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SHRIMP Dating of Detrital Zircons from the Sangun-Renge Belt of Sangun Metamorphic Rocks, Northern Kyushu, Southwest Japan

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Abstract Radiometric ages of detrital zircons from two psammitic schists from the Sangun-Renge Belt in northern Kyushu were obtained from $^{238}U/^{206}Pb$ ratio and isotopic compositions of Pb using a sensitive high resolution ion microprobe (SHRIMP II). The zircons show a main age cluster around the early to middle Paleozoic, with a few zircons that are older. The main provenances of the detrital zircons were formed during the Caledonian event. The youngest zircon ages of the samples from the Nokonoshima (NK) and Sangun (SG) areas indicate the Middle Paleozoic era, 430±22 Ma and 391±10 Ma, respectively. The white mica ages were reported around 300 Ma from the SG area. The older zircon ages in the sample from NK were obtained from two grains approximately 1800 Ma and two grains approximately 630–620 Ma, whereas, in the sample from SG, the zircon ages vary: 2700, 1880, 950, 800, and 620 Ma. These results imply that the detrital zircons in the Sangun-Renge Belt were derived mainly from the Caledonian orogenic belt on the South China Craton, and accretionary complexes of 'proto-Japan' began to grow beside the South China Craton during the Early to Middle Paleozoic era.

Key words: Sangun-Renge Belt, provenance, South China, detrital zircon, U–Pb age

Introduction

The Sangun Metamorphic Belt is one of the high pressure type metamorphic belts in Japan and was formed in the Late Paleozoic to Early Mesozoic. The Sangun Metamorphic Belt along with the Hida Metamorphic Belt were once considered to be paired metamorphic belts (Miyashiro, 1961). The result of some geotectonic (*e.g.*, Hara *et al.*, 1985; Hayasaka, 1987) and geochronological (Shibata and Nishimura, 1989 and references therein) studies brought up that Sangun Metamorphic Rocks are consist of several metamorphic belts with different metamorphic ages, including the Sangun-Renge Belt (ca. 300 Ma), Suo Belt (ca. 220 Ma), and Chizu Belt (ca. 180 Ma) (Shibata and Nishimura, 1989). Although older high P/T type metamorphic rocks have been found (*e.g.*, Kawamura *et al.*, 2007), they are very small bodies or tectonic blocks of serpentinite mélange. The Sangun-Renge Belt is scattered across southwest Japan and occurs as several km-size bodies in the Omi and Fukuoka areas. Some Paleozoic ages determined by white mica K–Ar and/or the Rb–Sr method were reported based on data from the high pressure type metamorphic rocks in southwest Japan, including the Sangun-Renge Belt (Shibata and Nishimura, 1989; Kunugiza *et al.*, 2004), parts of the Kurosegawa Belt (Ueda *et al.*, 1980), Joetsu Belt (Yokoyama, 1992), and the Kiyama Metamorphic Rocks (Ishizaka, 1972; Kabashima *et al.*, 1995). These belts or bodies are thought to have been formed at the accretionary complex in "proto-Japan" during the Paleozoic era.

To clarify the accretionary age of the parent sediments of the schists from the Paleozoic high-P/T metamorphic rocks in northern Kyushu, we investigated detrital zircons from two schist samples and measured their U–Pb ages using SHRIMP II equipment installed at Hiroshima University, Japan. The Pb closure temperature for the Pb–U–Th isotopic system in zircon is ~900°C for a diffusion radius of 100 μm at geologically reasonable cooling rates (Lee *et al.*, 1997; Cherniak and Watson, 2000) and the system usually remains closed under low- to medium-grade metamorphism. Therefore, the ages of detrital zircons in these rocks will not have been significantly disturbed during metamorphism and should provide information on the upper limit of the accretionary age and provenance of the parent sediments of these rocks.

Geological Setting

The Sangun-Renge Belt in the Fukuoka area in northern Kyushu, is one of the largest mass of Paleozoic metamorphic rocks in Japan. It is located around Hakata Bay (Fukuoka area; Fig. 1). The belt is separated by sedimentary covers and granitic intrusions into three terranes: the Sangun, Seburi, and Itoshima–Nokonoshima areas (Karakida *et al.*, 1969). The two samples were collected from the Sangun (SG) area and Nokonashima Island (NK) in the Itoshima–Nokonoshima area. The SG area consists mainly of greenschist, metabasite, and serpentinite with subordinate amounts of pelitic and siliceous schists (Tsuji, 1964). Psammitic schist is rare in the area. White mica K–Ar and Rb–Sr ages of this area are 259±6 Ma (K–Ar), 272±8 Ma (K–Ar), and 298±12 Ma (Rb–Sr), but there is a possibility that these ages are rejuvenated by the effect of contact metamorphism with the Cretaceous Kitasaki granodiorite (Shibata and Nishimura, 1989). The metamorphic rocks on Nokonoshima Island (NK) consist mainly of psammitic schist and greenschist. They clearly suffered contact metamorphism caused by contact with the Kitasaki granodiorite; Karakida (1965) classified the contact metamorphism around the sampling point as Zone II (green hornblende, actinolite, and epidote are observed in greenschist). No metamorphic age was reported from NK due to the strong contact metamorphism effect.

