2.11	0.0452 ± 0.0090	93.0 ± 2.8	93.3 ± 2.8			
UYS2_13.1	0.00	311	87	0.29	66.69 ± 1.65	0.0523 ± 0.0037	95.9 ± 2.4	95.4 ± 2.4			
UYS2_14.1	0.00	482	354	0.75	66.75 ± 1.27	0.0486 ± 0.0030	95.9 ± 1.8	95.8 ± 1.8			
UYS2_15.1	0.00	273	131	0.49	59.71 ± 1.59	0.0508 ± 0.0048	107.1 ± 2.8	106.7 ± 2.9			
UYS2_16.1	0.77	134	104	0.79	65.97 ± 2.46	0.0381 ± 0.0138	97.0 ± 3.6	97.7 ± 3.3			
UYS2_17.1	0.00	142	29	0.21	56.59 ± 1.74	0.0539 ± 0.0058	112.9 ± 3.4	112.1 ± 3.5			N
UYS2_19.1	0.00	125	120	0.99	64.73 ± 2.18	0.0413 ± 0.0054	98.8 ± 3.3	98.8 ± 3.3			
UYS2_20.1	0.00	166	92	0.56	65.65 ± 1.85	0.0454 ± 0.0043	97.4 ± 2.7	97.4 ± 2.7			
UYS2_21.1	0.08	436	98	0.23	66.90 ± 1.61	0.0505 ± 0.0047	95.7 ± 2.3	95.3 ± 2.3			
UYS2_22.1	0.00	99	74	0.77	71.02 ± 2.25	0.0747 ± 0.0116	90.1 ± 2.8	87.1 ± 3.0			D, N
UYS2_23.1	0.18	249	50	0.21	57.13 ± 1.42	0.0473 ± 0.0047	111.9 ± 2.8	112.0 ± 2.8			N
UYS2_24.1	0.00	297	259	0.89	71.14 ± 1.71	0.0499 ± 0.0040	90.0 ± 2.1	89.7 ± 2.2			N
UYS2_25.1	0.00	294	78	0.27	65.23 ± 1.61	0.0475 ± 0.0033	98.1 ± 2.4	98.1 ± 2.4			
UYS2_25.2	0.00	92	34	0.38	66.47 ± 2.42	0.0652 ± 0.0089	96.3 ± 3.5	94.2 ± 3.6			
UYS2_26.1	0.00	325	113	0.36	66.80 ± 1.40	0.0458 ± 0.0034	95.8 ± 2.0	95.8 ± 2.0			
UYS2_27.1	0.55	101	108	1.09	67.93 ± 3.02	0.0531 ± 0.0185	94.2 ± 4.2	93.6 ± 3.8			
UYS2_28.1	0.00	700	294	0.43	3.44 ± 0.04	0.1125 ± 0.0012	1646.4 ± 18.0	1627.4 ± 18.0	1842 ± 18	10.6	N
UYS2_28.2	0.00	72	64	0.91	62.45 ± 3.16	0.0595 ± 0.0098	102.4 ± 5.1	100.9 ± 5.2			
UYS2_29.1	0.00	77	58	0.76	69.10 ± 2.67	0.0433 ± 0.0073	92.6 ± 3.6	92.6 ± 3.6			
UYS2_30.1	0.35	1409	672	0.49	63.06 ± 0.80	0.0460 ± 0.0026	101.4 ± 1.3	101.7 ± 1.3			
UYS2_31.1	0.00	262	93	0.36	62.57 ± 1.41	0.0462 ± 0.0036	102.2 ± 2.3	102.2 ± 2.3			
UYS2_32.1	0.57	226	79	0.36	67.02 ± 1.81	0.0479 ± 0.0065	95.5 ± 2.6	95.5 ± 2.5			
UYS2_33.1	0.00	90	53	0.61	66.55 ± 2.53	0.0454 ± 0.0065	96.1 ± 3.6	96.1 ± 3.6			
UYS2_34.1	0.00	554	26	0.05	56.31 ± 1.08	0.0459 ± 0.0025	113.5 ± 2.2	113.5 ± 2.2			N
UYS2_34.2	0.68	95	39	0.42	70.96 ± 2.76	0.0388 ± 0.0119	90.2 ± 3.5	90.8 ± 3.4			
UYS2_35.1	0.00	180	159	0.91	65.73 ± 1.74	0.0473 ± 0.0044	97.3 ± 2.6	97.3 ± 2.6			
UYS2_36.1	1.57	409	83	0.21	38.35 ± 0.67	0.0447 ± 0.0038	165.9 ± 2.9	166.9 ± 2.9			N
UYS2_36.2	0.00	194	116	0.61	63.29 ± 1.73	0.0497 ± 0.0047	101.1 ± 2.7	100.8 ± 2.8			
UYS2_37.1	0.00	244	223	0.94	65.67 ± 1.74	0.0432 ± 0.0036	97.4 ± 2.6	97.4 ± 2.6			
UYS2_38.1	0.00	132	45	0.35	56.78 ± 1.73	0.0444 ± 0.0054	112.5 ± 3.4	112.5 ± 3.4			N
GJM1_01.1	0.00	727	233	0.33	58.15 ± 0.78	0.0534 ± 0.0019	109.9 ± 1.5	109.2 ± 1.5			D, N
GJM1_02.1	0.07	541	202	0.38	57.57 ± 0.83	0.0503 ± 0.0031	111.0 ± 1.6	110.7 ± 1.6			
GJM1_03.1	0.00	836	331	0.41	63.63 ± 0.90	0.0524 ± 0.0018	100.5 ± 1.4	100.0 ± 1.4			D, N
GJM1_04.1	1.26	987	355	0.37	60.58 ± 0.76	0.0514 ± 0.0033	105.5 ± 1.3	105.1 ± 1.3			
GJM1_05.1	0.14	584	248	0.44	57.31 ± 0.84	0.0481 ± 0.0033	111.5 ± 1.6	111.5 ± 1.6			
GJM1_05.2	0.77	673	249	0.38	58.65 ± 0.83	0.0462 ± 0.0035	109.0 ± 1.5	109.3 ± 1.5			
GJM1_06.1	0.18	755	214	0.29	58.45 ± 0.76	0.0484 ± 0.0027	109.3 ± 1.4	109.3 ± 1.4			
GJM1_07.1	0.00	1631	992	0.62	60.29 ± 0.63	0.0489 ± 0.0013	106.0 ± 1.1	105.9 ± 1.1			
GJM1_08.1	0.00	587	238	0.42	55.31 ± 0.79	0.0477 ± 0.0022	115.5 ± 1.6	115.5 ± 1.6			N
