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Chemical contrast of the Late Cretaceous granitoids of the Sanyo and Ryoke Belts, Southwest Japan: Okayama-Kagawa Transect

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Abstract: Late Cretaceous granitoids (41 samples) and gabbroids (6 samples) of the Inner Zone of SW Japan are studied chemically and microscopically in the southern Okayama - Kagawa Prefectures. The plutonic rocks are divided into the Sanyo Belt at north and the Ryoke Belt at south by distribution of the Ryoke metamorphic rocks and tungsten deposits. The former is composed of coarse- to medium-grained, massive granodiorite to monzogranite of batholithic units, which often contain pink K-feldspar, and fine-grained granitoids of various composition. The latter consists of coarse- to medium-grained, massive or stressed granodiorite to monzogranite of batholithic units, and fine-grained biotite monzogranite stocks of Aji granitoids.

As compared with the Ryoke granitoids, the Sanyo granitoids are higher in silica and alkali contents, especially of K_2O, and poorer in Al_2O_3 and lower in alumina saturation index (ASI). Rb is also rich in the Sanyo granitoids, particularly of muscovite-biotite leucogranite, and poor in the Aji (hornblende-)biotite granitoids. Sr contents show a reverse correlation with Rb. Therefore the Rb/Sr ratio is the highest in the leucogranite (~39) and lowest in the Aji granitoids (0.2). The Rb/Sr ratio implies degree of mgmatic fractionation. The fractionated leucogranite is also high in trace amount of Y, W, Sn, U, Th, Ta and Nb; many of these elements are concentrated in the surrounding ore deposits.

Chondrite normalized REE patterns can be grouped into (1) those with intermediate values on LREE, which become low from Eu to HREE; observed on the Sanyo granitoids and Ryoke granitoids, (2) those having higher values in all the elements than (1) with moderate Eu anomalies; observed typically on the pink Mannari Granite, and (3) flat pattern rich in HREE with strong Eu anomalies, observed not on the Aji Granite but on the fractionated leucogranite. The first pattern can be explained by the presence of garnet and amphibole in the protolith; the third pattern may be due to plagioclase fractionation.

The Ryoke granitoids, the Aji granitoids and garnet-muscovite-biotite granite in particular, have higher ASI and $\delta^{18}O$ value but lower K_2O content than the Sanyo granitoids, implying higher percentage of sedimentary rocks without abundant illites incorporated in the protolith, although both belong to magnetite-free, ilmenite series. Bulk compositions of the Ryoke granitoids are more mafic than the Sanyo granitoids. Mafic igneous rocks are rare in the Sanyo Belt, but are common in the Ryoke Belt where magma mingling and mixing textures are observed at many places. The mafic magmas injection from the upper mantle have occurred almost continuously in the Ryoke Belt during the granitic magmatism, an early phase of which resulted in the regional metamorphism of the Ryoke Belt, and also mingling and mixing of the mafic magmas from depth and felsic magmas from the crust made the bulk composition more mafic in the Ryoke Belt than in the Sanyo Belt.

Keywords: Late Cretaceous, granitoids, ilmenite series, major chemistry, trace elements, REE pattern, $\delta^{18}O$ value

1. Introduction

Late Cretaceous granitoids of the Sanyo and Ryoke Belts in the Inner Zone of Southwest Japan belong to ilmenite series. Major differences between two belts have been considered to be not chemical but physical in the Chubu District, and depth of the emplacements is thought also different, being epizonal in the Sanyo Belt while katazonal in the Ryoke Belt (Ishihara and Terashima, 1977).

In the southern Okayama-Kagawa region of the eastern Chugoku-Shikoku District, which is about 320 km west of the Chubu District, the late Cretaceous granitoids are often massive even in the Ryoke Belt.

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The granitoid assemblage is also different; abundant garnet-bearing two mica granites in the Chubu District are not exposed in the Kagawa Prefecture.

Purpose of this study is to elucidate chemical characteristics of the late Cretaceous granitoids across the southern Okayama and Kagawa Prefectures along roughly 134°E (Fig. 1), in order to find out source components for these granitods. The chemical analyses were performed by polarized XRF at the Macquarie University (see Ishihara, 2002 for the details) and ICP-MS methods for REE at Activation Laboratories Ltd.

2. Geological Setting

The studied southern Okayama-Kagawa region is underlain by Jurassic accretionary complex, late Cretaceous felsic volcanic and granitic rocks, which are overlain unconformably by late Cretaceous Izumi Sandstone, Miocene andesites and sediments. The Jurassic rocks in the Ryoke Belt have been converted to cordierite and/or sillimanite-bearing rocks and considered as Ryoke metamorphic rocks (Kutsukake *et al.*, 1979). Nureki *et al.* (1982) studied those of the Shiaku Islands and found them composed of amphibolite-grade gneisses originated in limestones, clastic rocks and pyroclastic rocks rich in TiO_2 and K_2O. The exposures are so sporadic (Sato, 1948) to draw any regional patterns of the metamorphic grade and compositional variation of the original rocks.

Late Cretaceous volcanic rocks are widely distrib-

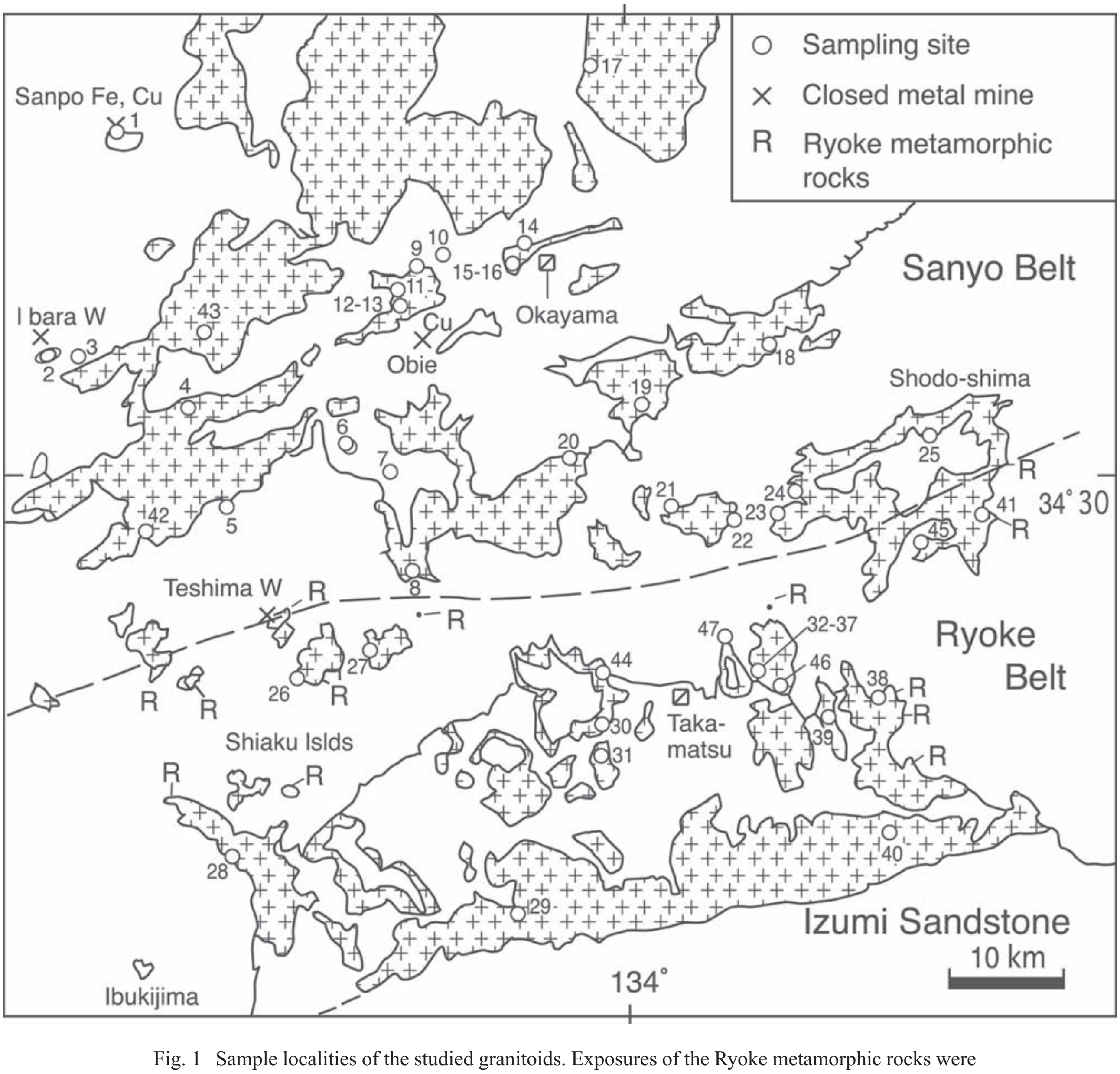

Fig. 1 Sample localities of the studied granitoids. Exposures of the Ryoke metamorphic rocks were taken from Makimoto *et al.* (1995) and Matsuura *et al.* (2002).

Fig. 2 Heterogeneous looking of Aji Granite, which is considered the best-grade tombstone in Japan. Tabuchi Quarry, Aji township, Kagawa Prefecture (x1).

uted in the southern Okayama Prefecture but only little or none in Kagawa Prefecture. They are mostly felsic ignimbrites associated locally with caldera subsidence (Ishihara and Imaoka, 1999). The late Cretaceous plutonic rocks are usually later than the volcanic rocks, and are composed of minor gabbroids and abundant granitoids. The gabbroids are particularly minor in the Sanyo Belt but rather abundant in the Ryoke Belt.

The Rb/Sr whole rock ages of the granitoids are determined to be 84.0±3.7 Ma in the Sanyo Belt of the southern Okayama Prefecture, and 82.1±3.0 Ma in the Ryoke Belt of the eastern Kagawa Prefecture (Kagami *et al.*, 1988). The initial Sr ratios range from 0.7072 to 0.7083 in the Sanyo granitoids and from 0.7073 to 0.7074 in the Ryoke granitoids (Kagami *et al.*, 1992).

The boundary line between the Sanyo and Ryoke Belts in Fig. 1 is drawn along the northern edge of the Ryoke metamorphic rocks described in Makimoto *et al*. (1995) and Matsuura *et al*. (2002), and the southern end of tungsten mineralization at the northern tip of Teshima Island in the Sanyo Belt, because the Ryoke Belt is characterized by absence of any metallic mineralizations.

Magnetic susceptibility measurement by Bison Model 3101 (Kanaya and Ishihara, 1973) indicates that both granitoids and gabbroids in the area of Fig. 1 have low magnetic susceptibility as follows:

Magnetic susceptibility:	0-1	50-100	100-500 $x10^{-6}$ emu/g
Sanyo Belt:	63	18	7 samples
Ryoke Belt:	66	3	1 samples

The rocks with magnetic susceptibility below 50 x 10^{-6} emu/g are completely magnetite free and those between 50 and 100 x10^{-6} emu/g contain very trace amount of magnetite, though both ranges are considered as ilmenite series. By the number of the measurement, percentage of the ilmenite-series plutonic rocks in the Sanyo Belt is 92 %, while that of the Ryoke Belt is 99 %. Thus, the plutonic rocks are more reduced in the Ryoke Belt than in the Sanyo Belt.

The studied inland-sea region is famous for stone mining for many years, because of abundant granites exposed along the coasts, which have advantage for transportation of heavy material, especially in historical time. The granites are still mined at many places, from high quality fine-grained rock for tombstone (Fig. 2) to coarse-grained granites for stone wall or wave-cut block at harbors.

3. Granitoids of Okayama Prefecture

Granitoids of the southern Okayama Prefecture consist essentially of coarse- to medium-grained phases having biotite and/or hornblende-biotite mineral assemblages and fine-grained granitic stocks with varying composition and muscovite-biotite leucogranites occurring at the highest level of the biotite granite batholith and related to tungsten ore deposits (Ishihara, 1971). Amphibole gabbroids occur very sporadically as inclusion bodies in the coarse- to medium-grained granitoids. The studied granitoids were collected from all these granitoids listed in Table 1 (nos. 1-25). Nureki *et al*. (1979) studied mineralogically these granitoids and classified them into types I to IV, and unclassified fine-grained phases as follows:

Type I: coarse- to medium-grained biotite syenogranite. K-feldspar is pinkish and has highest triclinicity, thus close to microcline.

Type II: coarse- to medium-grained hornblende-biotite monzogranite. K-feldspar is pink and porphyritic or glomeroporphyritic. This type has an intermediate triclinicity between microcline and orthoclase, and shows no microcline lattice texture under the microscope. The famous dimension stone of Mannari-ishi is mined from this type.