Samples and Analytical Method

The two psammitic schist samples were labeled NK and SG (sample locations are shown in Fig. 2). The sample NK was collected from Nokonoshima Island. SG was from the northern

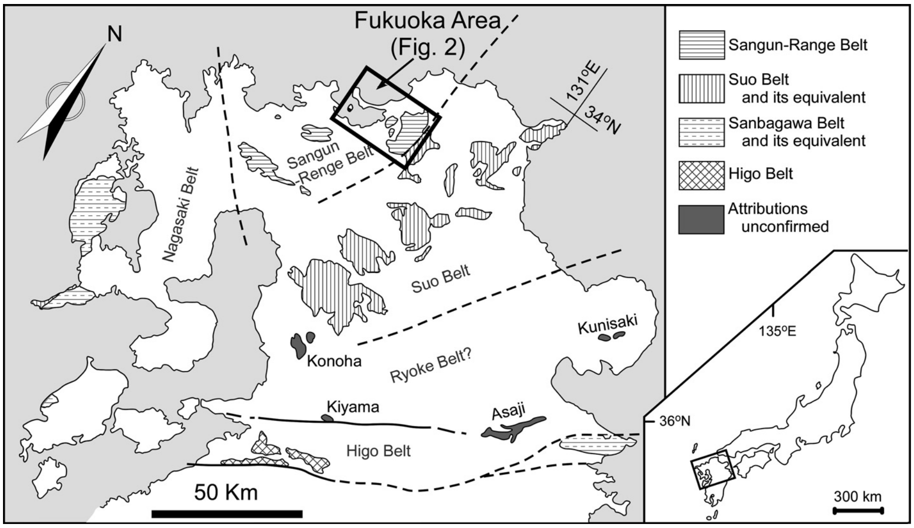

Fig. 1. Generalized tectonic map with distribution of metamorphic rocks on northern Kyushu.

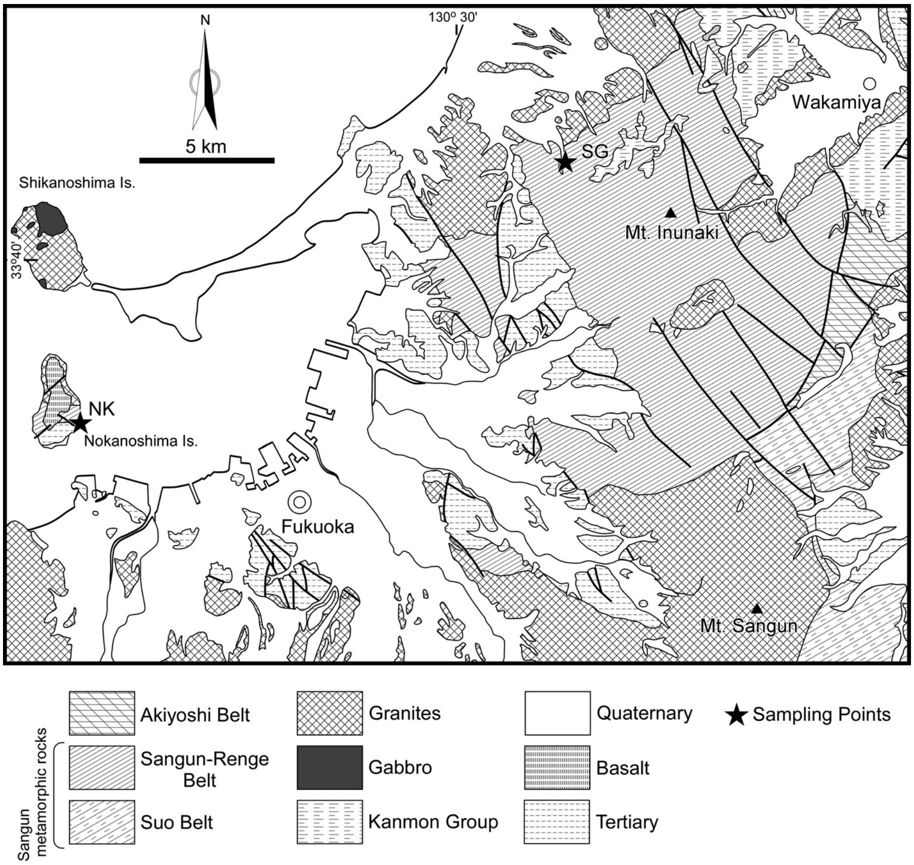

Fig. 2. Geological map of Fukuoka area, showing sample locations.