GJM1_09.1	0.04	703	378	0.55	59.53 ± 0.82	0.0482 ± 0.0034	107.4 ± 1.5	107.4 ± 1.4			
GJM1_10.1	0.09	543	420	0.79	59.99 ± 1.00	0.0493 ± 0.0049	106.6 ± 1.8	106.4 ± 1.7			
GJM1_11.1	0.00	922	428	0.48	58.55 ± 0.78	0.0455 ± 0.0017	109.2 ± 1.4	109.2 ± 1.4			
GJM1_12.1	0.00	1071	341	0.33	58.69 ± 0.75	0.0493 ± 0.0016	108.9 ± 1.4	108.8 ± 1.4			
GJM1_13.1	1.47	938	423	0.46	61.24 ± 0.89	0.0438 ± 0.0039	104.4 ± 1.5	105.0 ± 1.5			
GJM1_15.1	0.00	1330	809	0.62	57.13 ± 0.70	0.0490 ± 0.0013	111.9 ± 1.4	111.8 ± 1.4			
GJM1_16.1	0.59	1446	814	0.58	59.08 ± 0.71	0.0552 ± 0.0025	108.2 ± 1.3	107.3 ± 1.3			D, N
GJM1_17.1	1.08	709	256	0.37	59.17 ± 0.88	0.0455 ± 0.0037	108.0 ± 1.6	108.4 ± 1.6			
GJM1_18.1	0.00	863	325	0.39	60.32 ± 0.87	0.0515 ± 0.0017	106.0 ± 1.5	105.6 ± 1.5			
GJM1_19.1	0.29	1113	449	0.41	61.09 ± 0.76	0.0454 ± 0.0025	104.7 ± 1.3	105.0 ± 1.3			
GJM1_20.1	0.00	1501	733	0.50	58.90 ± 0.64	0.0486 ± 0.0014	108.5 ± 1.2	108.5 ± 1.2			
GJM1_21.1	0.00	780	205	0.27	60.36 ± 0.86	0.0509 ± 0.0018	105.9 ± 1.5	105.6 ± 1.5			
GJM1_22.1	0.00	1568	1795	1.17	58.90 ± 0.74	0.0473 ± 0.0013	108.5 ± 1.4	108.5 ± 1.4			
GJM1_23.1	0.00	796	614	0.79	58.50 ± 0.77	0.0488 ± 0.0018	109.3 ± 1.4	109.2 ± 1.5			
GJM1_27.1	0.00	1810	1093	0.62	58.40 ± 0.67	0.0483 ± 0.0013	109.4 ± 1.3	109.4 ± 1.3			
GJM1_29.1	0.00	407	199	0.50	60.06 ± 1.04	0.0509 ± 0.0026	106.4 ± 1.8	106.1 ± 1.8			
GJM1_30.1	0.18	746	243	0.33	59.52 ± 0.88	0.0540 ± 0.0031	107.4 ± 1.6	106.6 ± 1.6			
GJM1_31.1	0.15	733	336	0.47	57.52 ± 0.90	0.0471 ± 0.0030	111.1 ± 1.7	111.3 ± 1.7			
GJM1_32.1	0.37	548	285	0.53	58.96 ± 0.97	0.0491 ± 0.0042	108.4 ± 1.8	108.3 ± 1.7			
GJM1_33.1	0.67	848	308	0.37	59.89 ± 1.01	0.0446 ± 0.0035	106.7 ± 1.8	107.2 ± 1.8			
GJM1_34.1	0.33	747	265	0.36	57.47 ± 0.83	0.0474 ± 0.0036	111.2 ± 1.6	111.3 ± 1.6			
GJM1_35.1	0.09	351	46	0.13	54.67 ± 1.12	0.0461 ± 0.0037	116.9 ± 2.4	117.0 ± 2.3			N
GJM2_01.1	0.90	152	86	0.58	62.98 ± 1.97	0.0427 ± 0.0094	101.5 ± 3.2	102.2 ± 3.1			
GJM2_01.2	0.00	1488	525	0.36	58.79 ± 0.81	0.0477 ± 0.0014	108.7 ± 1.5	108.7 ± 1.5			
GJM2_02.1	0.00	118	61	0.53	59.67 ± 1.94	0.0421 ± 0.0059	107.1 ± 3.5	107.1 ± 3.5			
GJM2_03.1	0.00	549	262	0.49	55.06 ± 0.94	0.0475 ± 0.0024	116.0 ± 2.0	116.0 ± 2.0			N
GJM2_04.1	0.36	147	71	0.49	61.81 ± 1.75	0.0338 ± 0.0079	103.5 ± 2.9	103.8 ± 2.8			
GJM2_05.1	0.56	571	250	0.45	54.83 ± 1.00	0.0422 ± 0.0040	116.5 ± 2.1	117.2 ± 2.1			N
GJM2_06.1	0.00	818	310	0.39	59.67 ± 1.04	0.0491 ± 0.0021	107.1 ± 1.9	107.0 ± 1.9			
GJM2_07.1	0.07	1316	601	0.47	62.12 ± 0.91	0.0475 ± 0.0029	103.0 ± 1.5	103.0 ± 1.5			
GJM2_08.1	0.25	499	216	0.44	56.59 ± 1.12	0.0487 ± 0.0040	112.9 ± 2.2	112.8 ± 2.2			
GJM2_09.1	0.02	1177	568	0.50	58.71 ± 0.96	0.0503 ± 0.0030	108.9 ± 1.8	108.6 ± 1.7			
GJM2_10.1	0.10	1212	487	0.41	57.33 ± 0.86	0.0487 ± 0.0027	111.5 ± 1.6	111.4 ± 1.7			
GJM2_11.1	0.06	942	243	0.27	51.66 ± 0.87	0.0487 ± 0.0026	123.6 ± 2.1	123.5 ± 2.1			N
GJM2_12.1	0.03	476	175	0.38	57.51 ± 1.08	0.0414 ± 0.0038	111.1 ± 2.1	111.2 ± 2.0			
GJM2_13.1	0.25	841	373	0.45	60.38 ± 1.03	0.0441 ± 0.0034	105.9 ± 1.8	106.2 ± 1.8			
GJM2_14.1	0.00	1599	871	0.56	57.93 ± 0.90	0.0494 ± 0.0015	110.3 ± 1.7	110.2 ± 1.7			
GJM2_15.1	0.45	397	157	0.41	59.36 ± 1.14	0.0443 ± 0.0046	107.7 ± 2.1	108.2 ± 2.0			