Type III: coarse- to medium-grained hornblende-biotite monzogranite similar to the type II, but quartz is rounded and glomeroporphyritic. K-feldspar is pink with low degree of triclinicity.

Type IV: coarse- to medium-grained hornblende-biotite monzogranite. Plagioclase is porphyritic to glomeroporphyritic. K-feldspar is white and glomeroporphyritic.

Fine-grained granitoids includes fine-grained felsic phase containing abundant mafic microgranular enclaves (MME, e.g., Fukuwatari body) and muscovite-biotite leucogranite related to tungsten ore deposits at north of Kurashiki and Ibara cities.

The ore deposits are composed of wolframite-quartz veins of major Kibi (WO_3 51.7 tons) and Ibara (WO_3 34.5 tons) mines, and small mines of Okayama, Miyoshi, Sankei and Keigamaru. Uranium minerals, mainly coffinite as primary mineral, and many secondary minerals are often associated with them (e.g., Miyoshi; Hida *et al*., 1961). The largest metal mines in the southern Okayama Prefecture is Obie copper mine (Cu 16,500 tons) occurring in the Jurassic slates just above concealed fine-grained granite at east of Kurashiki (JMIA, 1968).

4. Granitoids in Kagawa Prefecture

Plutonic rocks of the Ryoke Belt are composed of sporadic gabbroids and overwhelming granitoids. The granitoids are divided into coarse- to medium-grained granodiorite and granite batholith and fine-grained biotite granitic stocks. The former rocks are massive or stressed, as shown by alignment of mafic silicates, microscopic kink and bend of biotite and feldspars, protoclastic textures in quartz. Such stressed granitoids occur in Shodoshima (Nanpudai) and Honjima to the mainland Kagawa Prefecture, and can be regarded as "older" granitoids related to the Ryoke metamorphism, although exact age determinations are necessary on zircon.

The granitoids of the eastern part of the main Kagawa Prefecture are classified as Shirotori, Shido and Aji Granites by Kutsukake *et al*. (1979). K-Ar honblende ages are 93.4 ± 0.9 Ma for the Shirotori Granites and 86.8 ± 0.9 to 82.3 ± 0.8 Ma for the Shido Granites (Yuhara *et al*., 2000). The Aji Granites intrude the Shido Granites.

The Shirotori Granites occur widely in the southeastern part of Kagawa Prefecture and overlain unconformably by the upper Cretaceous Izumi Sandstones to the south. The granitoids are coarse-grained and massive, ranging in composition from hornblende-biotite granodiorite to biotite granites. Mafic enclaves are rare. The K-feldspar is weakly pink in color.

Granitoids of the northeastern part are called as Shido Granites, and are coarse- to medium-grained, weak gneissic biotite-hornblende tonalite, hornblende-biotite granodiorite and porphyritic biotite monzogranite with K-feldspar megacrysts. Mafic enclaves and schlieren are commonly seen.

The Aji Granites occur in Aji Peninsula and Yashima, and are well known dimension stone for many years. The Aji Granites are mostly fine-grained biotite granite and partly hornblende-bearing biotite granodiorite with heterogenous spotty textures, "Fu" in Japanese, which are due to heterogeneity of the grain size and mineral assemblage, biotite and quartz providing dark transparency spot, while feldspars giving rise to

Table 1 Locality and rock types of the studied granitoids.

No.	Field No.	Locality	Rock description
1.	71TO281	Nariwa, Okayama	Medium, biotite granite ($\delta^{18}O$ 10.0‰)
2.	691099	Ibara, Okayama	Medium, biotite granite ($\delta^{18}O$ 10.5‰)
3.	691092	Ibara mine, Okayama	Fine, muscovite-bearing biotite leucogranite
4.	71TO267	Kamogata, Okayama	Medium, hornblende-biotite granite
5.	71TO263	Tamashima, Okayama	Medium, hornblende-biotite granodiorite
6.	71TO258	Mizushima, Okayama	Fine, hornblende-biotite granodiorite
7.	71TO257	Kurashiki, Okayama	Fine, biotite granite
8.	71TO255	Shimotsui, Okayama	Fine, biotite granite
9.	6910105	Sosha, Okayama	Medium, hornblende-biotite granite(8.5‰)
10.	6910104	Hozaki, Okayama-shi	Medium, pyroxene-horblende-biotite granodiorite ($\delta^{18}O$ 8.1‰, Sr_0 0.7077)
11.	72TO287	Sosha, Okayama	Fine, muscovite-biotite leucogranite
12.	6910157	Kurashiki, Okayama	Fine, muscovite-biotite leucogranite ($\delta^{18}O$ 7.7‰)
13.	72TO289	Kurashiki, Okayama	Fine, muscovite-biotite leucogranite, weakly altered
14.	70TO55	Koube, Okayama-shi	Medium, biotite pink granite, weakly altered
15.	70TO181	Yasaka, Okayama-shi	Coarse, biotite pink granite
16.	MAN01	Ukita quarry, Okayama-shi	Coarse, biotite pink granite
17.	70TO47	Tatebe, Okayama	Coarse, hornblende-bearing biotite granite
18.	71TO243	Oku, Okayama	Very coarse, biotite-hornblende granodiorite
19.	71TO248	Tamano-Toji, Okayama	Medium, biotite pink granite
20.	71TO249	Tamano, Okayama	Very coarse, biotite granite
21.	72TO301	Teshima, Kagawa	Medium, biotite pink granite($\delta^{18}O$ 9.2‰)
22.	72TO303	Teshima, Kagawa	Medium, biotite pink granite
23.	72TO304	Tonosho, Kagawa	Coarse, biotite pink granite
24.	72TO305	Tonosho, Kagawa	Fine biotite granite($\delta^{18}O$ 10.7‰)
25.	72TO308	Tonosho, Kagawa	Medium, biotite granite($\delta^{18}O$ 10.6‰)
26.	72TO385	Hiroshima, Okayama	Medium, biotite granite ($\delta^{18}O$ 9.1‰)
27.	72TO390	Honjima, Kagawa	Fine, biotite granite, stressed ($\delta^{18}O$ 10.9‰)
28.	72TO375	Takuma, Kagawa	Fine, biotite granite, stressed ($\delta^{18}O$ 10.8‰)
29.	72TO367	Mannou, Kagawa	Medium, horblende-biotite granodiorite, stressed ($\delta^{18}O$ 10.3‰)
30.	72TO363	Kokubunji, Kagawa	Fine, biotite-hornblende granodiorite, stressed ($\delta^{18}O$ 8.6‰, Sr_0 0.7078)
31.	72TO362	Kokubunji, Kagawa	Medium biotite granite, stressed ($\delta^{18}O$ 8.4‰)
32.	72TO329	Aji-Tabuchi, Kagawa	Fine biotite granite “Kome” ($\delta^{18}O$ 12.5‰)
33.	72TO330	Aji-Kimura, Kagawa	Fine-medium, biotite granite “Chume”
34.	AJI05	Aji-Nakatani, Kagawa	Fine biotite granite “Kome”
35.	AJI05e	ditto	Fine, mafic-intermediate igneous enclave
36.	AJI06	Aji-Nakatani, Kagawa	Fine-medium, biotite granite “Chume”
37.	AJI06e	ditto	Fine, intermediate igneous enclave
38.	72TO337	Shido, Kagawa	Fine, garnet-bearing muscovite- biotite granite, stressed ($\delta^{18}O$ 15.6‰)
39.	72TO339	Shido, Kagawa	Coarse, hornblende-biotite granodiorite, stressed ($\delta^{18}O$ 10.1‰)
40.	72TO340	Okawa, Kagawa	Very coarse, horblende-bearing biotite granite ($\delta^{18}O$ 6.1‰)
41.	72TO317	Uchinomi, Kagawa	Coarse, horblende-biotite granodiorite, stressed ($\delta^{18}O$ 10.6‰)
42.	71TO264	Nagahama, Kasaoka	Fine-medium, biotite-bearing amphibole gabbro (Sr_0 0.7075)
43.	71TO273	Yagake, Okayama	Fine-medium, amphibole gabbro (Sr_0 0.7071)
44.	72TO354	Kubocho, Takamatsu	Medium, amphibole gabbro (Sr_0 0.7081)
45.	72TO322	Tanoura, Kagawa	Fine-medium, amphibole gabbro, Tanoura Gabbroic Complex
46.	72TO333	Mure, Kagawa	Fine, amphibole gabbro
47.	NGA04	Nagasakihana, Yashima	Fine, biotite-hornblende quartz diorite

Bulk $\delta^{18}O$ values shown in parenthesis are taken from Ishihara and Matsuhisa (2002). Sr_0, initial Sr ratio, taken from Shibata and Ishihara (1979).

Table 2 Chemical composition of the Sanyo and Ryoke granitoids.

	Sanyo Belt-granitoids								
	1	2	3	4	5	6	7	8	9
	71TO281	**691092**	**691199**	**71TO267**	**71TO263**	**71TO258**	**71TO257**	**71TO255**	**6910105**
SiO_2	76.04	76.78	74.48	71.91	69.44	68.24	77.63	75.42	72.14
TiO_2	0.10	0.04	0.12	0.25	0.39	0.47	0.07	0.12	0.21
Al_2O_3	12.63	12.47	13.44	13.95	14.62	14.84	12.18	12.96	14.03
Fe_2O_3	1.25	0.84	1.65	3.39	3.95	4.13	1.06	1.77	2.37
MnO	0.02	0.03	0.04	0.09	0.09	0.08	0.02	0.04	0.06
MgO	0.15	0.02	0.15	0.31	1.01	1.32	0.07	0.18	0.46
CaO	1.11	0.51	1.38	2.00	3.07	3.70	0.71	1.16	2.34
Na_2O	3.36	4.14	3.54	4.21	3.67	3.45	3.64	3.52	3.68
K_2O	4.75	4.57	4.46	3.24	2.97	2.86	4.19	4.25	3.99
P_2O_5	0.03	0.02	0.05	0.10	0.11	0.12	0.03	0.05	0.04
S	0.01	<0.01	<0.01	0.01	0.02	0.01	0.02	0.01	0.01
H_2O^+	0.46	0.45	0.55	0.48	0.55	0.80	0.32	0.40	0.21
H_2O^-	0.21	0.10	0.07	0.07	0.15	0.11	0.07	0.13	0.4
CO_2	0.07	0.01	0.05	0.06	0.09	0.01	0.07	0.15	0.03
Total	100.19	99.98	99.98	100.07	100.13	100.14	100.08	100.16	99.97
Trace elements (ppm)									
Rb	238	282	205	117	113	105	146	139	141
Cs	8.7	3.9	7.6	9.2	5.2	5.3	3.9	3.4	7.7
Sr	73	16	86	170	196	222	61	98	167
Ba	223	21	433	527	510	534	571	645	591
Zr	87	80	104	189	107	100	79	107	104
Hf	5.3	7.4	5.4	6.7	4.1	4.2	4.6	4.9	4
Nb	8.4	16.4	9.9	13.2	7.4	7.6	7.8	10.4	6.8
Ta	3.1	5.7	1.9	3.5	2.5	3.4	2.5	3.2	< 1.6
Y	40	86	36	40	24	18	23	26	25
La	26	18	23	26	17	20	16	23	26
Ce	56	39	50	55	40	38	35	50	53
V	4	1	< 2.3	< 2.9	38	43	< 2.0	3	16
Cr	35	27	29	18	19	33	41	39	4
Co	5	6	4	11	9	10	3	7	10
Ni	1	1	< 0.7	< 0.8	< 0.8	1	< 0.6	< 0.6	< 0.7
Cu	6	1	< 0.4	0	5	< 0.4	2	< 0.4	1
Zn	21	48	53	77	56	54	35	40	41
Pb	21.7	34.3	24.1	13.9	18.4	17.3	23.5	25.9	16.7
Ga	14.9	16.5	16.7	18.3	15.6	15.5	14.6	15.8	16.1
Ge	1.8	1.4	1.4	1.5	1.6	1.2	1.3	1.2	1.6
As	6.3	0.8	< 0.5	0.3	0.6	1	< 0.5	< 0.5	0.5
Se	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.4	< 0.1
Mo	0.2	4.4	0.7	1.8	0.7	1.3	2.6	0.5	0.6
W	5.3	4.4	2.2	1.4	1.4	2.3	2.5	2.2	1.2
Sn	3.5	11.2	3	3.5	2.7	1.9	1.4	2.6	4.6
Cd	0.3	2.2	0.2	0.2	0.2	< 0.2	< 0.2	0.3	< 0.2
Tl	2.4	3.1	1.8	1.1	1.5	1.3	1.6	1.6	0.8
Bi	0.6	0.4	0.3	< 0.3	< 0.3	< 0.3	0.5	0.3	< 0.3
Th	19.8	28	12.3	9.3	10.2	10.5	10.8	17	12.3
U	4.4	7.3	4.2	< 0.5	14.6	2.8	3.9	3.2	2.6
Na_2O+K_2O	8.11	8.71	8	7.45	6.64	6.31	7.83	7.77	7.76
ASI	1.00	0.98	1.02	0.99	0.99	0.96	1.03	1.04	0.96
Rb/Sr	3.3	17.6	2.4	0.7	0.6	0.5	2.4	1.4	0.8

Table 2　Continued.