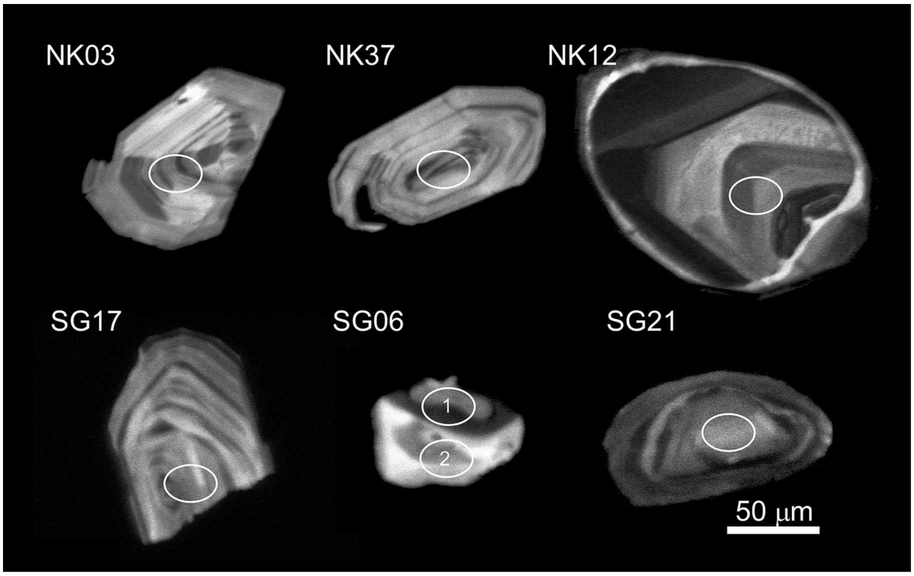

Fig. 3. Cathodoluminescence images (CL) of typical and characteristic zircon grains. Scale bars are 20 μm across. Eclipses on the images point to analyzed spots by SHRIMP.

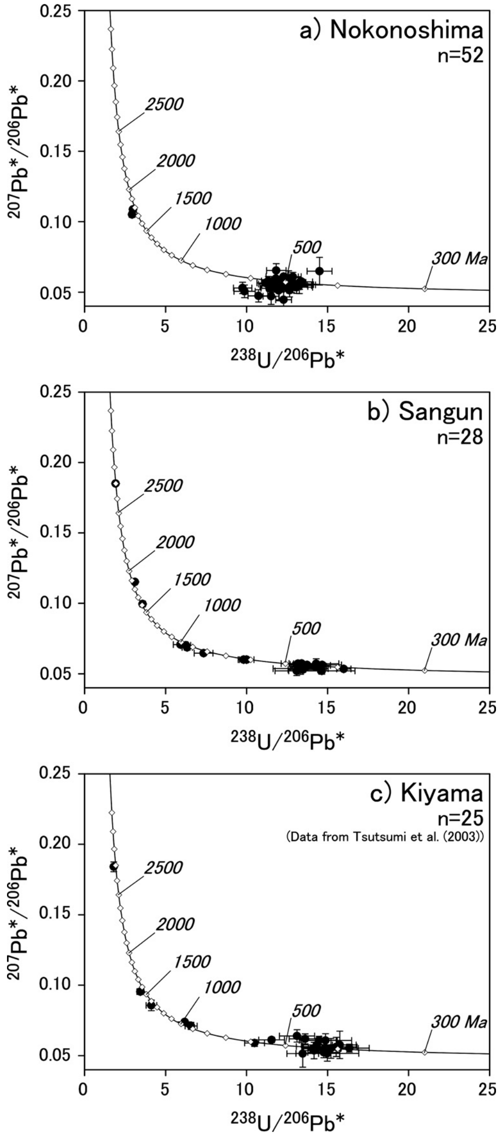

Fig. 4. Tera-Wasserberg U–Pb concordia diagrams of zircons from the samples NK (a), SG (b) and Kiyama (c; data from Tsutsumi *et al.*, 2003). ^{207}Pb* and ^{206}Pb* indicate radiometric ^{207}Pb and ^{206}Pb, respectively. Solid curve indicates concordia curve.

part of the SG area.

The zircon grains were separated from the samples by standard crushing and heavy-liquid techniques and then handpicked for purification purposes. The abundance of the zircons in these rock samples was found to be approximately 20 to 50 grains per kilogram. Most of the zircon grains in the samples had diameters of around 100 to 200 μm (Fig. 3). Zircon grains from the samples and the zircon standard AS3, the ID-TIMS ^{238}U–^{206}Pb* age of which is 1099.1 ± 0.5 Ma (Paces and Miller, 1993), were mounted in an epoxy resin and polished until the surface was flattened with the center of the embedded grains exposed. U–Pb dating of these samples was carried out using the SHRIMP II equipment installed at Hiroshima University, Japan. The experimental procedures followed for the measurements were the same as those reported by Williams (1998) and Sano *et al.* (2000). The spot size of the primary ion beam was approximately 25 μm. Both the backscattered electron images and cathodoluminescence images were used to select the sites for SHRIMP analysis. The ^{206}Pb/^{238}U elemental ratios of the samples were calibrated using the empirical relationship described by Claoué-Long *et al.* (1995). The concentration of U and Th in each analyzed spot was calibrated against an external standard SL13, which has a U content of 238 ppm (*e.g.*, Claoué-Long *et al.*, 1995). The measured ^{204}Pb was used for the correction of initial Pb, whose isotopic composition was assumed using a single-stage model (Compston *et al.*, 1984).

Result

Table 1 lists zircon data in terms of ^{204}Pb/^{206}Pb, ^{207}Pb/^{206}Pb, ^{238}U/^{206}Pb, and Th/U ratios and radiometric ^{238}U/^{206}Pb* and ^{207}Pb*/^{206}Pb* ages. All errors are stated at 1 sigma. Sub-numbered labels such as SG01.1 and SG01.2 in Table 1 indicate different pit positions in a single grain. Figure 4 and Figure 5 show Tera–Wasserberg concordia diagrams and probability distribution diagrams of ^{238}U/^{206}Pb ages ranging from 800 to 200 Ma for the samples, respectively. Almost all zircons in the samples show oscillatory zoning on backscattered electron and/or cathodoluminescence images which is commonly observed in igneous zircons (Corfu *et al.* 2003), and their Th/U ratios (>0.1) also support that they are ig-

Table 1. SHRIMP U–Pb data and calculated ages.