Table 1. Continued.

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)	^{238}U-$^{206}Pb^*$ age (2) (Ma)	$^{207}Pb^*/^{206}Pb^*$ age (1) (Ma)	Disc(3) (%)	Remarks
GJM2_15.2	0.00	1233	389	0.32	56.07 ± 0.79	0.0472 ± 0.0016	114.0 ± 1.6	114.0 ± 1.6			
GJM2_16.1	0.00	723	257	0.36	59.87 ± 0.90	0.0403 ± 0.0017	106.8 ± 1.6	106.8 ± 1.6			D, N
GJM2_17.1	0.00	1469	540	0.38	60.85 ± 0.78	0.0491 ± 0.0018	105.1 ± 1.3	104.9 ± 1.4			
GJM2_18.1	0.00	1086	531	0.50	59.40 ± 0.85	0.0487 ± 0.0020	107.6 ± 1.5	107.5 ± 1.6			
GJM2_19.1	0.00	1080	410	0.39	58.11 ± 0.85	0.0484 ± 0.0018	110.0 ± 1.6	110.0 ± 1.6			
GJM2_20.1	0.00	547	231	0.43	58.25 ± 0.99	0.0492 ± 0.0026	109.7 ± 1.9	109.6 ± 1.9			
GJM2_21.1	0.00	165	104	0.65	57.00 ± 1.59	0.0601 ± 0.0059	112.1 ± 3.1	110.4 ± 3.2			D, N
GJM2_21.2	0.00	920	413	0.46	61.82 ± 0.94	0.0497 ± 0.0021	103.4 ± 1.6	103.2 ± 1.6			
GJM2_22.1	0.30	350	184	0.54	59.86 ± 1.23	0.0428 ± 0.0060	106.8 ± 2.2	107.1 ± 2.1			
GJM2_23.1	0.00	1049	340	0.33	60.15 ± 0.80	0.0490 ± 0.0021	106.3 ± 1.4	106.2 ± 1.4			
GJM2_24.1	0.00	208	104	0.51	56.55 ± 1.37	0.0539 ± 0.0048	113.0 ± 2.7	112.2 ± 2.8			
GJM2_24.2	0.00	1180	475	0.41	58.15 ± 0.83	0.0474 ± 0.0017	109.9 ± 1.6	109.9 ± 1.6			
GJM2_25.1	0.00	904	367	0.42	58.03 ± 0.83	0.0488 ± 0.0023	110.1 ± 1.6	110.1 ± 1.6			
GJM2_26.1	0.00	2088	1545	0.76	60.60 ± 0.76	0.0468 ± 0.0013	105.5 ± 1.3	105.5 ± 1.3			
GJM2_27.1	0.13	847	452	0.55	59.65 ± 0.93	0.0444 ± 0.0042	107.2 ± 1.7	107.3 ± 1.6			
GJM2_28.1	0.28	121	62	0.52	57.02 ± 1.86	0.0335 ± 0.0095	112.1 ± 3.6	112.4 ± 3.5			
GJM2_28.2	0.00	1173	491	0.43	58.18 ± 0.85	0.0499 ± 0.0020	109.9 ± 1.6	109.6 ± 1.6			
GJM2_29.1	0.08	1202	463	0.40	59.26 ± 0.89	0.0467 ± 0.0029	107.9 ± 1.6	107.9 ± 1.6			
GJM2_30.1	0.00	1009	381	0.39	59.78 ± 0.84	0.0463 ± 0.0019	106.9 ± 1.5	106.9 ± 1.5			
GJM2_31.1	0.02	1339	1697	1.30	61.76 ± 0.93	0.0516 ± 0.0052	103.5 ± 1.5	103.1 ± 1.4			
GJM2_32.1	0.00	819	381	0.48	57.77 ± 0.91	0.0476 ± 0.0020	110.6 ± 1.7	110.6 ± 1.7			
GJM2_33.1	0.00	682	314	0.47	57.04 ± 1.06	0.0486 ± 0.0025	112.0 ± 2.1	112.0 ± 2.1			
GJM2_34.1	0.00	1147	421	0.38	57.85 ± 0.88	0.0515 ± 0.0020	110.5 ± 1.7	110.0 ± 1.7			
GJM2_36.1	0.22	2673	809	0.31	56.69 ± 0.82	0.0450 ± 0.0017	112.7 ± 1.6	113.0 ± 1.6			
GJM2_37.1	0.89	418	130	0.32	57.65 ± 1.13	0.0439 ± 0.0049	110.9 ± 2.2	111.5 ± 2.2			
GJM2_38.1	0.42	897	341	0.39	57.14 ± 1.03	0.0466 ± 0.0034	111.8 ± 2.0	112.1 ± 2.0			
GJM2_39.1	0.00	1984	1185	0.61	59.18 ± 0.84	0.0485 ± 0.0012	108.0 ± 1.5	108.0 ± 1.5			
GJM2_40.1	0.00	747	370	0.51	60.74 ± 1.16	0.0475 ± 0.0022	105.3 ± 2.0	105.3 ± 2.0			
KTZ_01.1	1.24	1191	860	0.74	56.33 ± 0.92	0.0487 ± 0.0044	113.4 ± 1.8	113.4 ± 1.8			
