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Notes and Comments

Trace and rare earth elements compositions of granitic rocks in Awaji Island, Southwest Japan Arc

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Abstract: Seven trace elements (As, Cr, Ga, Pb, S, Th and V) compositions of granitic rocks in Awaji Island were analyzed using X-ray fluorescence spectrometer at Fukuoka University. Rare earth elements (REE) compositions of some samples of the Granitic Rocks II and III from the island were also determined by instrumental neutron activation analysis at Ehime University. The variation trends of most trace elements of Granitic Rocks I, II and III overlap in Harker's diagrams. Samples, which were off main trend of major and trace elements in Harker's diagrams in previous analyses (Yuhara *et al*., 1998), are often off the variation trends of these trace elements in this study as well. Therefore, these trace elements are also useful for investigation of chemical variations of granitic rocks. Chondrite-normalized REE patterns are enriched in LREE and flat in HREE, and fit in those of granitic rocks in the Ryoke metamorphic belt.

Keywords: Awaji Island, Ryoke metamorphic belt, granitic rocks, trace elements, rare earth elements.

1. Introduction

The Ryoke metamorphic belt is a typical low-pressure / high-temperature type metamorphic belt formed at a convergent plate margin, and is characterized by intensive felsic magma activity (e.g. Okudaira *et al*., 2000). Thus, explication of generation, differentiation, rising and intrusion processes of granitic magmas and transition of their source materials are indispensable for understanding formation process of the Ryoke belt. The chemical compositions of granitic rocks are necessary for these analyses. However, not enough data are obtained from all granitic rocks in the Ryoke metamorphic belt.

Takahashi (1995) and Yuhara *et al*. (1998) have reported major and 7 trace elements compositions of granitic rocks in Awaji Island, respectively. We determined 7 trace elements compositions and rare earth element (REE) compositions of the same samples. Here, we report the features of these compositions.

2. Geological outline

Based on lithology and field occurrence, granitic rocks in Awaji Island are divided into 11 bodies, which are composed of three groups: Granitic Rocks I, II and III (Takahashi and Hattori, 1992; Fig. 1). The Granitic Rocks I, II and III correspond to the Older Ryoke Granitic Rocks, Younger Ryoke Granitic Rocks and San-yo type granitic rocks, respectively. Based on Sr and Nd isotopic compositions, these granitic rocks belong to the South Zone (Kagami *et al*., 2000). The field occurrence and petrography of these granitic rocks are reported by Huzita and Maeda (1984), Nakajima *et al*. (1985, 1986), Mizuno *et al*. (1990), Takahashi *et al*. (1992), Takahashi and Hattori (1992) and Takahashi (1995).

The Granitic Rocks I, distributed in the center of the district, are weakly deformed exhibiting foliation, and are partly recrystallized by intrusion of the Granitic Rocks II and III. The Granitic Rocks I are composed of the Shio Granite (K-feldspar porphyritic biotite granite to granodiorite), Tsushigawa Granite (coarse-grained hornblende-biotite granite to granodiorite), Shizuki Tonalite (medium-grained hornblende-biotite tonalite to granodiorite) and Ei Granodiorite (medium-grained hornblende- biotite granodiorite to granite).