Labels	^{204}Pb/^{206}Pb	^{207}Pb/^{206}Pb	^{238}U/^{206}Pb (ppm)	U (ppm)	Th	Th/U (Ma)	^{238}U-^{206}Pb age (Ma)	^{207}Pb*/^{206}Pb* age
Sample from Nokonoshima area (NK)								
NK.01.1	0.000485 ± 0.000300	0.0617 ± 0.0030	13.14 ± 0.74	230	131	0.57	468.7 ± 25.5	
NK.02.1	0.000326 ± 0.000249	0.0588 ± 0.0017	12.71 ± 0.99	323	89	0.28	485.6 ± 36.5	
NK.03.1	0.000403 ± 0.000258	0.0593 ± 0.0015	12.99 ± 0.97	241	112	0.47	474.7 ± 34.4	
NK.04.1	0.000201 ± 0.000139	0.0610 ± 0.0012	12.40 ± 0.89	191	127	0.67	498.2 ± 34.6	
NK.05.1	0.000225 ± 0.000174	0.0585 ± 0.0018	12.40 ± 0.98	199	109	0.55	468.5 ± 33.5	
NK.06.1	0.000019 ± 0.000020	0.0555 ± 0.0014	12.40 ± 1.00	510	333	0.65	473.3 ± 34.6	
NK.07.1	0.000034 ± 0.000031	0.0563 ± 0.0010	12.40 ± 0.62	657	524	0.80	544.1 ± 28.5	
NK.08.1	0.000283 ± 0.000121	0.0591 ± 0.0010	12.40 ± 0.37	200	162	0.81	530.6 ± 16.2	
NK.09.1	0.000113 ± 0.000083	0.0626 ± 0.0013	12.40 ± 1.08	202	87	0.43	504.5 ± 42.9	
NK.10.1	0.000996 ± 0.000274	0.0659 ± 0.0015	12.40 ± 0.15	398	193	0.49	490.5 ± 6.3	
NK.11.1	0.000309 ± 0.000129	0.0582 ± 0.0013	12.40 ± 0.39	457	279	0.61	479.5 ± 14.2	
NK.12.1	0.000007 ± 0.000021	0.1089 ± 0.0006	12.40 ± 0.10	588	135	0.23	1863 ± 54	1779 ± 11
NK.13.1	0.000649 ± 0.000273	0.0656 ± 0.0021	12.40 ± 0.60	204	131	0.64	486.1 ± 22.5	
NK.14.1	0.000334 ± 0.000174	0.0580 ± 0.0014	12.40 ± 0.66	219	125	0.57	510.2 ± 27.0	
NK.15.1	0.000003 ± 0.000011	0.0596 ± 0.0008	12.40 ± 0.31	494	270	0.55	501.7 ± 12.0	
NK.16.1	0.000475 ± 0.000265	0.0637 ± 0.0020	12.40 ± 0.44	125	75	0.60	489.6 ± 16.8	
NK.17.1	0.000037 ± 0.000046	0.0585 ± 0.0011	12.40 ± 0.54	541	423	0.78	515.3 ± 22.2	
NK.18.1	0.000829 ± 0.000211	0.0687 ± 0.0010	12.40 ± 0.54	444	224	0.51	528.3 ± 23.9	
NK.19.1	0.000363 ± 0.000185	0.0589 ± 0.0013	12.40 ± 0.42	309	171	0.55	495.1 ± 16.3	
NK.20.1	0.000451 ± 0.000194	0.0618 ± 0.0012	12.40 ± 0.38	270	167	0.62	484.2 ± 13.9	
NK.21.1	0.000027 ± 0.000124	0.0563 ± 0.0013	12.40 ± 0.33	342	288	0.84	521.2 ± 14.0	
NK.22.1	0.000013 ± 0.000111	0.0579 ± 0.0015	12.40 ± 0.32	196	107	0.55	494.3 ± 12.0	
NK.23.1	0.000018 ± 0.000059	0.0571 ± 0.0021	12.40 ± 0.37	228	104	0.46	467.5 ± 12.4	
NK.24.1	0.000078 ± 0.000054	0.0585 ± 0.0010	12.40 ± 0.65	632	435	0.69	463.2 ± 21.7	
NK.25.1	0.000217 ± 0.000142	0.0592 ± 0.0012	12.40 ± 0.44	242	113	0.47	522.3 ± 18.6	
NK.26.1	0.000191 ± 0.000132	0.0581 ± 0.0012	12.40 ± 0.80	353	186	0.53	480.4 ± 28.9	
NK.27.1	0.000052 ± 0.000040	0.0558 ± 0.0015	12.40 ± 0.37	172	91	0.53	521.2 ± 15.6	
NK.28.1	0.000224 ± 0.000128	0.0560 ± 0.0009	12.40 ± 0.53	306	213	0.70	541.2 ± 24.4	
NK.29.1	0.000575 ± 0.000316	0.0679 ± 0.0024	12.40 ± 0.60	155	76	0.49	524.0 ± 25.8	
NK.30.1	0.000343 ± 0.000162	0.0592 ± 0.0013	12.40 ± 0.25	180	82	0.45	530.6 ± 11.1	
NK.31.1	0.000235 ± 0.000158	0.0620 ± 0.0019	12.40 ± 0.23	219	162	0.74	491.9 ± 8.9	
NK.32.1	0.000026 ± 0.000071	0.0569 ± 0.0023	12.40 ± 0.48	141	84	0.59	515.7 ± 19.7	
NK.33.1	0.000118 ± 0.000046	0.0576 ± 0.0009	12.40 ± 0.26	1210	822	0.68	537.7 ± 11.9	
NK.34.1	0.000659 ± 0.000260	0.0602 ± 0.0018	12.40 ± 0.64	137	90	0.65	621.9 ± 39.3	
NK.35.1	0.000235 ± 0.000187	0.0613 ± 0.0014	12.40 ± 0.42	190	154	0.81	544.7 ± 19.4	
NK.37.1	0.000186 ± 0.000104	0.0570 ± 0.0012	12.40 ± 0.67	451	285	0.63	537.4 ± 30.3	
NK.38.1	0.000099 ± 0.000045	0.0571 ± 0.0010	12.40 ± 0.42	1001	473	0.47	520.9 ± 17.6	
NK.39.1	0.000200 ± 0.000064	0.0594 ± 0.0013	12.40 ± 0.51	918	1044	1.14	553.4 ± 24.4	
NK.40.1	0.001335 ± 0.000264	0.0845 ± 0.0022	12.40 ± 0.59	802	556	0.69	522.9 ± 25.6	
NK.41.1	0.000227 ± 0.000256	0.0590 ± 0.0022	12.40 ± 0.31	149	65	0.44	516.1 ± 13.0	