Sanyo Belt-granitoids									
10	11	12	13	14	15	16	17	18	19
6910104	**72TO287**	**6910157**	**72TO289**	**70TO55**	**70TO181**	**MAN01**	**70TO47**	**71TO243**	**71TO248**
63.59	76.92	76.4	77.11	73.74	72.63	74.27	70.78	69.66	75.81
0.64	0.04	0.04	0.04	0.12	0.18	0.19	0.22	0.33	0.09
16.04	12.70	12.22	12.60	12.81	13.61	12.93	14.39	15.25	13.40
5.68	0.85	1.07	0.97	1.81	2.52	2.61	2.91	3.06	1.26
0.10	0.02	0.03	0.03	0.04	0.06	0.06	0.05	0.06	0.04
2.22	0.04	0.09	0.03	0.14	0.22	0.23	0.39	0.71	0.17
5.70	0.50	0.62	0.54	1.25	1.64	1.34	2.19	3.44	1.15
3.06	3.97	3.78	3.70	4.22	4.32	3.51	3.71	3.59	3.40
2.05	4.60	4.91	4.73	4.87	4.18	4.43	3.86	2.87	4.32
0.13	0.03	<0.01	0.04	0.03	0.06	0.03	0.08	0.09	0.03
<0.01	0.02	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.71	0.39	0.5	0.37	0.50	0.41	0.40	0.93	0.69	0.19
0.32	0.05	0.28	0.04	0.29	0.14	0.01	0.41	0.24	0.22
0.03	0.10	0.01	0.01	0.08	0.01	0.01	0.10	0.03	0.08
100.27	100.23	99.95	100.21	99.91	99.99	100.03	100.03	100.03	100.17
61	370	373	394	167	142	157	134	107	199
< 1.5	7	9.2	10.4	4.1	5.1	6.7	4.8	3.3	5.4
304	11	11	10	92	122	102	203	243	83
553	19	27	20	621	665	655	733	628	303
147	77	78	74	123	169	166	108	120	76
6	7.2	7	7.7	6.5	6.6	6	4.9	5	5.2
7	16.8	18	19.3	9.4	10.5	11.8	7.5	6.8	7.1
4	6.5	5	6.1	4.8	1.3	2	3	2.6	2.8
23	76	76	97	40	39	39	22	23	29
23	14	23	13	19	30	28	16	21	15
54	39	50	36	43	69	63	40	44	35
84	1	3	< 1.2	< 2.3	< 2.7	7	27	20	2
34	28	47	25	20	29	3	21	30	34
19	5	6	5	8	7	5	12	12	6
6	2	2	2	< 0.7	< 0.7	< 0.7	4	< 0.7	1
11	< 0.5	1	< 0.5	1	< 0.4	< 0.4	4	3	< 0.4
67	23	32	28	42	57	52	41	55	31
12	36.9	36.6	37.9	18.8	16.5	17.2	23	16.6	30.1
18	18.2	18.4	17.7	16.4	18.5	17.5	16	17.1	14
2	2.1	2	1.9	1.5	1.7	1.5	1.4	1.2	1.2
1	0.5	4.5	< 0.6	1.8	0.8	1.4	11.2	< 0.4	< 0.5
< 0.1	0.2	< 0.1	0.6	0.2	< 0.1	0.1	0.2	0.3	0.4
1	0.4	< 0.2	0.7	1.9	1	2.6	0.6	1.3	< 0.2
< 1.2	5	5.2	7.4	1.8	3.2	1.5	2.2	3.6	3.8
1	4.9	7.9	3.6	3.1	2.9	2.7	2.3	2.2	4.1
1	0.5	0.6	0.3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.2
1	2.9	2.9	3.8	1.7	1.3	1.2	1.6	1.8	2.5
< 0.3	0.4	1.5	2.3	1.4	< 0.3	0.3	< 0.3	0.8	0.8
6	31.4	33.3	31.7	14.8	16.4	12.8	11.3	10.6	27.3
1	11.2	6.4	10.8	4.7	3.4	3.2	2.3	2.1	6.1
5	8.57	8.69	8.43	9.09	8.5	7.94	7.57	6.46	7.72
0.91	1.02	0.97	1.03	0.88	0.93	0.99	1.01	1.00	1.08
0.2	33.6	33.9	39.4	1.8	1.2	1.5	0.7	0.4	2.4

Table 2 Continued.

Sanyo Belt-granitoids						Ryoke Belt-granitoids			
20	21	22	23	24	25	26	27	28	29
71TO249	**72TO301**	**72TO303**	**72TO304**	**72TO305**	**72TO308**	**72TO385**	**72TO390**	**72TO375**	**72TO367**
77.41	76.22	76.91	75.4	76.94	76.11	72.99	76.01	75.64	62.62
0.03	0.05	0.06	0.09	0.03	0.08	0.15	0.08	0.08	0.71
12.47	12.75	12.24	12.44	12.68	12.72	14.24	12.83	13.28	16.90
1.06	1.12	1.27	1.47	0.63	1.40	1.98	1.19	1.30	6.41
0.05	0.04	0.05	0.04	0.02	0.04	0.06	0.04	0.05	0.12
0.07	0.08	0.09	0.15	0.04	0.14	0.28	0.12	0.16	1.29
0.78	0.84	0.73	1.14	0.58	1.19	1.51	0.90	1.38	5.29
3.45	3.65	3.45	3.56	3.68	3.55	3.66	3.19	3.37	3.58
4.52	4.65	4.32	4.94	4.65	4.10	4.61	5.11	4.13	2.03
0.02	0.02	0.03	0.03	0.03	0.05	0.06	0.03	0.04	0.21
0.01	0.01	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	0.01
0.24	0.35	0.51	0.43	0.45	0.51	0.26	0.33	0.38	1.08
0.11	0.12	0.23	0.19	0.13	0.25	0.11	0.33	0.17	0.29
0.01	0.04	0.06	0.03	0.04	0.01	0.08	0.04	0.05	0.01
100.23	99.94	99.96	99.92	99.91	100.17	99.99	100.20	100.03	100.55
192	194	188	137	232	137	171	230	122	63
4.9	6.1	6.6	3.3	5.3	5.2	5.1	7.3	2.9	1.3
37	42	38	89	21	130	128	60	123	312
151	213	192	573	83	691	548	136	606	532
71	64	75	85	71	80	81	63	82	277
5.4	4.5	5.1	4.8	5.6	3.5	4.7	5	4.5	7
8.2	7	8.5	5.8	8.2	8.9	9.2	7.5	7.5	13.8
4.5	2.2	2.9	2.7	2.4	2.1	3.9	3.7	2.9	3.3
29	32	37	17	52	17	35	29	23	28
16	16	16	18	15	18	18	17	18	23
32	35	31	38	33	40	38	37	39	57
< 1.4	< 1.7	< 1.7	2	< 1.3	< 2.2	5	< 1.9	< 2.3	29
27	29	20	29	28	24	31	41	30	24
4	7	7	4	3	6	< 4.5	5	3	12
< 0.6	< 0.6	< 0.6	< 0.6	2	< 0.6	1	1	< 0.6	< 1.0
< 0.4	< 0.4	1	< 0.4	0	1	< 0.4	1	7	8
27	35	39	33	29	42	46	32	37	92
29.2	31.2	29.9	25.5	39.2	25.3	30.4	37.4	33.5	15.2
14.9	14.6	14.5	12.8	15	16.1	16.1	14.1	14	19.2
1.8	1.7	1.6	1.5	1.9	1.4	1.5	1.8	1.4	1.4
< 0.5	0.4	0.8	< 0.5	< 0.6	< 0.5	< 0.5	0.5	< 0.5	< 0.4
0.2	0.2	0.2	0.3	0.2	0.1	0.5	0.3	0.3	0.3
< 0.2	< 0.2	< 0.2	0.3	< 0.2	0.3	0.4	< 0.2	0.2	1.7
2.5	2	2.7	1.9	4	2.4	2.2	2.2	2.7	< 1.4
4	4.1	4.6	2.2	4.3	2.5	3.7	3.6	2	1.4
< 0.2	< 0.2	< 0.2	< 0.2	0.2	< 0.2	< 0.2	< 0.2	0.2	0.5
1.8	1.8	2	1.7	1.9	1.6	2.5	2.6	1.5	1.4
0.4	0.4	0.7	< 0.3	1.5	0.3	0.7	< 0.3	0.6	0.4
11.9	16.4	16.4	11.7	22.8	9.3	12.1	18.9	11.9	7.6
4.3	6	4.8	2.3	10.4	3	4.3	8.9	2.6	0.9
7.97	8.3	7.77	8.5	8.33	7.56	8.27	8.3	7.5	5.61
1.04	1.01	1.05	0.94	1.04	1.02	1.04	1.03	1.06	0.95
5.2	4.6	4.9	1.5	11.0	1.1	1.3	3.8	1.0	0.2

Table 2 Continued.

Ryoke Belt-granitoids									
30	31	32	33	34	35	36	37	38	39
72TO363	**72TO362**	**72TO329**	**72TO330**	**AJI05A**	**AJIO5B**	**AJI06A**	**AJIO6B**	**72TO337**	**72TO339**
63.34	72.41	72.22	71.12	72.60	64.01	72.47	70.28	71.11	68.16
0.63	0.16	0.27	0.31	0.24	0.71	0.25	0.38	0.34	0.38
16.99	15.08	14.63	14.82	14.22	16.26	14.33	15.13	15.37	15.56
5.87	2.08	2.24	2.60	2.29	6.37	2.26	3.49	2.11	4.20
0.10	0.05	0.04	0.05	0.05	0.11	0.05	0.08	0.08	0.06
1.34	0.24	0.51	0.59	0.43	1.57	0.45	0.74	0.68	0.68
5.01	1.97	2.72	2.79	2.28	3.83	2.37	3.11	2.30	3.67
4.06	4.80	3.95	3.91	3.66	3.58	3.66	4.02	3.71	3.85
1.95	2.71	2.67	2.38	2.99	1.86	3.16	1.76	3.46	2.41
0.22	0.07	0.10	0.11	0.10	0.23	0.11	0.13	0.16	0.14
0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.02	<0.01
0.84	0.44	0.47	0.80	0.72	1.47	0.60	0.66	0.57	0.05
0.07	0.20	0.16	0.47	0.34	0.45	0.42	0.38	0.19	0.25
0.04	0.01	0.01	0.08	0.05	0.10	0.06	0.07	0.08	1.00
100.47	100.22	99.99	100.03	99.97	100.56	100.19	100.23	100.18	100.41
62	92	58	58	67	77	74	70	153	71
< 1.5	3.1	< 1.5	< 1.5	1.8	< 1.5	1.3	3.5	6.8	1.1
393	227	367	368	335	440	307	333	187	304
708	743	655	694	950	390	891	553	450	1201
209	143	155	164	149	150	139	138	104	229
5.8	4.9	4	6.2	5.2	4.4	4.6	4.6	4.4	5.9
10.4	10	8.9	9.9	9.4	10.7	9.6	14.7	12	10.5
1.4	1.8	1.7	1.6	< 1.7	3	2.5	3.7	3.5	1.9
23	21	10	11	12	16	14	14	19	25
31	30	24	28	25	14	21	23	20	47
67	62	50	60	48	33	49	44	42	90
41	< 2.7	< 3.2	< 3.3	< 3.3	29	< 3.1	11	14	18
20	25	41	17	23	45	17	40	30	31
9	5	< 4.8	7	7	8	7	8	5	7
< 0.9	1	1	1	1	< 1.0	< 0.7	< 0.8	1	< 0.8
< 0.5	< 0.4	1	< 0.4	3	4	7	5	15	1
81	51	54	61	58	147	59	86	52	63
10.9	16.1	18.8	18	20	12.4	20.2	14.9	26.7	12.8
21.9	19.6	18	18.7	17.3	22.9	17.9	21.3	17.1	18.2
1.3	1.6	0.9	1.2	0.8	1.2	1.2	1.1	1.7	1.1
< 0.4	< 0.4	< 0.4	< 0.4	1	< 0.4	< 0.4	< 0.4	< 0.5	< 0.4
0.3	0.2	0.2	0.3	0.3	0.2	0.1	0.2	0.3	0.1
1	0.8	< 0.2	0.5	0.5	0.7	0.3	0.7	0.3	0.3
< 1.3	2.2	2.7	2.1	3	< 1.6	2	1.2	2	2.2
0.8	1.6	1	1	1	0.4	0.9	1.3	2.9	1.3
0.3	0.3	0.3	0.6	0.5	0.2	< 0.2	0.3	< 0.2	0.4
1.1	0.9	1	1.3	1.2	1.1	1	0.8	1.6	1.2
< 0.3	0.5	0.5	0.3	0.5	< 0.3	0.3	< 0.3	0.4	0.6
4.6	10.6	4.3	5.9	6.2	1.7	5.8	3	8.3	10.4
< 0.5	2.1	0.3	< 0.5	0.4	< 0.5	0.7	< 0.5	2.7	1.2
6.01	7.51	6.62	6.29	6.65	n.c.	6.82	n.c.	7.17	6.26
0.95	1.05	1.02	1.05	1.06	1.09	1.04	1.07	1.1	1.00
0.2	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.8	0.2

Table 2 Continued.