The Granitic Rocks II are massive, and intruded into

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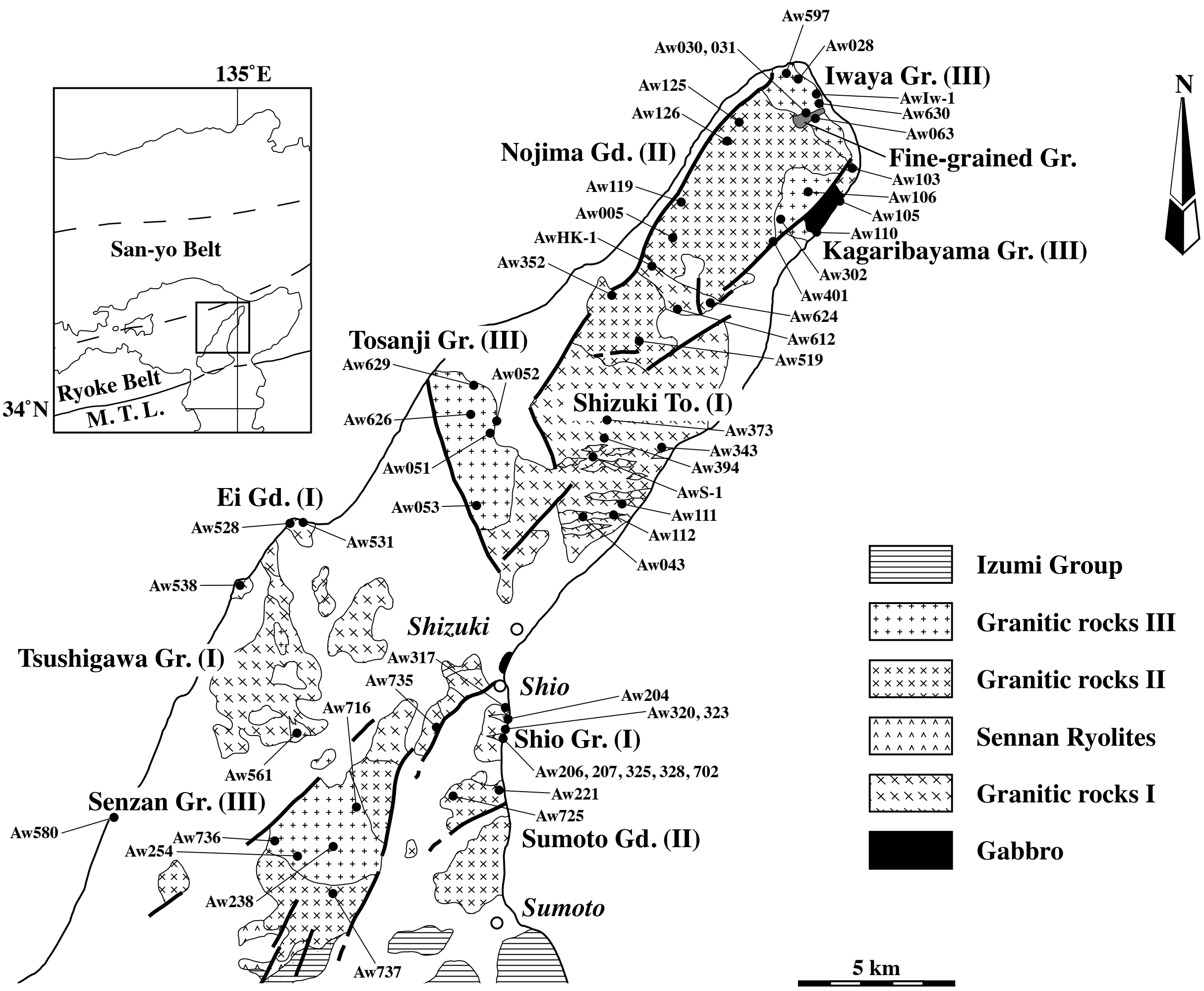

Fig. 1 Geological map of pre-Tertiary basement rocks in Awaji Island showing sample localities (modified from Takahashi, 1995).

the Granitic Rocks I at the south and north parts. The Granitic Rocks II are composed of the Sumoto Granodiorite (medium-grained hornblende-biotite granodiorite to quartz monzodiorite) and Nojima Granodiorite (medium-grained hornblende-biotite granodiorite to granite).

The Granitic Rocks III are massive granitic rocks, which intruded into the Granitic Rocks I and II, but did not have contact metamorphic effects on the Granitic Rocks II. The Granitic Rocks III are composed of the Tosanji Granite (medium-grained biotite granite to granodiorite), Senzan Granite (medium- to fine-grained biotite granite to granodiorite), Kagaribayama Granite (fine- to medium-grained leucocratic biotite granite), Iwaya Granite (medium- to coarse-grained biotite granite to granodiorite) and fine-grained granite.