^{206}Pb* and ^{207} Pb* mean radiometric ^{206}Pb and ^{207}Pb, respectively. All errors are stated at 1σ.

Table 1. (Continued)

Labels	$^{204}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{238}U/^{206}Pb$ (ppm)	U (ppm)	Th	Th/U (Ma)	^{238}U-^{206}Pb age (Ma)	$^{207}Pb^*/^{206}Pb^*$ age
NK.42.1	0.000123 ± 0.000050	0.0566 ± 0.0007	12.40 ± 0.47	1862	1063	0.57	519.0 ± 19.8	
NK.43.1	0.000144 ± 0.000138	0.0630 ± 0.0021	12.40 ± 0.34	204	101	0.49	483.0 ± 12.4	
NK.44.1	0.000478 ± 0.000307	0.0667 ± 0.0022	12.40 ± 0.42	280	158	0.56	492.5 ± 16.1	
NK.46.1	0.002962 ± 0.000505	0.1076 ± 0.0041	12.40 ± 0.72	1029	628	0.61	429.7 ± 22.1	
NK.47.1	0.000069 ± 0.000055	0.0569 ± 0.0011	12.40 ± 0.38	674	276	0.41	485.5 ± 13.8	
NK.48.1	0.000997 ± 0.000401	0.0593 ± 0.0021	12.40 ± 0.47	141	57	0.40	504.5 ± 19.1	
NK.49.1	0.000002 ± 0.000004	0.1052 ± 0.0020	12.40 ± 0.17	374	164	0.44	1892 ± 98	1717 ± 34
NK.50.1	0.000317 ± 0.000420	0.0559 ± 0.0033	12.40 ± 0.67	120	51	0.42	516.7 ± 28.1	
NK.51.1	0.000320 ± 0.000171	0.0580 ± 0.0020	12.40 ± 0.49	366	175	0.48	528.6 ± 21.3	
NK.52.1	0.000584 ± 0.000249	0.0560 ± 0.0018	12.40 ± 0.65	423	222	0.53	573.8 ± 33.7	
NK.53.1	0.000373 ± 0.000236	0.0584 ± 0.0015	12.40 ± 0.57	201	112	0.56	629.1 ± 35.1	
NK.54.1	0.000288 ± 0.000169	0.0592 ± 0.0011	12.40 ± 0.60	391	236	0.60	535.3 ± 26.9	
Sample from Sangun area (SG)								
SG.01	0.000092 ± 0.000048	0.0567 ± 0.0009	12.40 ± 0.69	371	278	0.75	438.1 ± 20.7	
SG.01.2	0.000173 ± 0.000050	0.0560 ± 0.0009	12.40 ± 0.44	528	296	0.56	390.8 ± 10.4	
SG.02.1	0.000037 ± 0.000016	0.0565 ± 0.0009	12.40 ± 0.52	351	135	0.38	425.7 ± 14.7	
SG.03.1	0.000280 ± 0.000077	0.0561 ± 0.0021	12.40 ± 2.03	270	160	0.59	425.9 ± 57.6	
SG.04.1	0.000014 ± 0.000004	0.1154 ± 0.0005	12.40 ± 0.14	973	41	0.04	1797 ± 69	1883 ± 8
SG.05.1	0.000063 ± 0.000039	0.0581 ± 0.0034	12.40 ± 1.40	1254	914	0.73	435.9 ± 41.2	
SG.06.1	0.000036 ± 0.000018	0.0652 ± 0.0010	12.40 ± 0.58	370	25	0.07	822.7 ± 61.0	764 ± 33
SG.06.2	0.000050 ± 0.000021	0.0694 ± 0.0019	12.40 ± 0.32	159	66	0.42	944.9 ± 44.1	889 ± 57
SG.07.1	0.000011 ± 0.000007	0.0575 ± 0.0011	12.40 ± 0.78	231	120	0.52	464.2 ± 26.0	