	Ryoke Belt-grds		Sanyo Belt-gabbroids		Ryoke Belt-gabbroids			
	40	41	42	43	44	45	46	47
	72TO340	**72TO317**	**71TO264**	**71TO273**	**71TO354**	**71TO322**	**71TO333**	**NGA04**
	72.27	70.73	49.35	50.53	46.18	46.85	50.22	55.69
	0.27	0.22	0.54	0.59	1.09	2.31	0.45	1.31
	13.78	15.82	15.53	19.23	22.50	17.78	20.42	17.46
	2.73	2.27	10.05	8.89	6.22	13.77	6.28	8.60
	0.05	0.04	0.16	0.15	0.12	0.23	0.12	0.14
	0.57	0.20	10.45	5.65	6.36	4.64	6.56	3.17
	2.28	3.52	9.74	9.55	14.08	9.73	12.35	7.34
	3.37	3.73	1.69	2.31	1.14	2.65	1.45	3.07
	3.49	3.14	0.93	0.83	0.14	0.40	0.45	1.73
	0.10	0.09	0.11	0.15	0.03	0.40	0.06	0.32
	<0.01	<0.01	0.01	<0.01	0.05	0.14	<0.01	<0.01
	0.99	0.31	2.02	2.59	1.67	1.64	1.96	1.33
	0.32	0.01	0.18	0.30	0.18	0.18	0.08	0.28
	0.05	0.01	0.13	0.05	0.10	0.25	0.10	0.07
	100.27	100.09	100.89	100.82	99.86	100.97	100.50	100.51
	118	100	37	22	5	9	12	40
	5.2	4.5	1.3	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5
	152	266	285	382	469	455	402	459
	550	1542	178	171	47	101	137	437
	150	196	61	51	14	60	34	165
	5.6	7	3.3	1.6	1.4	1.9	1.2	5.2
	9.9	8.1	4.5	4	1.4	10.4	2.8	11.1
	2.7	3.6	4.6	3.5	3	< 3.9	< 2.3	2.8
	30	28	13	11	3	28	7	20
	30	48	7	7	2	8	6	21
	64	99	21	16	5	28	13	49
	9	6	123	93	142	256	171	124
	25	21	198	35	189	3	328	43
	8	6	48	37	20	33	23	20
	< 0.8	1	22	4	15	< 1.6	11	2
	1	< 0.4	7	< 0.5	20	28	5	17
	56	41	96	79	45	129	50	102
	21.8	20.1	11.3	7.2	2.8	6	3.8	10.1
	17	17.9	13.3	17.1	16.1	22.1	15.2	20.3
	1.4	1	0.9	1.1	1	1.2	1.2	1.4
	< 0.5	< 0.4	< 0.4	< 0.4	< 0.3	< 0.4	< 0.3	< 0.4
	0.2	0.6	0.4	0.4	0.4	0.3	0.2	0.2
	0.9	0.4	0.4	0.3	< 0.2	0.2	0.3	0.8
	1.4	2.7	< 1.8	< 1.5	1	< 2.0	1.7	< 1.6
	3	1.8	1.6	1.4	< 0.4	0.4	< 0.4	< 0.4
	< 0.2	1	1.1	0.6	0.5	0.6	0.4	0.3
	1.5	2.3	1.6	1.3	0.7	0.7	0.6	1
	< 0.3	1	1.3	0.9	0.7	0.4	0.5	< 0.4
	13.9	10.1	3.6	2.2	< 0.5	1.1	1.4	3.5
	2.8	0.9	1	1	0.9	0.5	0.9	0.6
	6.86	6.87	2.62	3.14	1.28	3.05	1.9	4.8
	1.02	0.99	0.72	1.01	0.81	0.79	0.81	0.86
	0.8	0.4	0.13	0.16	0.01	0.02	0.03	0.9

surrouding whitish color (Fig. 2). Very fine-grained granitoids with the spotty heterogeneity are considered as the best tombstone for the Japanese graveyard (Ishihara, 1991). This granitoid contains sometimes white to gray megacrysts of poikilitic K-feldspar and small amounts of mafic to intermediate igneous enclaves, and patchy biotite-rich (sedimentary) enclaves. The Aji granitic stocks accompany no ore deposits but molybdenite and chalcopyrite occurrences along cooling joints and quartz veinlet, which give -3.7 and -7.2 ‰ $\delta^{34}S$, respectively (Ishihara and Sasaki, 2002).

Granitoids of the western half of Kagawa Prefecture are still unclassified. They are mostly coarse- to medium-grained hornblende-biotite granodiorite to biotite monzogranite, which may be partly porphyritic. The stressed granodiorites are seen in Mannou and Kokubunji, south and southeast of Goshikidai (nos. 29, 30, 31, Table 1), and stressed granites are observed in Hon-jima and Takuma, Shonai Peninsula (nos. 27, 28, Table 1).

Plutonic rocks of the Shodoshima and other islands in the Seto Inland Sea are classified as gabbroids and granodiorites in the southern Ryoke Belt and biotite granites of the northern Sanyo Belt. All the granite-stone quarries are located in massive granites of the Sanyo Belt. In the Shodoshima, the Tanoura Gabbroic Complex (TGC), Nanpudai Granodiorite and Yoshino Granodiorite are distinguished in the southeastern, Ryoke Belt, while massive granites in the northwestern Sanyo Belt are called Shodoshima Adamellite

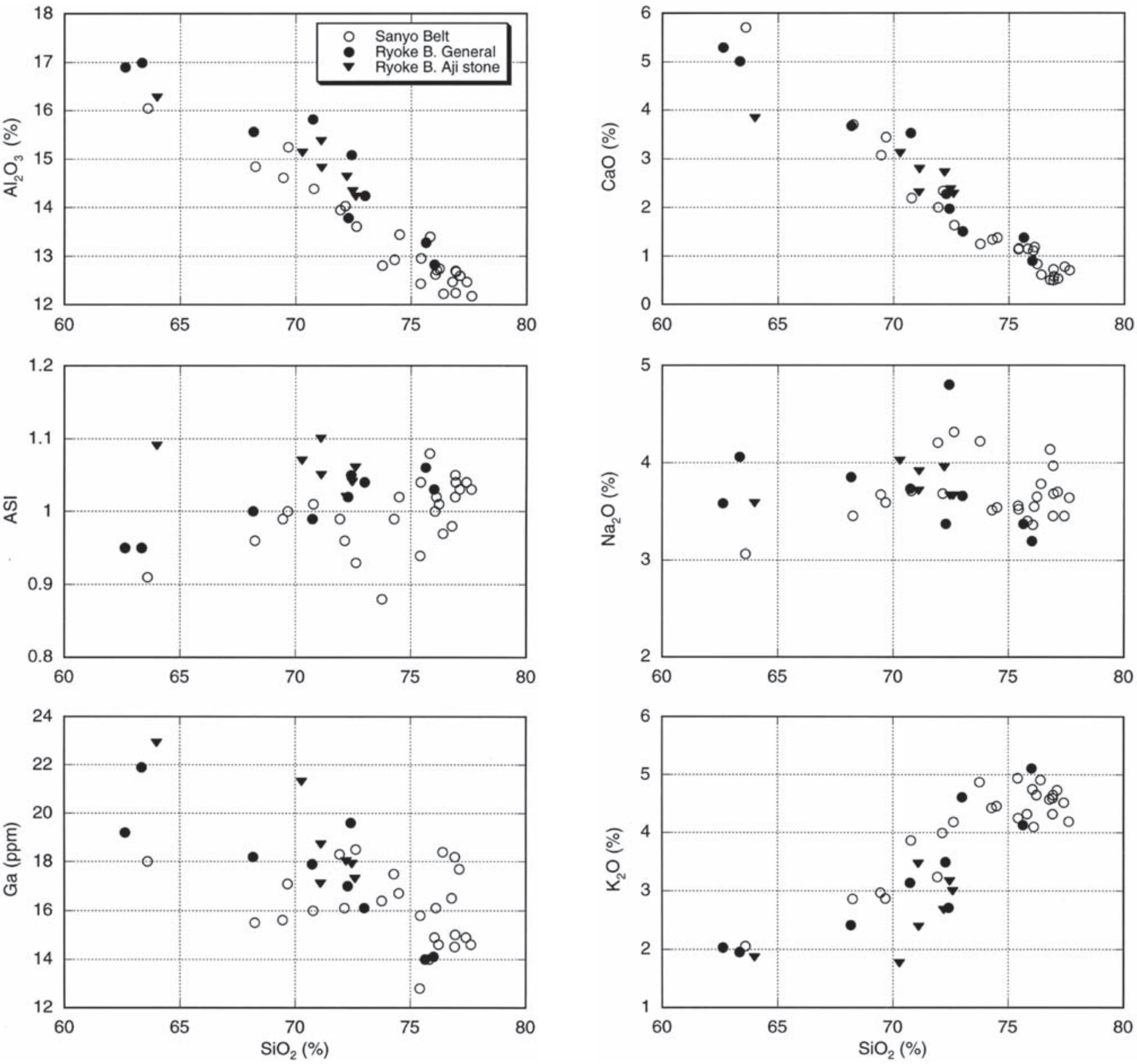

Fig 3 Variation diagrams for Al_2O_3, ASI (alumina saturation index) and Ga (left) and for CaO, Na_2O and K_2O (right).

(Yokoyama, 1984).

Granitoids of the Shodoshima are especially interesting, because of synplutonic mafic dikes of various stages. Yokoyama (1984) recognized 5 stages and totaling 896 mafic, 143 intermediate, and 331 felsic compositions of dike intrusions in the island, as follows:

	Mafic	Intermediate	Felsic	Strike & Dip
Stage I	85	0	1	E-W, gentle
Stage II	77	0	11	NW, steep
Stage III	705	143	319	NNW - NNE, steep
Stage IV	21	0	0	NNE, steep
Stage V	8	0	0	E-W - ENE, steep

These dikes of Stage I and II occur from the Tanoura Peninsula to the east in "older Ryoke" granitoids, and those of Stage III are present in the whole island intruding into all the granitoids of the Ryoke and Sanyo Belts. Many of these dikes are synplutonic and composite in character, implying that these granitoids were formed by multiple pulsation of mafic magmas injected into still fluid solidifying granitic magmas (Yokoyama, 1984).