K-Ar mineral ages and Rb-Sr whole-rock isochron ages of granitic rocks in Awaji Island were reported by Takahashi (1992) and Yuhara *et al*. (1998), respectively (Table 1). A K-Ar hornblende age of 89.4 ± 4.5 Ma (Shizuki Tonalite), K-Ar biotite ages of 72.7 ± 3.6 Ma and 84.0 ± 4.2 Ma (Tsushigawa Granite), 78.7 ± 3.9 Ma and 88.0 ± 4.4 Ma (Shizuki Tonalite) have been reported from the Granitic Rocks I. A K-Ar hornblende age of 89.6 ± 4.5 Ma, a K-Ar biotite age of 84.6 ± 4.5 Ma and an Rb-Sr whole-rock isochron age of 99 ± 11 Ma have been reported from the Sumoto Granodiorite of the Granitic Rocks II. A K-Ar hornblende age of 87.7 ± 4.4 Ma, a K-Ar biotite age of 80.9 ± 4.0 Ma and an Rb-Sr whole-rock isochron age of 95 ± 15 Ma have been reported from the Nojima Granodiorite. Age data for the Granitic Rocks III include a K-Ar biotite age of 86.7 ± 4.3 Ma and an Rb-Sr whole-rock isochron age of 83.8 ± 4.9 Ma from the Tosanji Granite, a K-Ar biotite age of 69.5 ± 3.5 Ma and an Rb-Sr whole-rock isochron age of 84.1 ± 9.0 Ma from the Senzan Granite, an Rb-Sr whole-rock isochron age of 75.5 ± 5.8 Ma from the Kagaribayama Granite, K-Ar biotite ages of 70.3 ± 3.5 Ma and 80.9 ± 4.0 Ma and an Rb-Sr whole-rock isochron age of 76.4 ± 3.9 Ma from the Iwaya

Table 1 Radiometric ages of granitic rocks in Awaji Island.

		K-Ar age (Ma)*		Rb-Sr whole-rock
		Hornblende	Biotite	isochron age (Ma)**
Granitic Rocks I	Shizuki Tonalite	89.4 ± 4.5	78.7 ± 3.9	
			88.0 ± 3.9	
	Tsushigawa Granite		72.7 ± 3.6	
			84.0 ± 4.2	
Granitic Rocks II	Sumoto Granodiorite	89.6 ± 4.5	84.6 ± 4.5	99 ± 11
	Nojima Granodiorite	87.7 ± 4.4	80.9 ± 4.0	95 ± 15
Granitic Rocks III	Tosanji Granite		86.7 ± 4.3	83.8 ± 4.9
	Senzan Granite		69.5 ± 3.5	81.4 ± 9.0
	Kagaribayama Granite			75.5 ± 5.8
	Iwaya Granite		70.3 ± 3.5	76.4 ± 3.9
			80.9 ± 4.0	
	fine-grained granite			74 ± 12

*:Takahashi (1992), **: Yuhara *et al.* (1998).

Granite, and an Rb-Sr whole-rock isochron age of 74 ± 12 Ma from fine-grained granite.

3. Whole-rock trace element composition

Trace elements (As, Cr, Ga, Pb, S, Th and V) analyses were undertaken for samples, which were reported major and trace elements compositions by Takahashi (1995) and Yuhara *et al*. (1998), by XRF (RIGAKU ZSX100e) at Fukuoka University, after the methods of Yuhara and Taguchi (2003a, b), Yuhara *et al*. (2004) and Takamoto *et al*. (2005). Cr, S and V were determined using glass bead, and As, Ga, Pb and Th contents using powder pellet, respectively. Trace elements concentrations are listed in Table 2.

Except for the Granitic Rocks I, variation range of SiO_2 content in each body is narrow (Takahashi, 1995). Major elements compositions of these granitic rocks represent linear trend on the Harker's diagrams (Takahashi, 1995). The Granitic Rocks II and III have relatively higher SiO_2 content than the Granitic Rocks I. Trace elements compositions also show linear trends, whereas the Shio Granite has relatively higher Rb content (Yuhara *et al*., 1998). Some samples are off the main trends. Yuhara *et al*. (1998) did not use these samples to measure Rb-Sr whole-rock isochron age. The Granitic Rocks I, II and III are plotted in the field of volcanic-arc type granite in the Y vs. Nb and Rb vs. (Y+Nb) discriminative diagrams as defined by Pearce *et al*. (1984) as for the Ryoke granitic rocks (Yuhara *et al*., 1998). Arsenic (As) contents are low, and are lower than lower limit of detection in almost samples. As for major and trace elements (Takahashi, 1995; Yuhara *et al*., 1998), variation trends of the Granitic Rocks I, II and III overlap in Harker's diagrams (Fig.2). S is scattered, and does not show an obvious trend. Pb and Th increase, whereas Ga and V decrease with increasing SiO_2 contents. Abundances of Cr are nearly constant except for some samples. Samples, which were off the main trend of major and trace elements in Harker's diagrams in previous analyses (Yuhara *et al*., 1998), are often off variation trends of these trace elements in this study as well. The results suggest that these trace elements compositions are also useful for investigation of chemical variations of granitic rocks and for sample selection on Rb-Sr whole-rock isotopic analyses (Yuhara, 1994).