KTZ_02.1	0.00	894	177	0.20	57.76 ± 0.89	0.0464 ± 0.0019	110.7 ± 1.7	110.7 ± 1.7			
KTZ_03.1	1.11	542	136	0.26	58.59 ± 1.08	0.0481 ± 0.0042	109.1 ± 2.0	109.1 ± 2.0			
KTZ_04.1	0.00	1021	150	0.15	58.68 ± 0.90	0.0504 ± 0.0019	108.9 ± 1.7	108.6 ± 1.7			
KTZ_05.1	0.00	665	378	0.58	57.07 ± 1.00	0.0511 ± 0.0026	112.0 ± 1.9	111.6 ± 2.0			
KTZ_06.1	0.21	753	250	0.34	57.17 ± 0.97	0.0492 ± 0.0032	111.8 ± 1.9	111.7 ± 1.9			
KTZ_08.1	0.11	736	359	0.50	37.25 ± 0.52	0.0444 ± 0.0032	170.8 ± 2.4	171.0 ± 2.3			N
KTZ_08.2	0.00	1162	344	0.30	54.10 ± 0.73	0.0469 ± 0.0018	118.1 ± 1.6	118.1 ± 1.6			N
KTZ_10.1	0.00	2687	2490	0.95	58.14 ± 0.73	0.0474 ± 0.0011	109.9 ± 1.4	109.9 ± 1.4			
KTZ_11.1	0.25	1605	308	0.20	57.35 ± 0.80	0.0466 ± 0.0022	111.4 ± 1.5	111.7 ± 1.5			
KTZ_12.1	0.00	432	122	0.29	56.88 ± 1.19	0.0446 ± 0.0035	112.3 ± 2.3	112.3 ± 2.3			
KTZ_13.1	0.00	1876	742	0.41	55.63 ± 0.76	0.0471 ± 0.0013	114.8 ± 1.5	114.8 ± 1.5			
KTZ_14.1	0.07	986	493	0.51	55.85 ± 0.93	0.0479 ± 0.0037	114.4 ± 1.9	114.5 ± 1.9			
KTZ_15.1	0.00	1817	535	0.30	55.52 ± 0.75	0.0495 ± 0.0016	115.1 ± 1.5	114.9 ± 1.5			
KTZ_16.1	0.00	877	445	0.52	58.44 ± 0.96	0.0528 ± 0.0021	109.4 ± 1.8	108.8 ± 1.8			D, N
KTZ_17.1	1.48	742	432	0.60	59.73 ± 1.02	0.0485 ± 0.0051	107.0 ± 1.8	107.0 ± 1.8			
KTZ_18.1	0.55	2083	992	0.49	59.66 ± 0.87	0.0471 ± 0.0028	107.2 ± 1.5	107.3 ± 1.5			
KTZ_19.1	0.00	2065	2480	1.23	58.76 ± 0.76	0.0510 ± 0.0013	108.8 ± 1.4	108.4 ± 1.4			D, N
KTZ_19.2	0.95	1414	304	0.22	56.77 ± 0.82	0.0541 ± 0.0023	112.6 ± 1.6	111.7 ± 1.6			D, N
KTZ_20.1	0.00	106	72	0.70	58.84 ± 2.09	0.0597 ± 0.0074	108.6 ± 3.8	107.1 ± 3.9			
KTZ_22.1	0.03	1480	48	0.03	59.69 ± 0.79	0.0494 ± 0.0018	107.1 ± 1.4	106.9 ± 1.4			
KTZ_23.1	0.89	709	77	0.11	58.02 ± 1.05	0.0422 ± 0.0037	110.2 ± 2.0	111.0 ± 2.0			
KTZ_23.2	4.19	2982	1018	0.35	57.71 ± 0.89	0.0545 ± 0.0085	110.8 ± 1.7	109.9 ± 1.7			
KTZ_24.1	0.38	1403	646	0.47	57.56 ± 0.88	0.0515 ± 0.0032	111.0 ± 1.7	110.6 ± 1.7			
KTZ_25.1	0.00	1016	804	0.81	58.72 ± 1.06	0.0608 ± 0.0023	108.9 ± 2.0	107.2 ± 1.9			D, N
KTZ_26.1	0.00	374	187	0.51	59.24 ± 1.21	0.0425 ± 0.0033	107.9 ± 2.2	107.9 ± 2.2			
KTZ_27.1	0.00	2163	1515	0.72	59.45 ± 0.83	0.0488 ± 0.0011	107.5 ± 1.5	107.4 ± 1.5			
KTZ_28.1	0.00	1622	676	0.43	59.31 ± 0.80	0.0547 ± 0.0017	107.8 ± 1.4	106.9 ± 1.5			D, N
KTZ_29.1	0.00	2934	1227	0.43	58.25 ± 0.74	0.0496 ± 0.0011	109.7 ± 1.4	109.5 ± 1.4			
KTZ_31.1	0.13	1793	804	0.46	57.67 ± 0.87	0.0570 ± 0.0048	110.8 ± 1.7	109.6 ± 1.6			
KTZ_32.1	1.09	421	212	0.52	55.25 ± 1.18	0.0396 ± 0.0058	115.6 ± 2.5	116.9 ± 2.4			N
KTZ_33.1	0.00	1580	928	0.60	59.63 ± 0.90	0.0484 ± 0.0015	107.2 ± 1.6	107.2 ± 1.6			
KTZ_34.1	0.00	2603	1563	0.62	54.39 ± 0.75	0.0486 ± 0.0012	117.5 ± 1.6	117.4 ± 1.6			N