SG.08.1	0.000074 ± 0.000027	0.0713 ± 0.0008	12.40 ± 0.29	235	287	1.22	956.7 ± 41.9	935 ± 28
SG.08.2	0.000078 ± 0.000013	0.0718 ± 0.0007	12.40 ± 0.45	1150	92	0.08	1006 ± 71	948 ± 20
SG.09.1	0.000164 ± 0.000034	0.0575 ± 0.0009	12.40 ± 0.77	525	371	0.71	459.3 ± 25.2	
SG.09.2	0.000111 ± 0.000054	0.0576 ± 0.0012	12.40 ± 0.59	308	157	0.51	455.9 ± 19.2	
SG.10.1	0.000237 ± 0.000078	0.0597 ± 0.0012	12.40 ± 1.19	192	78	0.40	425.3 ± 33.6	
SG.11.1	0.000054 ± 0.000024	0.0573 ± 0.0010	12.40 ± 0.50	307	139	0.45	470.9 ± 17.2	
SG.12.1	0.000132 ± 0.000075	0.0566 ± 0.0010	12.40 ± 0.50	260	158	0.61	471.4 ± 17.2	
SG.13.1	0.000010 ± 0.000005	0.0563 ± 0.0009	12.40 ± 0.43	2154	819	0.38	468.1 ± 14.6	
SG.14.1	0.000041 ± 0.000021	0.0555 ± 0.0004	12.40 ± 0.68	812	569	0.70	437.2 ± 20.3	
SG.15.1	0.000107 ± 0.000041	0.0579 ± 0.0008	12.40 ± 0.47	302	166	0.55	453.2 ± 15.0	
SG.16.1	0.000051 ± 0.000019	0.1002 ± 0.0007	12.40 ± 0.17	191	132	0.69	1586 ± 68	1615 ± 13
SG.17.1	0.000348 ± 0.000122	0.0595 ± 0.0007	12.40 ± 0.58	251	113	0.45	457.0 ± 18.9	
SG.18.1	0.000010 ± 0.000011	0.0601 ± 0.0004	12.40 ± 0.45	640	307	0.48	614.1 ± 26.3	
SG.19.1	0.000213 ± 0.000110	0.0561 ± 0.0009	12.40 ± 0.91	182	114	0.62	461.6 ± 30.2	
SG.20.1	0.000021 ± 0.000010	0.0603 ± 0.0007	12.40 ± 0.33	303	385	1.27	625.5 ± 20.0	
SG.21.1	0.000012 ± 0.000004	0.1852 ± 0.0007	12.40 ± 0.10	563	344	0.61	2703 ± 116	2699 ± 6
SG.22.1	0.000217 ± 0.000109	0.0569 ± 0.0037	12.40 ± 1.69	255	163	0.64	466.3 ± 57.2	
SG.22.2	0.000554 ± 0.000196	0.0601 ± 0.0012	12.40 ± 1.33	224	91	0.41	474.2 ± 46.9	
SG.23.1	0.000036 ± 0.000020	0.0576 ± 0.0015	12.40 ± 1.04	1065	269	0.25	471.8 ± 36.0	

$^{206}Pb^*$ and $^{207}Pb^*$ mean radiometric ^{206}Pb and ^{207}Pb, respectively. All errors are stated at 1σ.

neous in origin (Williams and Claesson, 1987; Schiøtte *et al.*, 1988; Kinny *et al.*, 1990; Hoskin and Black, 2000).

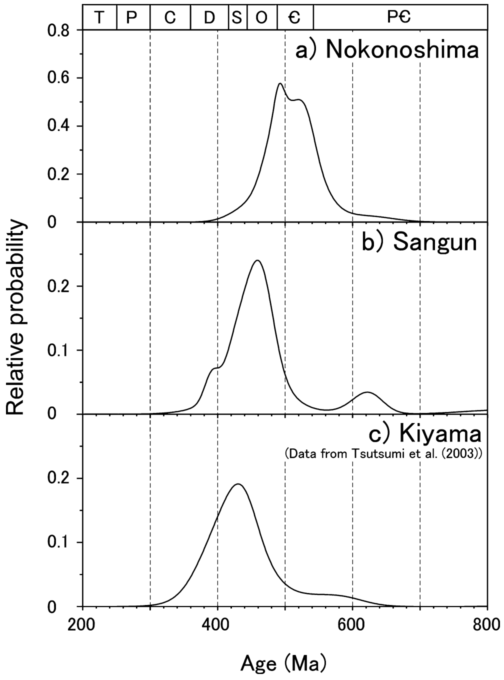

Fig. 5. Probability distribution diagrams of zircon ages (800 to 200 Ma) from samples NK (a), SG (b) and Kiyama (c; data from Tsutsumi *et al.*, 2003).