4. Rare earth element composition

REE and trace elements (Cs, Hf and U) analyses were carried out for samples selected from the Granitic Rocks II and III by instrumental neutron activation analysis using a neutron source at the Research Reactor Institute, Kyoto University, from which the Rb-Sr whole-rock isochron ages were obtained by Yuhara *et al*. (1998). The analytical procedures are described in Sano *et al*. (1996). REE and trace elements concentrations are listed in Table 3.

Chondrite-normalized REE patterns of the Granitic Rocks II and III are enriched in light REE (LREE) and flat in heavy REE (HREE) (Fig.3). The Granitic Rocks II do not show Eu anomalies. REE patterns of the Granitic Rocks III can be divided into two groups. One including the Tosanji, Kagaribayama and Iwaya Granites shows negative Eu anomalies. The other group, which includes the Senzan Granite, shows positive Eu anomaly and low HREE. These patterns are within those of granitic rocks in the Ryoke metamorphic belt (Fig.3).

5. Summary

Seven trace elements (As, Cr, Ga, Pb, S, Th and V) compositions of granitic rocks in Awaji Island were analyzed using XRF. In addition, rare earth and trace elements compositions of some samples were determined by instrumental neutron activation analysis. The varia-

Table 2 Trace element concentrations of granitic rocks in Awaji Island.

	Granitic Rocks I											
	Shio Gr.						Tsushigawa Gr.					
Sample No.	Aw204	Aw206	Aw207	Aw325	Aw328	Aw702	AwHK-1	Aw043	Aw112	Aw323	Aw538	Aw612
As (ppm)	n.d.	n.d.	<4	n.d.	n.d.	<4	n.d.	n.d.	n.d.	<4	n.d.	n.d.
Cr	8	11	5	8	28	9	5	<4	26	4	5	<4
Ga	20	19	18	17	20	18	15	18	17	20	16	21
Pb	16	20	21	22	11	15	28	21	19	18	30	39
S	31	25	22	25	75	75	n.d.	n.d.	n.d.	11	17	n.d.
Th	18	13	24	16	<4	38	12	14	15	15	15	13
V	25	22	20	14	158	31	7	15	11	15	8	11

	Granitic Rocks I								
	Shizuki To.							Ei Gd.	
Sample No.	AwS-1	Aw111	Aw317	Aw320	Aw343	Aw373	Aw394	Aw528	Aw531
As (ppm)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	7	65	13	9	11	11	16	7	<4
Ga	22	21	20	18	22	20	20	19	16
Pb	12	14	15	25	12	10	11	26	20
S	6	7	47	176	4	34	166	37	5
Th	10	10	4	12	8	8	7	11	14
V	22	27	38	31	37	41	63	4	5

	Granitic Rocks II											
	Nojima Gd.							Sumoto Gd.				
Sample No.	Aw005	Aw119	Aw125	Aw126	Aw352	Aw519	Aw624	Aw221	Aw580	Aw725	Aw735	Aw737
As (ppm)	<4	n.d.	n.d.	n.d.	n.d.	<4	n.d.	n.d.	<4	n.d.	n.d.	n.d.
Cr	9	67	9	<4	9	8	5	8	7	8	6	9
Ga	18	18	16	18	17	15	19	18	18	18	18	21
Pb	15	18	18	26	16	26	19	16	19	16	20	14
S	19	18	9	5	7	1406	13	<3	n.d.	41	n.d.	122
Th	12	11	12	13	12	11	8	10	13	11	12	5
V	36	27	32	13	33	27	24	17	17	18	17	8

	Granitic Rocks III											
	Kagaribayama Gr.					Iwaya Gr.					Tosanji Gr.	
Sample No.	Aw105	Aw106	Aw110	Aw302	Aw401	AwIw-1	Aw028	Aw063	Aw103	Aw597	Aw052	Aw053
As (ppm)	<4	<4	n.d.	n.d.	n.d.	<4	n.d.	<4	<4	n.d.	n.d.	n.d.
Cr	5	27	6	<4	5	4	4	55	67	6	<4	36
Ga	15	15	15	14	16	17	16	16	17	16	16	18
Pb	33	24	25	35	27	17	21	25	18	22	22	26
S	171	n.d.	17	n.d.	n.d.	12	75	74	20	15	7	n.d.
Th	22	12	15	12	22	15	14	13	12	14	17	14
V	6	7	8	<4	8	12	11	6	8	9	9	<4