Errors are 1-sigma; Pb_c and Pb^* indicate the common and radiogenic portions, respectively.
Remarks; D: discordant, N: not used for weighted mean age calculation
(1) Common Pb corrected by assuming $^{206}Pb/^{238}U$–$^{208}Pb/^{232}Th$ age-concordance
(2) Common Pb corrected by assuming $^{206}Pb/^{238}U$–$^{207}Pb/^{235}U$ age-concordance
(3) The degree of discordance for an analyzed spot indicates the chronological difference between the two ages determined by Pb–Pb and U–Pb methods, and is defined as $\{1-(^{238}U/^{206}Pb^*\ \text{age})/(^{207}Pb^*/^{206}Pb^*\ \text{age})\} \times 100$ (%) (e.g., Song *et al.*, 1996).

indicates 98.0 ± 1.2 Ma (MSWD = 1.63, Fig. 5E).

GJM1: Gyojamisaki plutonic complex

The sample was collected from a quarry, southeastern part of the Kunisaki City, Oita Prefecture (lat: N 33°26′55.6″, long: E 131°40′16.6″). This is a medium-grained weathered granite. The registration number is 138244.

Most of zircon grains are partly rounded and are 140 to 220 μm in length with elongation ratios of 1.7 to 3.3. CL images of the grains are relatively bright with distinct oscillatory and/or sector zoning. 31 spots from 30 grains were analyzed and 28 data were concordant. Concordant data indicate 105–116 Ma. After 2 older data were excluded, the weighted mean age of 26 data indicates 108.0 ± 0.9 Ma (MSWD = 2.18, Fig. 5F).