5. Chemical Characteristics

The analytical results are divided into granitoids of the Sanyo Belt (tentatively called Sanyo granitoids) and Ryoke Belt (similarly Ryoke granitoids) and are listed in Table 2. The Ryoke granitoids are subdivided into general batholithic granitoids and fine-grained Aji biotite granitoids in stock form. Garnet-bearing muscovite-biotite granite occurring as irregular dike forms in gneiss in Shido township (no.38, Table 1), may be grouped in the Aji granitoids. Two small enclaves

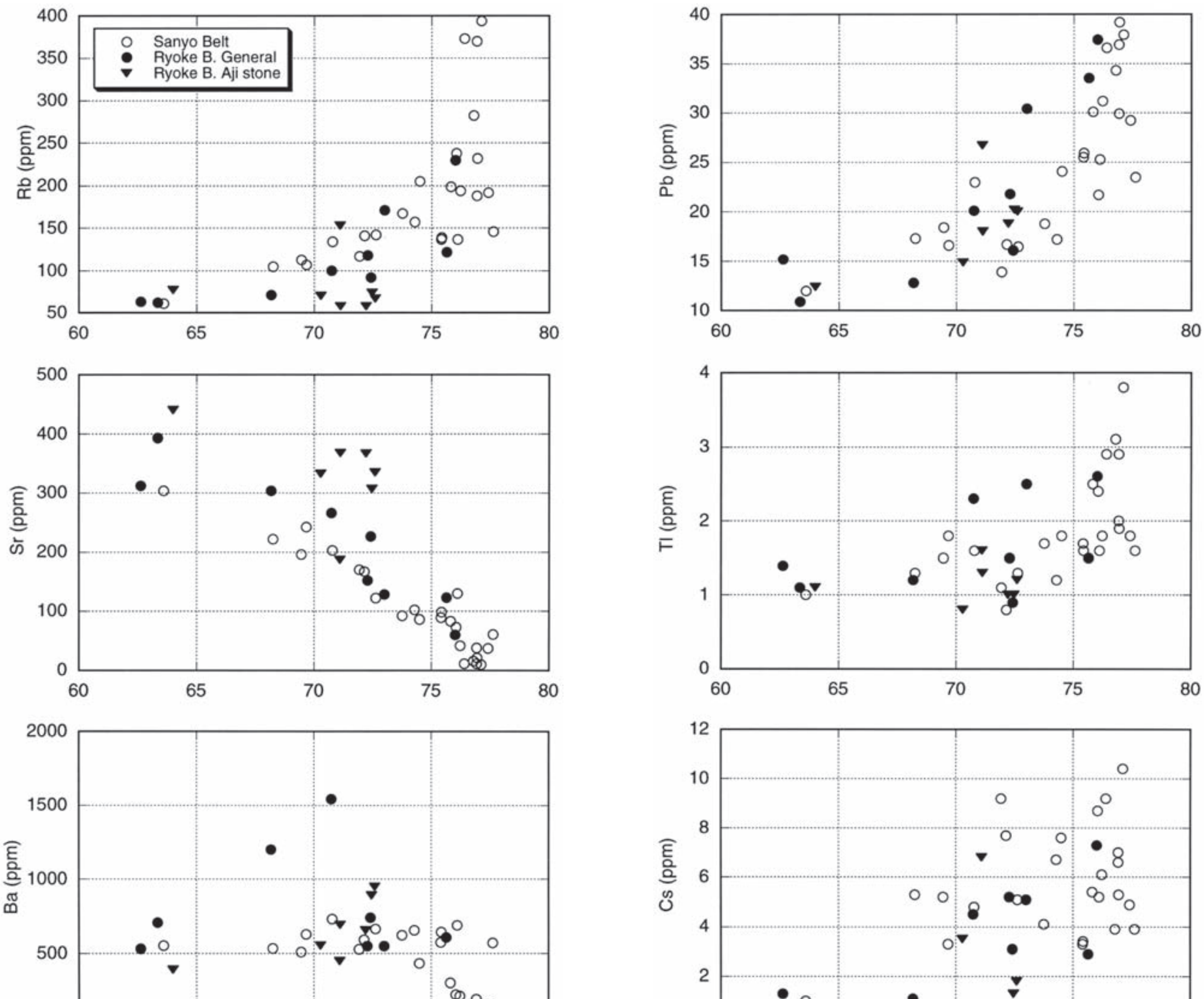

Fig. 4 Variation diagrams for Rb, Sr and Ba (left) and for Pb, Tl and Cs (right).

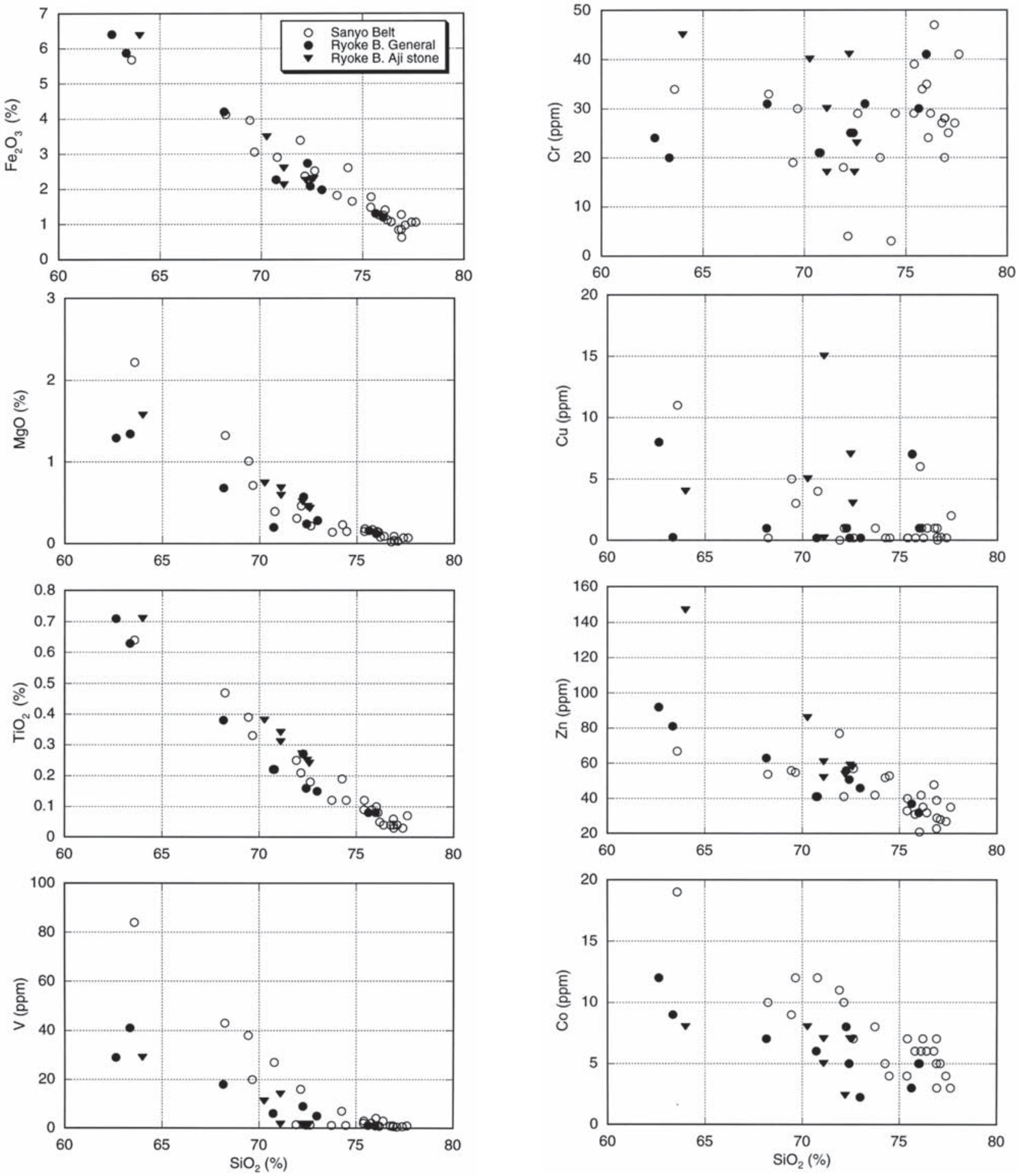

Fig. 5 Variation diagrams for Fe_2O_3, MgO, TiO_2 and V (left), and for Cr, Cu, Zn and Co (right).

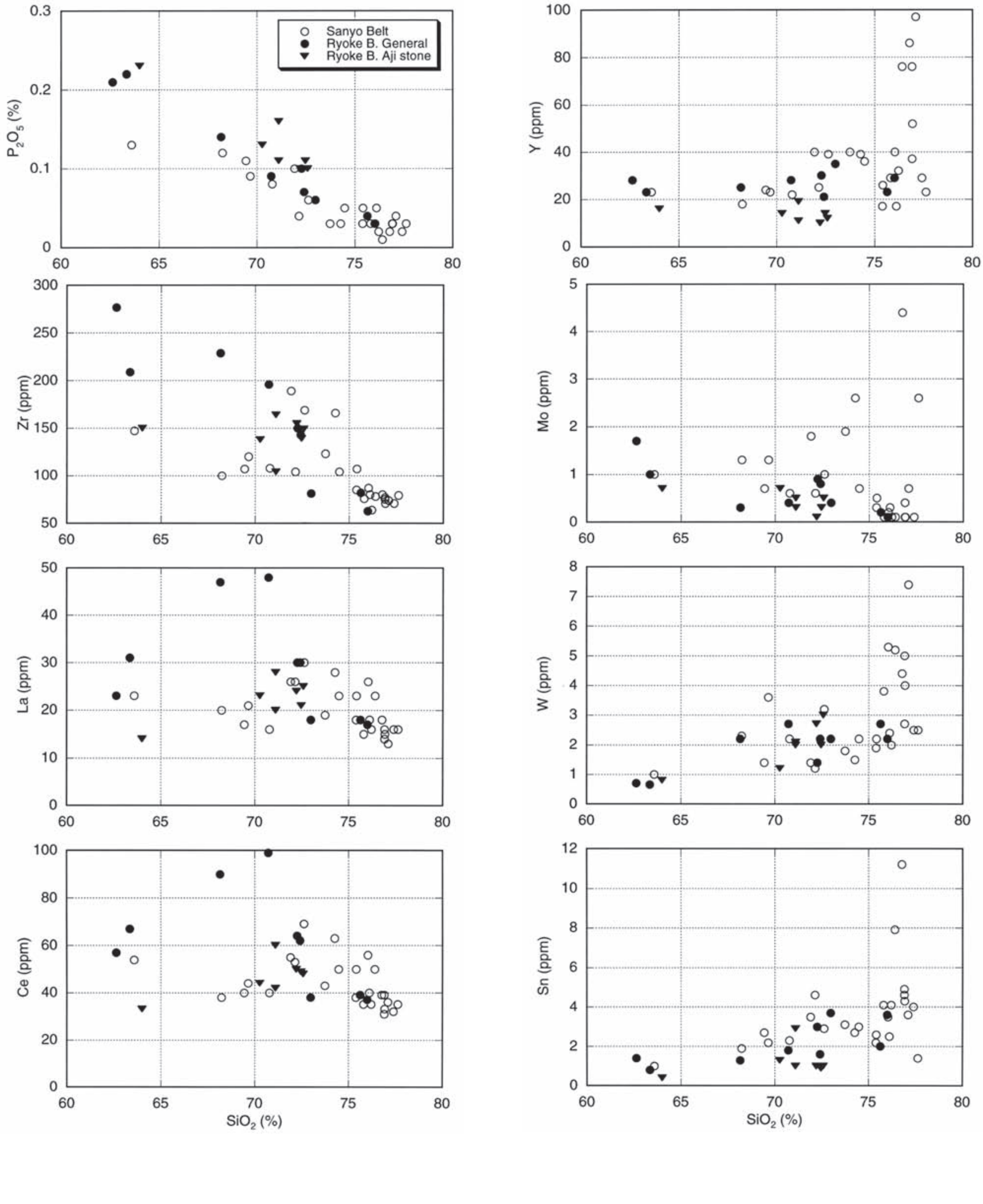

Fig. 6 Variation diagrams for P_2O_5, Zr, La and Ce (left), and for Y, Mo, W and Sn (right).

contained in the Aji granitoids were analyzed and included in Table 2 (nos.35, 37). Representative elements are plotted against SiO_2 in Figs. 3 through 7.

As is seen in Fig. 3, silica contents of the Sanyo granitoids vary from 63.6 to 77.4 % with an average of 74.1 % (n=25); while those of the Ryoke granitoids range from 62.6 to 75.6 % with an average of 71.0 % (n=14). Thus, the Sanyo granitoids are more silicic than the Ryoke granitoids. Average contents of the total alkalis are 7.80 % (n=25) for the Sanyo granitoids, and 6.91 % (n=14) for the Ryoke granitoids. The Sanyo granitoids are more felsic than the Ryoke granitoids. In terms of the alkali-lime index of Peacock (1931), both the granitoids belong to calcic series, the index higher than 61, but the Sanyo granitoids of 64.5, are more calcic than the Ryoke granitoids of 61.0.