The ^{238}U–^{206}Pb ages of zircons from NK, 48 among 52 from the age data, cluster in the range of about 430 to 540 Ma. The youngest zircon is 430±22 Ma. Two of the remaining four data points were ~1800 Ma, while the last two data points were ~630 Ma (Fig. 4a). There were 28 spots analyzed in the zircons from the SG sample, with 19 spots among them scattered between 390 and 470 Ma and the youngest zircon indicate 391±10 Ma. The remaining 9 spots were 2700 (1 spot), 1880 (1 spot), 1600 (1 spot), 950 (3 spots), 800 (1 spot), and 620 (2 spots) Ma (Fig. 4b).

Discussion

Accretionary and metamorphic ages

The youngest age of detrital zircons and the white mica K–Ar age indicate the older and younger limit on accretionary age, respectively (*e.g.*, Tsutsumi *et al.*, 2009). The youngest zircon ages of this study are 430±22 Ma (NK) and 391±10 Ma (SG). There is no report on metamorphic ages from the NK area because the schists on the island clearly suffered contact metamorphism (Karakida, 1965). Shibata and Nishimura (1989) reported white mica K–Ar and Rb–Sr ages from the SG area of 259±6 Ma (K–Ar), 272±8 Ma (K–Ar), and 298±12 Ma (Rb–Sr). It is probable that the time lag between

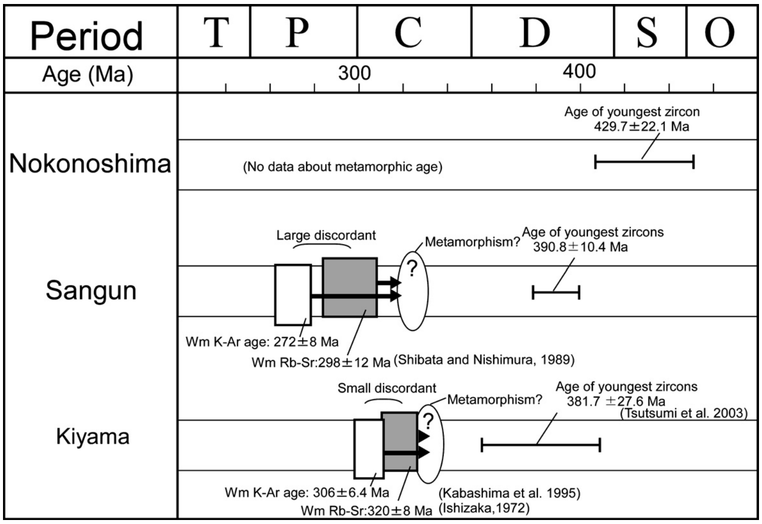

Fig. 6. Chronological summary of Sangun-Renge Belt on northern Kyushu.

the depositional and metamorphic age of SG is too long to be able to estimate the accretionary ages. There is a possibility that 'new' zircon was not transported from the provenances, because magmatism in eastern Asia was not active from 400 to 300 Ma as evidenced from age histograms of China (Wang, 1986) and Korea (Lee, 1987). Even though we admit that this method is not very effective, the youngest zircon ages and white mica ages in this study indicate older and younger limits on accretionary ages.

Another possibility is the rejuvenation of the white mica age. The closure temperature of Rb–Sr and K–Ar systems in white mica are estimated to be around 500°C and 350°C, respectively (*e.g.* Wagner *et al*., 1977). When white mica in a metamorphic rock is affected by the thermal effect after formation, the K–Ar age method is affected more easily than the Rb–Sr age method in the white mica (Shibata and Nishimura, 1989). Actually, the ages 272±8 Ma (K–Ar) and 298±12 Ma (Rb–Sr) are from the same sample. Although biotite formed by contact metamorphism was not observed in the sample (Shibata and Nishimura, 1989), the age result demonstrates that the absence of biotite is not sufficient to explain the absence of rejuvenated white mica K–Ar and/or Rb–Sr ages. Hence, it is probable that white mica ages quoted in this study cannot restrict the younger limit of depositional age effectively.

In the outer zone of southwest Japan, plutonic intrusions are scarcely observed and extensive contact metamorphism has not been described. The Sanbagawa Belt is a good example for setting a younger limit on depositional age using white mica K–Ar ages (Tsutsumi *et al*., 2009). On the other hand, there are many extensive plutonic intrusions in the inner zone of southwest Japan, and the primary structure of accretionary complexes and metamorphic rocks are thought to remain only as thin roof pendants (*e.g.*, Isozaki *et al*., 2010). The SG area is also surrounded by Cretaceous granites on a geologic map (Fig. 2). Therefore, we should treat white mica ages from pre-Cretaceous rocks in the inner zone of southwest Japan carefully to avoid the effect of rejuvenation.

Provenance of the clastics

Cambrian to Silurian zircons were abundant in the NK sample, 48 of the 52 spots/grains, whereas Ordovician to Devonian zircons were abundant in the SG sample, 19 of the 28 spots (16 of 23 grains). These results indicate that the main provenance of the clastics in the Sangun-Renge Belt was igneous rocks formed during the Caledonian stage. Caledonian detrital monazites are common in river sands from the major rivers of China (Yokoyama *et al*., 2007). The main age populations of zircon in the NK and SG samples are 510 Ma and 460 Ma, respectively (Fig. 5).