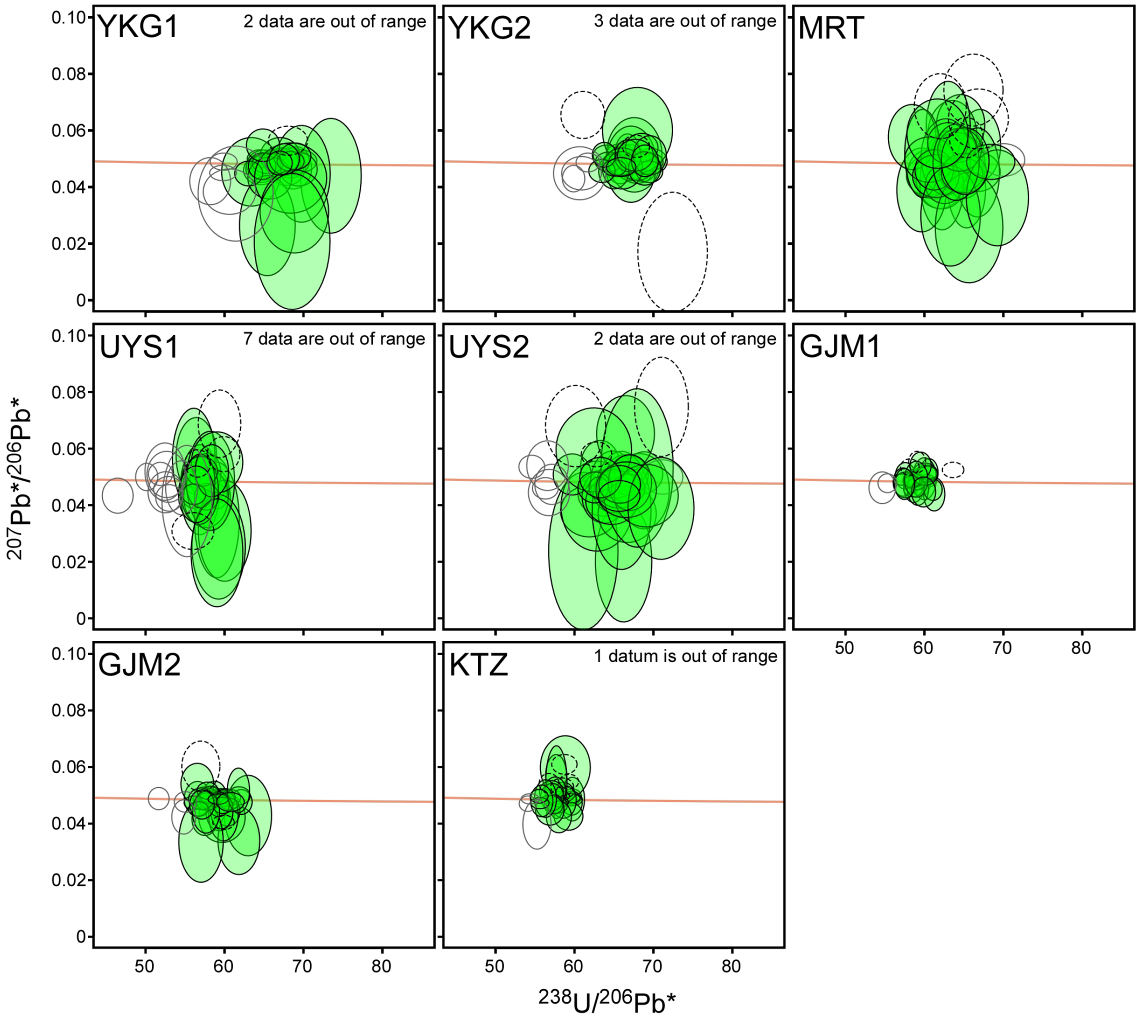

Fig. 4. Tera-Wasserberg U–Pb concordia diagrams of zircons from the samples. Error ellipses are 68.3% conf. Solid ellipses: concordant data; broken ellipses: discordant data; filled ellipses: used for age calculation.

GJM2: Gyojamisaki plutonic complex

The sample was collected from eastern coast of Kunisaki Peninsula, near the Oita airport (lat: N 33°29′33.0″, long: E 131°43′48.8″). This is a coarse-grained biotite granite. The major minerals of this rock are plagioclase, quartz, alkali feldspar and biotite. Plagioclase occurs as euhedral to subhedral crystal and exhibits indistinct albite twin and oscillatory zoning. Undulatory extinction is observed in quartz. Opaque minerals are common accessory minerals. The registration number is 138245.

Most of zircon grains are prismatic and are 140 to 280 μm in length with elongation ratios of 1.4 to 3.0. CL images of the grains are relatively bright with distinct oscillatory zoning. 44 spots from 39 grains were analyzed and 42 data are concordant. Concordant data indicate 102–117 Ma and 124 Ma. After 3 older data were excluded, the weighted mean age of 39 data indicates 108.2 ± 1.0 Ma (MSWD = 2.98, Fig. 5G).

KTZ: Kurotsuzaki area

The sample was collected from eastern coast of Kunisaki Peninsula, north of the Oita airport (lat: N 33°32′34.0″, long: E 131°44′40.0″). This is a medium grained biotite granite. The major minerals of this rock are plagioclase, quartz, alkali feldspar and biotite. Plagioclase occurs as euhedral to subhedral crystal and exhibits indistinct albite twin and oscillatory zoning. Undulatory extinction is observed in quartz. Opaque minerals are common accessory minerals. The registration number is 138246.

Most of zircon grains are prismatic and are 120 to

300 μm in length with elongation ratios of 2.1 to 5.0. CL images of the grains are relatively bright with distinct oscillatory zoning. 33 spots from 31 grains were analyzed and 28 data are concordant. Concordant data indicate 107–118 Ma and 171 Ma. After 4 older data were excluded, the weighted mean age of 24 data indicates 110.2 ± 1.1 Ma (MSWD = 2.26, Fig. 5H).