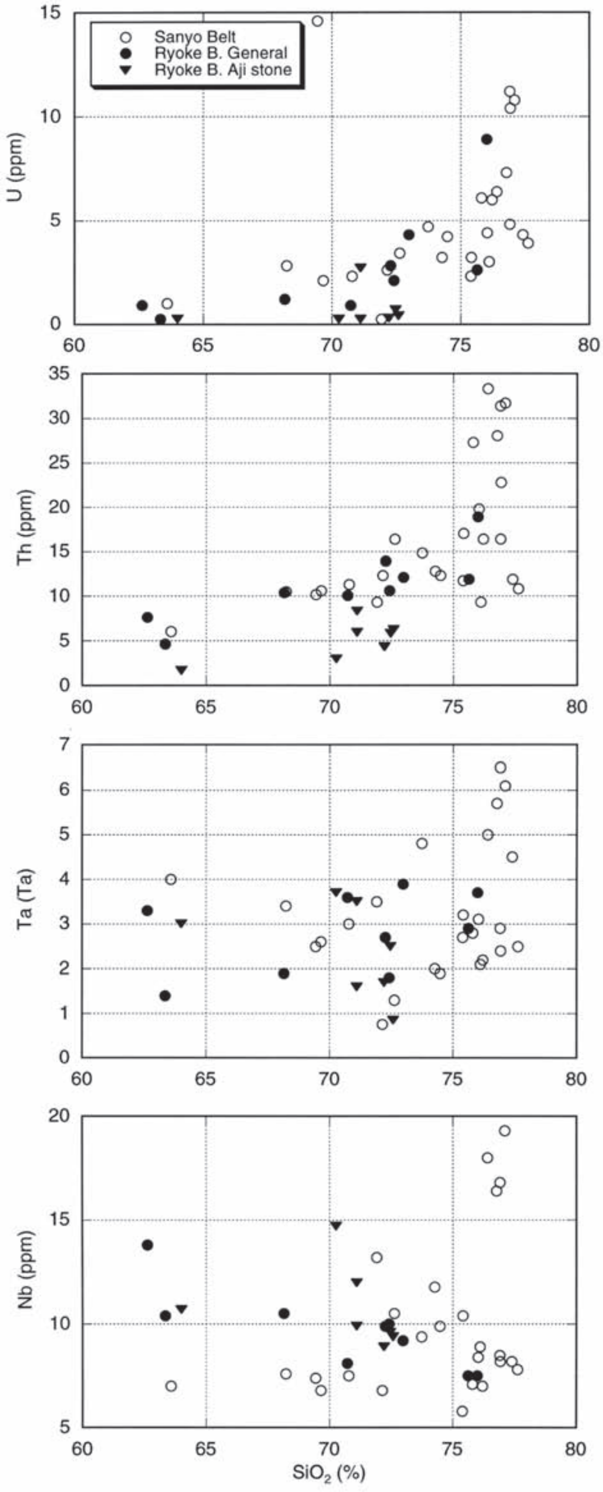

Fig. 7 Variation diagrams for U, Th, Nb and Ta.

5.1 Feldspar Components

Al_2O_3 contents are higher in the Ryoke granitoids than in the Sanyo granitoids (Fig. 3). This tendency is also true in the alumina saturation index (ASI). The highest value of 1.10 was obtained from garnet-bearing muscovite-biotite granite (no. 38, Tables 1, 2), occurring in biotite-quartz gneiss. The lowest value of 0.88 at just north of the Mannari quarries (no. 14, Tables 1, 2) is due to decomposition of feldspar by weak hydrothermal alteration. The ASI varies 0.91 to 1.08 on the Sanyo granitoids, 0.95 to 1.06 on the Ryoke general granitoids, and 1.02 to 1.10 on the Aji granitoids.

Ga which substitutes Al shows no distinct regional variations (Fig. 3). Enclaves contained in the Aji granitoids are higher in Ga than the other granitoids.

There are no clear regional variations on CaO (Fig. 3). Na_2O shows decreasing tendency with SiO_2 in the Ryoke granitoids, but generally increasing with SiO_2 in the Sanyo granitoids. K_2O is enriched in the Sanyo granitoids than the Ryoke granitoids. Two exceptionally high values of 5.11% (no. 27, Tables 1, 2) and 4.61 % (no.26, Tables 1, 2) were obtained from biotite granites in Hon-jima and Hiroshima at just south of the southern border of the Sanyo Belt. These granitoids may belong to the Sanyo granitoids.

Rb substitutes generally K and increases with increasing SiO_2 (Fig. 4). The element is constantly low in the Aji granitoids as 58 to 74 ppm (nos. 32-37, Tables 1, 2). These granitoids are high in Sr although Ca is not particularly high, giving rise to low Rb/Sr ratio of 0.2. On the other hand, muscovite-biotite leucogranite of the Sanyo Belt are highest in Rb, as 370 to 394 ppm (nos. 11-13, Tables 1, 2) but lowest in Sr (10-11 ppm) and also CaO (0.5-0.62 %), thus yielding Rb/Sr ratios of 33.6 - 39.4. These granites are related to wolframite-quartz vein mineralizations. Similar leucogranite at the Ibara tungsten mine stock (no. 3, Tables 1, 2) is also high in Rb (282 ppm) and Rb/Sr ratio (17.6) but low in CaO (0.51 %). Ba substitutes K in general; however, there are poor correlation between Ba and K or Rb.

Pb, Tl and Cs substitute also K; thus they increase with increasing SiO_2 (Fig. 4). There is no difference on the distribution patterns between the granitoids of the Sanyo Belt and Ryoke Belt. However, Cs is rather poor in the Ryoke granitoids, especially of the Aji Granites.

5.2 Mafic Silicates Components

Mafic elements are correlated negatively with SiO_2 (Fig. 5). The total iron is higher in the Ryoke Belt of granite composition, say SiO_2 more than 70 %, while magnesium is lower in the Ryoke granitoids except for the Aji stone. Ti is high in the Aji granitoids and is least in the general Ryoke granitoids. V is definitely higher in the Sanyo granitoids than the Ryoke granitoids. Cr and Cu are erratically distributed (Fig. 5), but Zn and Co are negatively correlated with SiO_2. Co is higher in the Sanyo granitoids than in the Ryoke granitoids.

5.3 Accessory Mineral Components

P is negatively correlated with SiO_2 in the order of abundance of the Aji granitoids, Ryoke general granitoids and Sanyo granitoids. These contents may reflect those of not monazite but apatite. There are no regional variations on Zr, La and Ce (Fig. 6). Two granitoid localities rich in the LREE are grnodiorite at Shido (no. 39, Tables 1, 2) and stressed granodiorite at Nanpudai (no.41, Tables 1, 2). Allanite in trace amounts are easily observed under the microscope in these granitoids; thus La and Ce are considered to be contained in this mineral.

Y is especially high, as 76 to 96 ppm (nos. 3, 11-13, Tables 1, 2), in muscovite-bearing biotite leucogranite related to W-ore deposits which contain trace amount of cassiterite. Both W and Sn are similarly high in the leucogranite as 5.0 - 7.4 ppm and 3.5 to 7.9 ppm, respectively. Mo is, however, not as high as W and Sn in the leucogranite. Y, Mo, W and Sn are generally higher in the Sanyo granitoids than in the Ryoke granitoids, and are most depleted in the Aji granitoids.

U and Th show similar distribution patterns to those of W and Sn, reflecting possibly accessory occurrence of U and Th minerals in the W ore deposits. Ta is similarly distributed to W (Fig. 7). Nb, however, is only abundant in the muscovite-bearing leucogranite as16.4 - 19.3 ppm (nos. 3, 11-13, Tables 1, 2), and no clear differences on the other Sanyo and Ryoke granitoids.

5.4 Rare Earth Elements

Rare earth elements (REE) were analyzed by ICP-MS on the selected granitoids and the results are listed in Table 3. They were normalized by the chondrite values recommended by Ogasawara (1989), and shown in Figs. 8 and 9. The REE patterns of the Sanyo granitoids are shown by three distinct groups.

The first one is shown by pyroxene-hornblende-biotite granodiorite (no. 10, Tables 1, 2), which has intermediate values on the LREE, but low values from Eu to HREE. The second pattern is shown by the pink

Table 3 REE contents of the selected granitoids.

	Sanyo Belt							Ryoke Belt					
	6910104	691099	691092	70TO55	70TO181	72TO287	72TO289	72TO339	72TO317	AJI05A	AJI05B	AJI06A	AJI06B
Rb	63	204	295	176	147	359	407	76	90	66	77	75	75
Sr	318	87	14	93	126	9	9	326	297	340	455	313	348
Ba	532	441	23	644	678	21	25	1,220	1,395	955	390	884	568
La	22.6	26.6	15.9	23.4	33.8	14.5	15.7	60.6	60.0	27.7	17.1	32.5	22.6
Ce	48.9	56.5	38.9	52.6	72.9	37.3	40.5	114	116	55.3	34.9	64.7	44.9
Pr	5.42	6.08	4.98	6.10	8.10	4.78	5.13	11.7	11.7	5.72	3.89	6.70	4.73
Nd	21.3	23.3	20.7	24.3	31.8	20.5	22.1	42.0	42.0	20.8	16.1	24.5	17.8
Sm	4.36	5.28	7.03	5.59	6.61	7.28	7.93	7.29	6.94	3.61	3.61	4.40	3.45
Eu	1.12	0.625	0.071	0.728	0.999	0.067	0.064	1.69	1.68	1.01	0.965	0.982	0.940
Gd	4.32	5.46	9.70	6.05	6.50	9.71	10.4	6.53	6.31	3.25	3.64	3.82	3.31
Tb	0.70	1.04	2.18	1.10	1.16	2.06	2.41	0.97	0.94	0.44	0.59	0.57	0.55
Dy	4.00	6.18	13.7	6.52	6.67	12.6	15.3	5.13	5.15	2.21	3.12	2.89	2.92
Ho	0.84	1.34	3.16	1.46	1.46	2.81	3.47	1.04	1.06	0.45	0.63	0.57	0.58
Er	2.47	3.95	9.75	4.46	4.41	8.23	10.5	2.86	3.04	1.22	1.66	1.56	1.58
Tm	0.356	0.610	1.55	0.714	0.677	1.31	1.68	0.403	0.423	0.166	0.226	0.221	0.219
Yb	2.25	3.87	9.77	4.51	4.28	8.33	10.6	2.40	2.56	1.04	1.20	1.36	1.36
Lu	0.349	0.600	1.51	0.721	0.664	1.27	1.57	0.367	0.387	0.156	0.174	0.211	0.195
Y	24.4	38.8	103	42.5	40.8	77.3	106	27.5	28.9	12.3	16.9	15.7	15.9
Th	6.22	12.6	30.0	15.1	14.3	29.8	31.6	11.6	12.2	5.93	1.82	6.99	3.63
U	1.16	2.77	6.92	3.92	3.39	9.21	8.65	1.23	1.10	0.55	0.45	0.98	0.71

Mannari Granite (nos. 14, 15, Tables 1, 2) and biotite granite at Ibara (no. 3, Tables 1, 2), which have higher LREE but intermediate HREE with weak Eu anomaly (Fig. 8). The third pattern is shown by muscovite-biotite leucogranites related to wolframite mineralizations. They have flat pattern with strong Eu anomalies, which is characteristic pattern of the Naegi Granite (Ishihara and Wu, 2001), and is considered as fractionated I-type granite (Champion and Chappell, 1992).

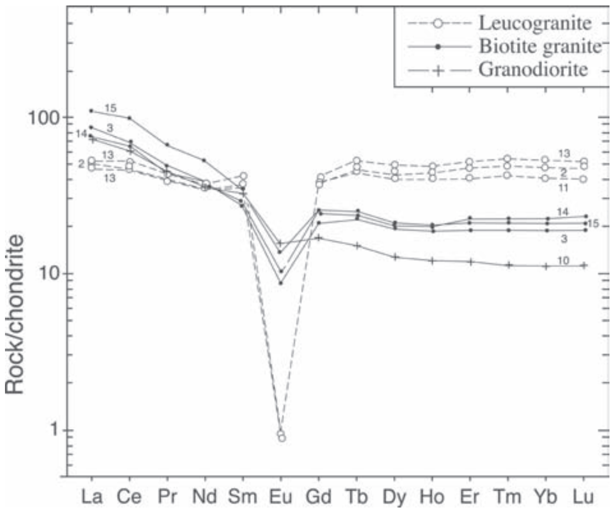

Fig. 8 REE pattern of the Sanyo granitoids.