Although Paleoproterozoic to Archean detrital zircons are common in Japan (*e.g.*, Tsutsumi *et al*., 2003), they are not common in the samples of this study. Such old detrital zircons are commonly thought to be derived from the North China Craton (*e.g.*, Tsutsumi *et al*., 2003) where ages concentrate between 2600–2400 Ma and 2000–1750 Ma (Zhao *et al*., 2001). But the South China Craton also has rocks similar in age (*e.g.* Qiu *et al*., 2000) and detrital zircon age data show some Paleoproterozoic to Archean peaks (Xu *et al*., 2007 and references therein). Some of the old zircons in the SG sample, with ages of 950, 800, and 620 Ma are scarce in the North China Craton. Especially, the ∼800 Ma age is remarkable; there is a wide range of ages corresponding to the breakup of the Rodinia supercontinent on the South China Craton (ca. 840–740 Ma; Li *et al*., 2003). Although there is not no report of the ∼800 Ma ages on the North China Craton, these are scarce there. Therefore, it is reasonable to be considered that zircons in the SG sample were derived from the South China Craton. The North and South China cratons amalgamated during the Triassic (ca. 220 Ma) collision event (*e.g.*, Li *et al*., 1993), and they isolated from each other during the Carboniferous period (359 to 299 Ma). Zircons around 500 Ma, the main age cluster of the NK sample, are also scarce in the North China Craton but exist on the South China Craton (Rino *et al*., 2008), on the Khanka Block (Khanchuk *et al*., 1996) and on the Jiamusi Block (Wilde *et al*., 2000; 2003). Supposing continuity of locality between SG and NK, it is reasonable that the clastics in the NK sample were also derived from the South China Craton. Taking the above together, it is considered that the provenance of the zircons in the Sangun-Renge Belt was the Caledonian orogenic belt on the South China Craton. Accretionary complexes of the Japanese Islands are thought to have begun to grow beside the South China Craton during the Early Paleozoic era (*e.g.* Isozaki and Maruyama, 1991). The results of this study support this hypothesis.

Accretionary complexes of the Shikhote-Alin district in eastern Russia are thought to correspond to the Shimanto and Mino-Tamba belts (*e.g.* Yamakita and Otoh, 2000). Age analyzes of detrital monazite signify that sandstones of the Maizuru Belt in central Japan and sediment in the Abrek Bay area in eastern Russia have similar deposition age and provenance containing a ~500 Ma peak (Yokoyama *et al*., 2009). Detrital zircon data of the Maizuru Belt also have the same peak (Nakama *et al*., 2010). It is probable that these ~500 Ma detrital materials in Permian to Triassic sediments were derived from the Khanka and/or Jiamusi blocks, which is different from the results of this study.

Relation of the other Paleozoic metamorphic rocks

The Kiyama Metamorphic Rocks in central Kyushu, yield white mica K–Ar ages of ~300 Ma (Kabashima *et al*., 1995) and the white mica Rb–Sr isochron age of 320±8 Ma (Ishizaka, 1972). There is also a possibility that the white mica K–Ar and Rb–Sr ages rejuvenate. Moreover, the main age peak of detrital zircons show 470 to 380 Ma and the youngest age is 382±28 Ma (Tsutsumi *et al*., 2003; Fig. 6). Considering that the white mica ages, the main age peak of detrital zircons, and the youngest zircon age of Kiyama Metamophic Rocks resemble the data of SG, the Kiyama Metamorphic Rocks are thought to be a kind of klippe of the Sangun-Renge Belt.

The age distribution of the Sangun-Renge Belt on NK is clearly older than that on the SG area. It seems that the schist on the NK area corresponds to older high P/T type metamorphic units. In northeast Japan, ~300 Ma and ~380 Ma high P/T type metamorphic rocks are recognized: Matsugataira-Motai Metamorphic Rocks (*e.g.*, Kawano and Ueda, 1965) and the Nedamo Complex (Kawamura *et al*., 2007), respectively. There is a possibility the schists on NK and the SG area correspond to the schists on the Nedamo Complex and Matsugataira-Motai Metamorphic Rocks, respectively. Unfortunately, there is no sufficient age datum at present to make a clear correlation between them.

Conclusion

1. The older limit of accretionary ages of the Nokonoshima (NK) and Sangun (SG) areas estimated from the youngest age of detrital zircon are ~430 Ma and ~390 Ma, respectively. The younger limit on accretionary age of the SG area is ~300 Ma which is from white mica K–Ar and Rb–Sr ages.
2. The reason for the large time lag between younger and older limits on the accretionary age of the SG sample is thought to be as follows: One is that the youngest zircons cannot restrict the older limit of the deposition ages effectively because 'new' zircons were not transported from the provenances and because of the small number of analyzed zircons. Another is that white mica K–Ar and Rb–Sr ages were rejuvenated by the thermal effect from the surrounding Cretaceous granites.
3. Regarding the age distribution of detrital zircons, it is considered that provenances of the zircons were the Caledonian orogenic belt on the South China Craton, which contrasts with the ~500 Ma detrital materials from the Permian to Triassic sediments in Japan and eastern Russia. The latter are thought to be derived from the Khanka and/or Jiamusi blocks.

4. Considering the age data and horizontal structure of the Japanese Islands, the Kiyama Metamorphic Rocks are thought to be a klippe corresponding to the Sangun-Renge Belt. Moreover, there is a possibility that the Sangun-Renge belt has a close relationship with the Paleozoic high P/T type metamorphics in northeast Japan.

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