Discussion

Formation age of the granitoids in the Kunisaki district

Zircon U–Pb age is commonly interpreted to indicate the plutonic age of granitoids because of the high closure temperature of the decay system and robust nature of the crystal. Granite samples from western part of the Kunisaki district, the Yamakunigawa, Ajimu and Ushiyashiki areas, YKG1, YKG2, MRT and USY2 indicated 95.5 ± 1.0 Ma, 95.5 ± 1.0 Ma, 100.4 ± 1.2 Ma and 98.0 ± 1.2 Ma, respectively, and the ages ranged from 96 Ma to 100 Ma. Whereas granite samples from eastern part of the district, the Gyojamisaki, Kurotsuzaki areas and granodiorite sample from the Ushiyashiki area, GJM1, GJM2, KTZ and USY1 indicated 108.0 ± 0.9 Ma, 108.2 ± 1.0 Ma, 110.2 ± 1.1 Ma and 110.8 ± 1.1 Ma, respectively, and the ages are relatively older than the ages from the western part. Both the older and younger granitoids occur in the Ushiyashiki area. The Gyojamisaki Plutonic Complex and rocks in the Kurotsuzaki area consist of both felsic granitic rocks and mafic gabbro and diorite. All mafic rocks coexist with granitic rocks as syn-plutonic dikes and mafic magmatic enclaves, strongly suggesting contemporaneous magmatism with the granitic activity. The ages of the granitic samples may also reflect the age of mafic magmatism.

Zoning of the granitoids (Murakami, 1994) together with the zircon age results, indicates that the ages of the granitoids in the Kunisaki district broadly become younger from oceanic side to continental side, from southeast to northwest. The same age trend is also observed on the western side of central to northern Kyushu (Owada et al, 1999; Tsutsumi, 2022).

Western extension of the Ryoke belt in Kyushu

The zircon U–Pb ages of granitoids in the western part of the Kunisaki district are consistent with the ages of the Yanai and Takanawa districts of the Ryoke belt where ages are 94–105 Ma (Skrzypek *et al.*, 2016), and 89–99 Ma (Shimooka *et al.*, 2019), respectively. The western part of the Kunisaki district is interpreted to be an extension of the Ryoke belt on the basis of geographic continuity, zircon age similarity and presence of high-*T* type metamorphics. The ages of the granitoids in the eastern part of the Kunisaki district are consistent with the Higo Plutonic Complex (108–113 Ma; Tsutsumi, 2022) rather than the younger Ryoke granitoids. The western extent of the Ryoke belt in Kyushu remains unclear because exposed basement rocks are scarce in central Kyusyu due to tectonic subsidence and post-Cretaceous volcaniclastic cover.

In the Chikuhi district, western side of central Kyushu, the ages of the granitoids indicate ca. 106 Ma (Miyazaki *et al.*, 2019; Tsutsumi, 2021). High-*T* type metamorphics have been recognized there. This district was interpreted to be the western extension of the Ryoke belt because of the similar metamorphic grade of the Konoha metamorphic rocks (Fujimoto and Hashimoto, 1960), but there is a possibility that the Konoha metamorphic rocks are a contact metamorphosed part of the Suo belt because the high-grade part occurs along the margin of the Tamana granodiorite (Karakida *et al.*, 1969). Hence, the attribution of the Konoha metamorphic rocks remains unresolved. The metamorphic complex in the Omuta area is not contact metamorphosed but rather is the product of regional metamorphism. Isograds are not parallel with the Tamana granodiorite, and the grade of metamorphism is similar to the metamorphic rocks in the Yanai district (Ikeda *et al.*, 2017). The metamorphic rim of a zircon grain from the metamorphic rocks indicated a concordant age of 105.1 ± 5.3 Ma (2σ) and is considered to be the age of the regional metamorphism (Miyazaki *et al.*, 2017). Miyazaki *et al.* (2017) proposed that the Omuta area is the western extension of the Ryoke belt in the western side of Kyushu based on nature of the metamorphics, geographic direction and age similarity. However, regional metamorphism in the Yanai district occurred from 100 to 94 Ma (Skrzypek *et al.*, 2016),