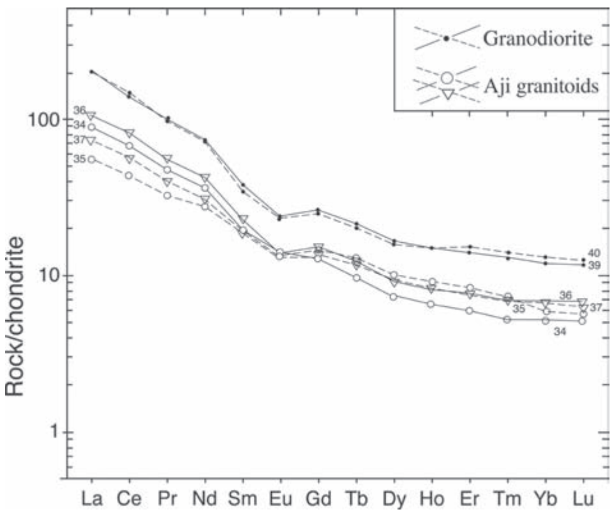

Fig. 9 REE pattern of the Ryoke granitoids.

From the Ryoke Belt, "Older" granodiorite of nos. 39 and 41 (Tables 1, 2), and "Younger" Aji granitoids were selected. The older granidiorites show similar REE pattern to that of the no.10 granodiorite of the Sanyo Belt, which may be younger granitoids relative to the Ryoke granitoids. The younger Aji granitoids show similar patterns to the Ryoke older granitoids, but depleted in all the REE (Fig. 9). Two mafic and intermediate enclaves exhibit similar REE patterns to those of the host granitoids.

6. Source of the Granitoids

Late Cretaceous granitoids of the Sanyo and Ryoke Belts belong to ilmenite series and have relatively higher $\delta^{18}O$ (Ishihara and Matsuhisa, 2002) and lower, negative $\delta^{18}S$ values (Ishihara and Sasaki, 2002) than

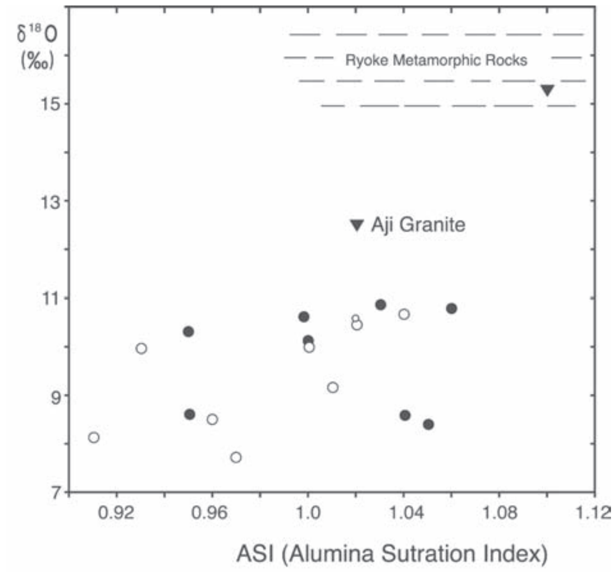

Fig. 10 $\delta^{18}O$ vs. ASI of the Sanyo granitoids (open circle) and Ryoke granitoids (solid circle).

magnetite-series granitoids, implying that the granitoids were generated involving such reducing agents of sedimentary origin as organic carbon and/or biogenic sulfur.

Whole rock $\delta^{18}O$ values of the coarse-grained granodiorite-monzogranite of the Sanyo Belt vary from 8.1 to 10.7 permil, and the average is 9.7 permil (n=8). Similar granitoids of the Ryoke Belt range from 8.4 to 10.9 permil, and averaged as 9.9 permil, which is slightly higher than that of the Sanyo Belt. Alumina saturation index is also high in the Ryoke granitoids. The alkali contents are, however, higher in the Sanyo granitoids than in the Ryoke granitoids. Therefore, the sources of the Sanyo granitoids could well be composed of more felsic igneous rocks than sedimentary components, while the ratio may be reversed in the Ryoke granitoids. REE contents of the batholithic granidiorites of both the Sanyo and Ryoke Belts show different abundances but the same patterns decreasing to the HREE side, without negative Eu anomaly. These patterns may imply existence of garnet and/or amphibole in the source region.

Among fine-grained granitoids, the Aji granitoids are high in $\delta^{18}O$ values(12.5‰) and ASI (1.02), but low in

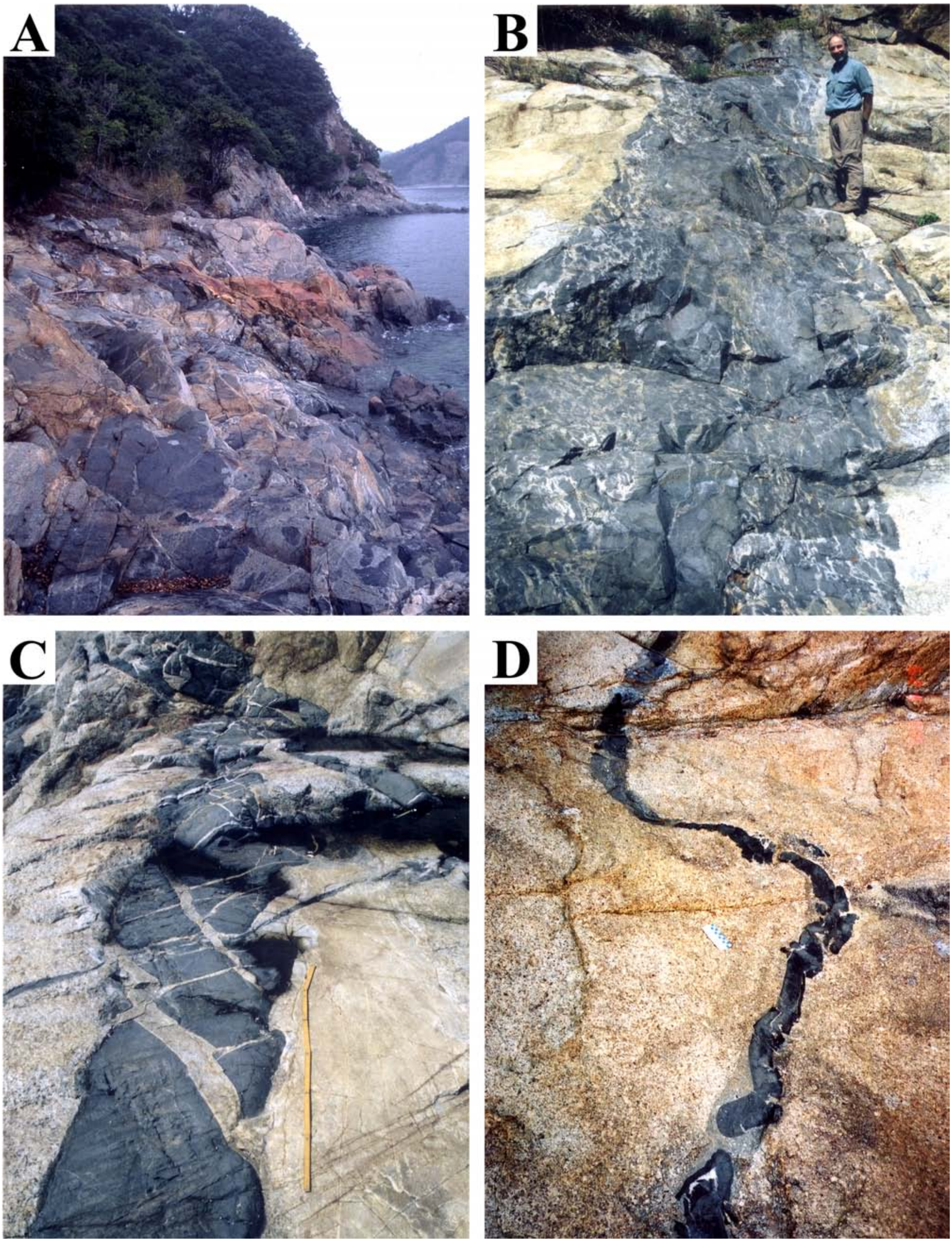

Fig. 11 Magma mingling and synplutonic dikes observed along the southern coast of the Tanoura Peninsula, Shodo-shima. A, General view of the coast; B, Mafic and fragmented dike (N45°W, stage II of Yokoyama, 1984) in the host granitoids; C, Mafic dike (stage I of Yokoyama, 1984) cut by the host granitic veins ("backed vein," scale is 1 m); D, Basalt-hybrid composite dikelet in the host granitoid, indicating a deep to shallow level of the magma mingling (scale is 10 cm).

K_2O content (Fig. 3). The granitoids contain more commonly igneous enclaves than sedimentary ones. Thus, they are considered originated in a sediments-dominant crustal materials, not having much illite components. A similar fine-grained rock having garnet-muscovite-biotite assemblage is extremely high as 15.6 permil (no. 18, Tables 1, 2). As mentioned previously, the Ryoke metamorphic rocks are not well remained from erosion in the Okayama-Kagawa region. Limited studies indicate that the metamorphic rocks could contain more mafic igneous rocks than, e.g., in the Chubu District, which is composed of sandstones, shales and cherts. An average $\delta^{18}O$ value of the metamorphic rocks in the Chubu District is estimated to be 15.6 permil (Ishihara and Matsuhisa, 2002). It can be assumed that the garnet-muscovite-biotite granite in Shido township could be originated 100 % in sedimentary rocks of psammitic and pelitic origin.

In the Sanyo Belt, leucogranites are considered as highly fractionated, chilled phase of the biotite granite for the mode of occurrence and the chemical characteristics. The fluid phase concentrating metals such as W, Sn, U, etc, were deposited along fractures in the solidifying magmas. One leucogranite sample near the tungsten deposits with slight lower $\delta^{18}O$ value of 7.7 permil than that of the coarse-grained biotite granite, may be due to meteoric water interaction, because the leucogranite occurs in the highest level of the granitic batholith.

As mentioned previously, the major batholithic granitoids are more mafic in the Ryoke Belt than in the Sanyo Belt. Many small mafic igneous bodies occur with granitoids in the Ryoke Belt, but are scarce in the Sanyo Belt. They are generally fine- to medium-grained, brown and pale green amphiboles and plagioclase rocks, which may contain small amount of biotite and pyroxene. They are generally holocrystalline but partly diabasic in texture, and called gabbroids in this paper though sometimes called meta-diabase (Kutsukake *et al.*, 1979). A few examples of chemistry are given in Table 2 (nos. 42-47).

These mafic rocks show mingling textures with the Ryoke granitoids at many places along the northern coast of the mainland Kagawa Prefecture (e.g., Shonai Peninsula - Awashima, Yashima) and Shodo Islands (Yokoyama, 1984; Yoshikura and Atsuta, 2000). Along the southern coast of the Tanoura peninsula (Fig. 11A), the mafic rocks occur as NNW-trending synplutonic dikes (Fig. 11B), which is cut by granitic veins (Fig. 11C). The mafic dikes are followed by an intermediate mixed magma (Figs. 11 C, D) and chilled basaltic dike (Fig. 11D). All of these evidences indicate that the mafic magmas were active at the time of the granitoid intrusion and emplacement, and the two magmas interacted from a deep to a shallow level.

Initial $^{87}Sr/^{86}Sr$ (Sr_0, Table 1) of these gabbroids and granitoids are similar; i.e., 0.7081 (no. 45, Table 1) vs. 0.7078 (no.31), respectively, in the Ryoke Belt, and 0.7071 (no. 44) and 0.7075 (no. 43) vs. 0.7077 (no. 10) , respectively, in the Sanyo Belt, implying they are chemically homogenized during the intrusions. These facts may further imply that the mafic magmas were closely associated with the generation of the granitic magmas. The mafic magmas provided both heat and materials to the granitic magmas generated within the continental crust. Wherever the mafic magmas were abundantly mixed with the crust-born felsic magmas, the bulk composition became granodiorite, as seen in the Ryoke Belt.

None or little mixing formed coarse-grained biotite granites of the Sanyo Belt. Some felsic parts of the biotite granite and fine-grained muscovite-biotite leucogranite of the Sanyo Belt with distinct Eu anomaly is considered formed by an extreme magmatic fractionation of the coarse-grained granitoids.

References

Champion, D. C. and Chappell, B. W. (1992) Petrogenesis of felsic I-type granites; An example from northern Queensland. *Trans. Royal Soc. Edingburgh: Earth Sci.*, **83**, 115-126.

Hida, N., Shimazu, M. and Igarashi, T. (1961) Granitic rocks and related uranium metallic ore deposits in Sanyo District. In *Natural Occurrence of Uranium in Japan*. Rept. Geol. Surv. Japan no. 190, 68-79 (in Japanese with English abstract).

Ishihara, S. (1971) Modal and chemical compositions of the granitic rocks related to the major molybdenum and tungsten deposits in the Inner Zone of Southwest Japan. *Jour. Geol. Soc. Japan*, **77**, 441-452.

Ishihara, S. (1991) The Aji stone: The historical and modern use and its geologic background. *Chishitsu News*, no. 441, 60-67 (in Japanese).