	Granitic Rocks III										
	Tosanji Gr.		Senzan Gr.					fine-grained Gr.			Dyke
Sample No.	Aw626	Aw629	Aw238	Aw254	Aw561	Aw716	Aw736	Aw030	Aw031	Aw630	Aw051
As (ppm)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5	<4	<4	n.d.
Cr	<4	5	7	5	7	6	4	4	4	4	<4
Ga	16	17	17	16	18	21	17	16	15	17	16
Pb	22	24	23	21	21	15	22	26	29	22	24
S	5	6	<3	5	5	8	n.d.	12	7	100	n.d.
Th	17	16	12	9	11	16	13	16	13	15	14
V	9	6	10	12	10	25	6	5	9	7	9

n.d.: not detected.

Gr.: Granite, To.: Tonalite, Gd.: Granodiorite.

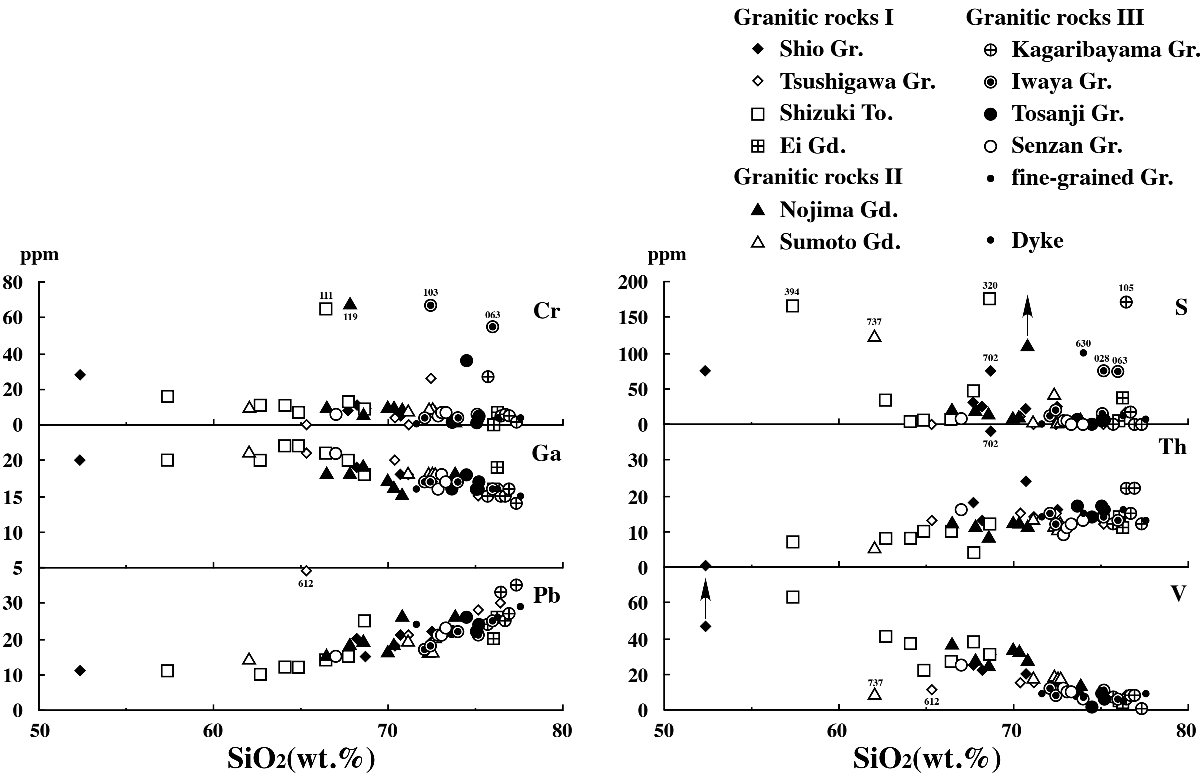

Fig. 2 SiO_2-trace elements diagrams of granitic rocks in Awaji Island.

Table 3 Rare earth and trace elements concentrations of granitic rocks in Awaji Island.