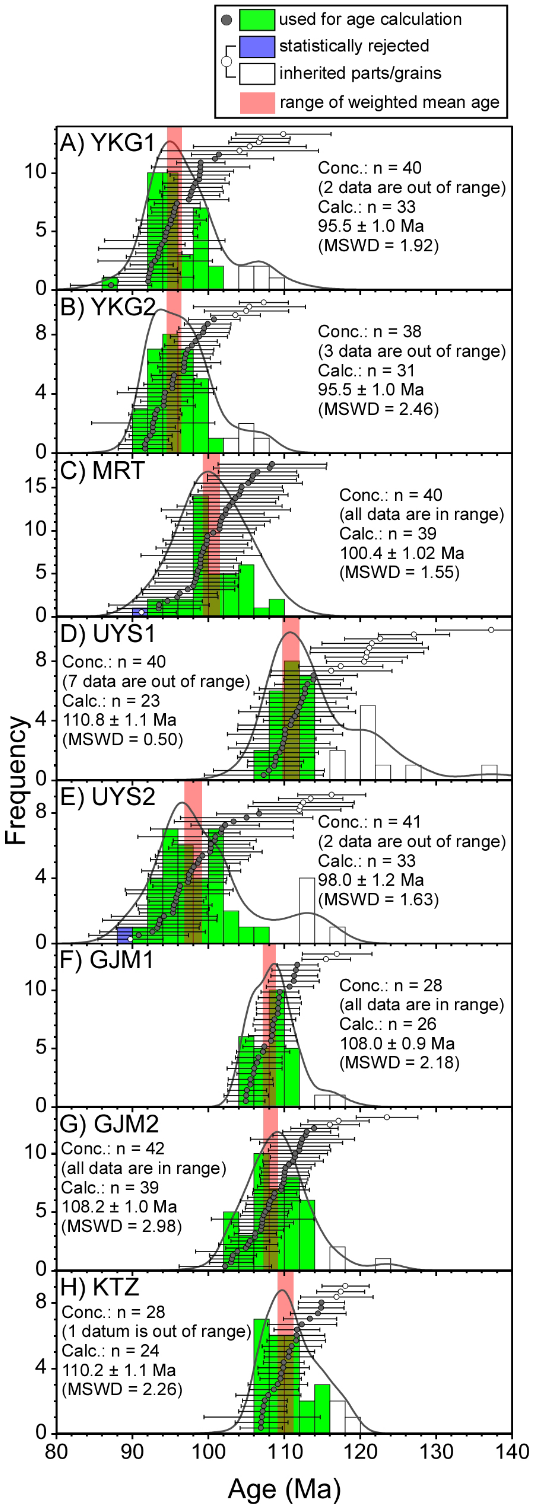

Fig. 5. Probability distribution diagrams, histograms and age scatter plots of zircon ages from the samples. Conc.: concordant, Calc.: used for age calculation.

5 Myr younger than the Omuta district. Therefore, the Ryoke belt in the western side of the central Kyushu is still not confirmed.

Difference of zircon U–Pb ages and the other radiometric ages

New zircon ages of this study and most zircon ages previously reported from Kyushu granitoids are older than published K–Ar ages (Tsutsumi, 2021, 2022; Tsutsumi and Tani, 2022, and references therein). Re-examination of K–Ar ages of granitoids in Kyushu may be necessary (Tsutsumi and Tani, 2022). Here we consider why zircon U–Pb ages and WRI RB–Sr ages are different.

The WRI Rb–Sr age obtained by analyzing various plutonic rock samples from all over the Gyojamisaki and Kurotsuzaki areas is 142.2 ± 2.1 Ma (2σ, Osanai *et al.*, 1993). This is far older than zircon ages of this study. WRI Rb–Sr ages are obtained using samples which although lithologically similar, may not all be the same age. For example, although the WRI Rb–Sr age of the Itoshima granodiorite in northern Kyushu indicated 116 ± 17 Ma (2σ, Owada *et al.*, 1999), the zircon U–Pb ages from northwestern, central and southeastern part of the Itoshima granodiorite indicated 102 ± 2 Ma (2σ, Adachi *et al.*, 2012), 105.6 ± 1.5 Ma and 97.9 ± 1.7 Ma (95% conf., Miyazaki *et al.*, 2019), respectively. Because the ages of the Itoshima granodiorite vary between sampling locations, the Rb–Sr "isochron" is a pseudo-isochron. Therefore, isochrons which are obtained from the isotopic data of multiple samples from a granitoid body that are assumed to be part of the same magmatic event based on lithology alone, are unreliable. Future zircon U–Pb chronological studies may reveal further discords between WRI ages using multiple samples and individual sample zircon U–Pb ages.

Conclusions

Eight new zircon U–Pb ages of granitoids in the Kunisaki district, eastern part of northern Kyushu, are presented; the ages in western part of the district ranged from 96 Ma to 100 Ma while the ages in eastern part of the district ranged from 108 Ma to 110 Ma. These granitoids correspond to the Ryoke belt and the Higo Plutonic Complex, respectively. The granitoids in the district broadly become younger from oceanic side to continental side as well as the western side of central to northern

Table 2. Summary of localities and weighted mean ages of each sample.

Sample name	Rock body	Reg. No.[1)]	Rock type	Locality	n of data			Age	
					All	Conc.	Calc.		MSWD
YKG1	Yamakunigawa	138218	weathered granite	N33°33′20.1″ E131°09′57.1″	41	40	33	95.5 ± 1.0	1.92
YKG2	Yamakunigawa	138219	biotite granite	N33°31′34.0″ E131°10′00.3″	41	38	31	95.5 ± 1.0	2.46
MRT	Maruta	138220	weathered granite	N33°21′14.0″ E131°23′55.9″	44	40	39	100.4 ± 1.2	1.55
UYS1	Ushiyashiki	138241	biotite granodiorite	N33°27′59.3″ E131°30′42.6″	44	40	23	110.8 ± 1.1	0.50
UYS2	Ushiyashiki	138243	two mica granite	N 33°28′12.1″ E 131°31′26.1″	44	41	33	98.0 ± 1.2	1.63
GJM1	Gyojamisaki	138244	weathered granite	N33°26′55.6″ E131°40′16.6″	31	28	26	108.0 ± 0.9	2.18
GJM2	Gyojamisaki	138245	biotite granite	N33°29′33.0″ E131°43′48.8″	44	42	39	108.2 ± 1.0	2.98
KTZ	Kurotsuzaki	138246	biotite granite	N33°32′34.0″ E131°44′40.0″	33	28	24	110.2 ± 1.1	2.26

Age errors are 95% conf.; Conc.: concordant, Calc.: used for age calculation.
[1)] The redistration number of rock specimen in the collection database of the National Museum of Nature and Science (http://db.kahaku.go.jp/webmuseum_en/).

Kyushu. It is confirmed that the Ryoke belt extends to the eastern side of Kyushu, but remains unclear how far the Ryoke belt extends in Kyushu.

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