Ishihara, S. (2002) Chemical characteristics of the mineralized granitoids (I). Mo and W provinces of the Inner Zone of Southwest Japan. *Bull. Geol. Surv. Japan*, **53**, 657-671 (in Japanese with English abstract).

Ishihara, S. and Imaoka, T. (1999) A proposal of caldera-related genesis for the Roseki deposits in the Mitsuishi mining area, Southwest Japan. *Resource Geol.*, **49**, 157-162.

Ishihara, S. and Matsuhisa, Y. (2002) Oxygen isotopic constraints on the geneses of the Cretaceous-Paleogene granitoids in the Inner Zone of southwest Japan. *Bull. Geol. Surv. Japan*, **53**, 409-426.

Ishihara, S. and Sasaki, A. (2002) Paired sulfur isotopic belts: Late Cretaceous-Paleogene ore deposits of Southwest Japan. *Bull. Geol. Surv. Japan*, **53**, 461-477.

Ishihara, S. and Terashimas, S. (1977) Chemical variation of the Cretaceous granitoids across southwestern Ja-

pan —Shirakawa-Toki-Okazaki transection—. *Jour. Geol. Soc. Japan*, **83**, 1-18.
Ishihara, S. and Wu, C. Y. (2001) Genesis of late Cretaceous-Paleogene granitoids with contrasting chemical trends in the Chubu District, central Japn. *Bull. Geol. Surv. Japan*, **52**, 471-491.
Japan Mining Industry Association (JMIA, 1968) *Ore Deposits of Japan*, Vol. II, 682 p. (in Japanese).
Kagami, H., Honma, H., Shirahase, T. and Nureki, T. (1988) Rb-Sr whole rock isochron ages of granites from northern Shikoku and Okayama, Southwest Japan: Implications for the migration of the late Cretaceous to Paleogene igneous activity in space and time. *Geochem. J.*, **22**, 69-79.
Kagami, H., Iizumi, S., Tainosho, Y. and Owada, M. (1992) Spatial variations of Sr and Nd isotope ratios of Cretaceous-Paleogene granitoid rocks, Southwest Japan Arc. *Contrib. Mineral. Petrol.*, **112**, 165-177.
Kanaya, H. and Ishihara, S. (1973) Regional variation of magnetic susceptibility of the granitic rocks in Japan. *Jour. Japan. Assoc. Miner. Petrol. Econ Geol.*, **68**, 211-224 (in Japanese with English abstract).
Kutsukake, T., Hayama, Y., Honma, H., Masaoka, K., Miyagawa, K., Yamada, T. and Yoshida, M. (1979) Geology and petrography of the Ryoke belt in the Shodo-shima island and the eastern Sanuki region. *Mem. Geol. Soc. Japan*, no. 17, p.47-68 (in Japanese with English abstract).
Makimoto, H., Toshimitsu, S., Takahashi, Y., Mizuno, K., Komazawa, M. and Shichi, R. (1995) *Geological map of Japan 1: 200,000, Tokushima*. Geol. Surv. Japan (in Japanese).
Matsuura, H., Kurimoto, C., Yoshida, F., Saito, Y., Makimoto, H., Toshimitsu, S., Iwaya, T., Komazawa, M. and Hiroshima, T. (2002) *Geological map of Japan 1: 200,000, Okayama and Marugame*. Geol. Surv. Japan (in Japanese).
Nureki T., Asami, M. and Mitsuno, C. (1979) Granitic rocks in central to southern Okayama Prefecture. *Mem. Geol. Soc. Japan*, no. 17, p.35-46.
Nureki T., Asami, M., Shibata,T. and Ohira, K. (1982) The Ryoke Belt of the southwestern part of Shiaku-shoto area in the Seto Inland Sea. *Jour. Geol. Soc. Japan*, **88**, 499-510 (in Japanese with English abstract).
Ogasawara, M. (1989) Geochemisty of rare-earth elements. *Mining Geol.*, **39**, 166-176 (in Japanese with English abstract).
Peacock, M. A. (1931) Classification of igneous rock series. *Jour. Geol.*, **39**, 54-67.
Sato, M. (1948) *Explanatory text of the geological map of Japan, Takamatsu*. Scale 1:75,000, 56 p., Geol. Surv. Japan (in Japanese with English abstract).
Shibata, K. and Ishihara, S. (1979) Initial $^{87}Sr/^{86}Sr$ ratios of plutonic rocks in Japan. *Contrib. Mineral. Petrol.*, **70**, 381-390.
Yokoyama, S. (1984) Geological and petrological studies of late Mesozoic dyke swarms in the Inner Zone of Southwest Japan. *Geol. Rept. Hiroshima Univ.*, **24**, 1-63. (in Japanese with English abstract).
Yoshikura, S. and Atsuta, S. (2000) Magma mingling and mixing phenomena recorded in granitic bodies. *Chikyu Monthly, Gogai* no. 30, 140-145 (in Japanese).
Yuhara, M., Kagami, H. and Nagai, K. (2000) Geochronological characterization and petrogenesis of granitic rocks in the Ryoke belt, Southwest Japan Arc: constraints from K-Ar, Rb-Sr and Sm-Nd systematics. *The Island Arc.*, **9**, 64-80.

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付録　化学分析試料の産地

No.	Field No.	Locality
1.	71TO281	岡山県川上郡成羽町吉木, 山宝鉱山対面
2.	691099	岡山県井原市井原町花野
3.	691092	岡山県井原市井原町古谷奥, 井原鉱山
4.	71TO267	岡山県浅口郡鴨方町小坂東, 谷口
5.	71TO263	岡山県倉敷市玉島黒崎岩谷西方
6.	71TO258	岡山県倉敷市水島亀島町
7.	71TO257	岡山県倉敷市呼松町北方
8.	71TO255	岡山県倉敷市下津井北西方1km
9.	6910105	岡山県総社市新庄下大山
10.	6910104	岡山県岡山市甫崎
11.	72TO287	岡山県総社市水別, 岡山タングステン鉱山母岩
12.	6910157	岡山県倉敷市西坂北方
13.	72TO289	岡山県倉敷市西坂, 三吉鉱山対面
14.	70TO55	岡山市首部（万成北方）"万成石"
15.	70TO181	岡山市矢坂"万成石"
16.	MAN01	岡山市矢坂東町保井堂3140 浮田丁場
17.	70TO47	岡山県御津郡建部町西谷
18.	71TO243	岡山県邑久郡邑久町松峠
19.	71TO248	岡山県児島郡東児町梶岡
20.	71TO249	岡山県玉野市田井西方
21.	72TO301	香川県小豆郡土庄町豊島甲崎, 石切場
22.	72TO303	香川県小豆郡土庄町豊島鰯山海岸
23.	72TO304	香川県小豆郡土庄町小瀬北方, 重岩, 石切場
24.	72TO305	香川県小豆郡土庄町大谷北東方1km
25.	72TO308	香川県小豆郡土庄町大部, 赤嶽乙201石切場
26.	72TO385	岡山県都窪郡庄村山地
27.	72TO390	香川県丸亀市本島町尻浜-生の浜
28.	72TO375	香川県三豊郡詫間町大浜名部戸
29.	72TO367	香川県仲多度郡満濃町炭所西, 常包橋下
30.	72TO363	香川県綾歌郡国分寺町新居奥谷
31.	72TO362	香川県綾歌郡国分寺町下福家伽藍山南麓
32.	72TO329	香川県本田郡庵治町丸山 田渕丁場"小目"
33.	72TO330	香川県本田郡庵治町丸山 木村丁場"中目"
34.	AJI05	香川県本田郡庵治町丸山 中谷丁場
35.	AJI05e	香川県本田郡庵治町丸山 中谷丁場
36.	AJI06	香川県本田郡庵治町丸山 中谷丁場
37.	AJI06e	香川県本田郡庵治町丸山 中谷丁場
38.	72TO337	香川県大川郡志度町本小田,神社下
39.	72TO339	香川県大川郡志度町鴨庄,西側の山地
40.	72TO340	香川県大川郡大川町砕石（くだきいし）
41.	72TO317	香川県小豆郡内海町橘峠北200m
42.	71TO264	岡山県笠岡市長浜西方500m
43.	71TO273	岡山県小田郡矢掛町東川面,向山
44.	72TO354	香川県高松市神在川窪町長磯
45.	72TO322	香川県小豆郡内海町谷切北端
46.	72TO333	香川県木田郡牟礼町源氏ヶ峯西方
47.	NGA04	香川県高松市屋島北端長崎鼻

地名対照表：Aji－庵治, Awashima－粟島, Fukuwatari－福渡, Ibara－井原, Keigamaru－経ヶ丸, Mannari－萬成, Mannou－満濃, Miyoshi－三吉, Obie－帯江, Sankei－三敬, Shido－志度, Shirotori－白鳥, Shonai－荘内, Tanoura－田浦.

山陽帯と領家帯の白亜紀後期花崗岩類の化学的性質の対照性：岡山南部-香川断面の場合

石原舜三

要　旨

西南日本内帯に属する岡山県南部-香川県地域の白亜紀後期花崗岩類（山陽帯，25試料；領家帯，16試料）の主成分・微量成分について分析し，両地帯の特性を明らかにした．また斑れい岩（6試料）の役割についても言及した．これら深成岩類を領家変成岩類とタングステン鉱床の分布域から，山陽帯と領家帯に地帯区分する．山陽帯花崗岩類は粗粒～中粒花崗閃緑岩-花崗岩バソリス，および細粒花崗閃緑岩～花崗岩ストックからなり，ごく少量の斑れい岩類を伴う．細粒花崗岩の一部は白雲母-黒雲母優白花崗岩で，タングステン鉱床を伴っている．領家花崗岩類は同様に，粗粒～中粒花崗閃緑岩-花崗岩バソリスそして細粒花崗岩ストック（庵治花崗岩）からなり，頻繁に細粒斑れい岩類を伴う．また片麻状構造や鏡下での鉱物の変形から固結時の偏圧の影響が推察される．庵治花崗岩はストック状ではあるが，鉱床を伴わない．

山陽帯と領家帯の花崗岩類を，バソリス状粗粒岩類，ストック状細粒岩類に分けて比較すると，次のような特徴がある．山陽帯花崗岩類は領家帯花崗岩類に比べてシリカとアルカリ(特にK_2O)に富み，アルミナに乏しく，アルミナ飽和指数が低い，Rbは山陽帯花崗岩類に多く含まれ、特に細粒優白花崗岩で著しく高く，領家帯の庵治花崗岩で最も低い．SrはRbと全く逆の傾向を示し，従って Rb/Srは優白花崗岩で最も高く(～39)，庵治花崗岩で最も低い(0.2)．Rb/Srはマグマ分化度を示すから，庵治花崗岩は未分化の，優白花崗岩は著しく分化したマグマから固結したものと考えられる．この分化花崗岩はY, W, Sn, U, Th, Ta, Nbにも富んでおり，その一部は花崗岩の周辺に鉱床を形成した．

コンドライトで規格化した希土類元素パターンは(1) 軽希土類で中間的な値を持ち，Euから重希土類にかけて低下するもの：山陽帯の花崗閃緑岩や領家帯の花崗岩類で一般的，(2) 上記より全般的に希土類に富み，若干のEu負異常を持つもの：桃色の万成花崗岩で代表される，(3)重希土類に富み，全体的に水平パターンを示し，斜長石の分別晶出による著しいEu 負異常を示すもの：これはタングステン鉱化を伴なう優白花崗岩類で特徴的である．庵治花崗岩類は領家帯では最末期花崗岩と考えられているが，このような分化パターンを示さない．

領家帯花崗岩類は山陽帯花崗岩類よりアルミナ飽和指数が高く，アルカリ含有量が低いから，その原岩の堆積岩の比率が高い可能性があり，酸素同位体データ（Ishihara and Matsuhisa, 2002）はそれを裏づけている．庵治花崗岩や片麻岩中の白雲母-黒雲母花崗岩の$\delta^{18}O$値は特に高く，その原岩に堆積岩比率が高かったことを示すが，K_2O含有量は低くイライトに富む頁岩が少なかった可能性がある．山陽帯と領家帯花崗岩類の平均的組成は領家帯でやや苦鉄質である．苦鉄質岩は細粒斑れい岩類として領家帯にしばしば産出し，花崗岩質マグマとの間における幅広い深度の混交・混合組織を示す．従って領家帯では上部マントルからの苦鉄質マグマの上昇量が多く，それが広域変成帯を生じる熱を供給し，更に大陸地殻の火成・堆積岩起源の珪長質マグマと混交・混合することにより，山陽帯よりやや苦鉄質な花崗岩類を形成したものと考えられる．