	Nojima Gd.	Sumoto Gd.	Kagari. Gr.	Iwaya Gr.	Tosanji Gr.	Senzan Gr.
Sample No.	Aw352	Aw725	Aw110	Aw597	Aw626	Aw561
Cs (ppm)	2.53	1.91	3.24	3.85	2.02	1.88
La	31.69	31.97	46.8	27.85	36.99	20.01
Ce	64.88	59.75	89.81	54.35	73.72	46.66
Nd*	22.0	21.8	17.6	21.1	28.7	13.7
Sm*	4.07	3.87	3.09	4.46	5.36	2.42
Eu	1.03	0.92	0.61	0.69	0.72	0.86
Tb	0.51	0.48	0.70	0.59	0.66	0.25
Yb	2.29	1.86	1.79	3.14	2.44	1.29
Lu	0.35	0.29	0.28	0.44	0.37	0.19
Hf	4.66	3.34	3.09	3.32	4.41	4.42
U	2.44	2.37	2.54	2.81	1.58	1.80

*: determined by isotope dilution method (Yuhara *et al.,* 1998).
Gd.: Granodiorite, Gr.: Granite, Kagari.: Kagaribayama.

tion trends of most trace elements of the Granitic Rocks I, II and III overlap those in Harker's diagrams. Samples, which were off main trend of major and trace elements in the previous analyses, are often off variation trends in this study as well. Chondrite-normalized REE patterns of the Granitic Rocks II and III are within those of granitic rocks in the Ryoke metamorphic belt.

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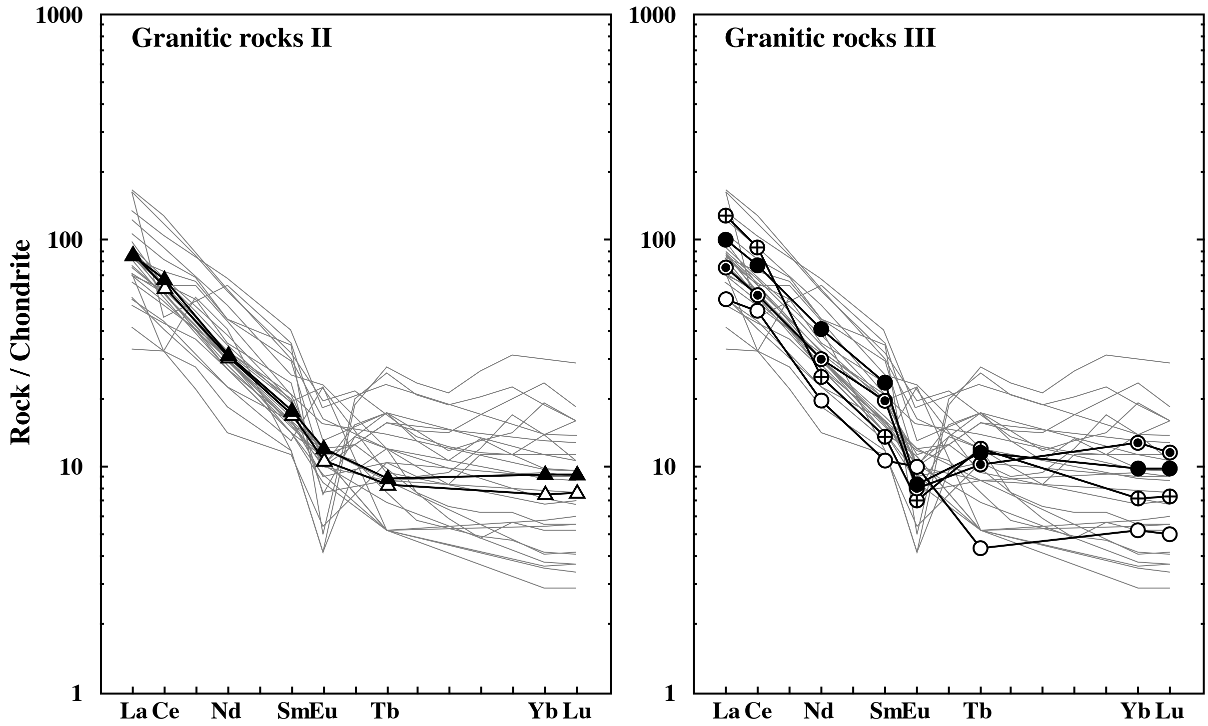

Fig. 3 Chondrite-normalized rare earth elements patterns of granitic rocks in Awaji Island.
The normalizing values are from Anders and Grevesse (1989).
Grey lines indicate patterns of granitic rocks in the Ryoke metamorphic belt (Ishihara and Wu, 2001; Kutsukake, 2002; Ishihara, 2003; Ishihara and Chappell, 2007; Yuhara, 2008, 2011). Symbols are the same as those in Fig. 2.

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