Rb, Sr, Sm and Nd concentrations of GSJ, KIGAM and BCR-1 rock reference samples analyzed by isotope dilution method.

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Abstract

Rb, Sr, Sm and Nd concentrations of thirteen GSJ (Geological Survey of Japan), six KIGAM (Korea Institute of Geology, Mining and Materials) rock reference samples along with one reference rock sample, BCR-1 (provided by U. S. Geological Survey) have been measured by isotope dilution method using both MAT261 and MAT262 thermal ionization mass spectrometers in Niigata University. Both $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of JB-1b and KIGAM rock reference samples also have been measured. The measurements of three to fourteen separate analyses for each reference sample show excellent agreement with the reported values within small standard deviations. Rb, Sr, Sm and Nd concentrations of these rock reference samples are also in well agreement with the reported values.

$^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of JB-1b are 0.704098 ± 0.000012, 0.512786 ± 0.000010, respectively, and these ratios are identical with those of JB-1a.

Key words: BCR-1, GSJ rock reference samples, isotope dilution method, KIGAM rock reference samples, Rb, Sr, Sm and Nd concentrations, $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios.

Introduction

In our laboratory of Niigata University, Rb and Sr concentrations and isotopic ratios of whole-rock samples with close Rb/Sr ratios and mineral separates as well, are analyzed by isotope dilution method. In addition to that, Sm - Nd concentrations and isotopic ratios of samples are also analyzed following the same method. Thus, it is very important to know the estimated error range of these analyses.

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We, therefore, measured Rb, Sr, Sm and Nd concentrations of the standard samples of "igneous rock series" provided by the Geological Survey of Japan (GSJ rock reference samples) (JB-1a, JB-1b, JB-2, JB-3, JA-1, JA-2, JA-3, JG-1a, JG-2, JG-3, JGb-1, JR-1, JR-2), which are being widely used for analytical references for geological samples, and their chemical composition have been analyzed by various methods so far. Furthermore, we also analyzed $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of JB-1b. In addition to that, $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios, Rb, Sr, Sm and Nd concentrations of six igneous rock reference samples provided by Korea Institute of Geology, Mining and Materials (KB-1, KD-1, KGB-1, KT-1, KG-1, KG-2) were measured. Along with these, Rb, Sr, Sm and Nd concentrations of BCR-1 of U. S. Geological Survey also have been measured.

Analytical Procedures

Rb, Sr, Sm and Nd concentrations were analyzed by isotope dilution method using ^{87}Rb-^{84}Sr and ^{149}Sm-^{150}Nd mixed spikes. In order to minimize errors, the most suitable amount of spike and sample were taken using equations of Webster (1960) and Colby et al. (1981). Discomposing of these mixtutures and separation procedure of Rb, Sr, Sm and Nd were carried out following the method of Hamamoto et al. (2000).

Isotopic analyses were carried out using both MAT261-type (modified from MAT260) and MAT262-type mass spectrometers in Niigata University. $^{87}Sr/^{86}Sr$ ratios and $^{143}Nd/^{144}Nd$ ratios were normalized with respect to $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$, respectively. During the whole mass - spectrometric analyses internal precision of $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopic ratios were monitered with NBS-987 Sr isotopic standard and JNdi-1 Nd isotopic standard (provided by the Geological Survey of Japan) respectively which are giving $^{87}Sr/^{86}Sr = 0.710251$ and $^{143}Nd/^{144}Nd = 0.512106$ (against the LaJolla Nd isotopic standard $^{143}Nd/^{144}Nd = 0.511851$) respectively. We measured $^{85}Rb/^{87}Rb$, $^{88}Sr/^{84}Sr$, $^{88}Sr/^{86}Sr$, $^{152}Sm/^{149}Sm$, $^{152}Sm/^{147}Sm$, $^{146}Nd/^{150}Nd$ and $^{146}Nd/^{144}Nd$ ratios of spiked samples for concentration measurement.

Results

1. Rb, Sr, Sm and Nd concentrations of BCR-1

Rb, Sr, Sm and Nd concentrations of BCR-1 shown in Table 1. Average value of Sr concentration obtained in this study is identical with the value of Glandney and Roelandts (1990). Rb concentration is little higher, but the average Sm and Nd concentrations are in well agreement with the reported values (Table 2).

2. Rb, Sr, Sm and Nd concentrations of GSJ rock reference samples

Average $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of JB-1b obtained in this study are 0.704098 ± 0.000012 (standard deviation) and 0.512786 ± 0.000010, respectively (Table 3), which are

identical with the reported values for JB-1a (Miyazaki and Shuto, 1998). Thus, JB-1b and JB-1a are identical with respect to both Sr and Nd isotopic compositions.

Rb, Sr, Sm and Nd concentrations of JB-1a and JB-1b shown in Table 4. These Rb, Sm and Nd concentrations are in excellent agreement with the recommended values from Imai et al. (1995). Relative difference between Sr concentration obtained in this study and recommended value is about 2%. Rb and Sr concentrations of JB-1b are differ from JB-1a, but Sm and Nd concentrations are almost identical. Relative errors of these separate analyses of both $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ ratios are within 0.5% and 0.2%, respectively.

Moreover, Rb, Sr, Sm and Nd concentrations of eleven GSJ rock reference samples are shown in Table 5. Most of the relative errors of three to five times separate analyses of Rb and Sr concentrations, $^{87}Rb/^{86}Sr$ ratios, Sm and Nd concentrations and $^{147}Sm/^{144}Nd$ ratios are within 0.9%, 0.8%, 0.2%, 0.07%, respectively. But, relative errors of Sr concentration and $^{87}Rb/^{86}Sr$ ratio of JGb-1, Sm and Nd concentrations of JG-1a, JG-2, JG-3 and JGb-1 and $^{147}Sm/^{144}Nd$ ratios of JG-1a, JG-2 and JG-3 are clearly large. This may be due to inhomogeneous concentrations of these elements in the rock samples.

3. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of KIGAM rock reference samples

$^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of KIGAM rock reference samples are shown in Table 6. Standard deviation of three to five separate analyses for these samples are under 0.00002 (0.0026%). These errors are almost equal to the reported values of Miyazaki and Shuto (1998).

4. Rb, Sr, Sm and Nd concentrations of KIGAM rock reference samples

Rb, Sr, Sm and Nd concentrations of KIGAM rock reference samples are shown in Table 7. Most of Rb and Sr concentrations obtained in this study are within the range of Murata (1993) and Kimura et al. (1996) (Table 8). According to Kimura et al. (1996), relative errors of Rb and Sr concentrations measured by XRF and Photon activation analyses are under 10%. Thus, data obtained in this study are more or less identical to these within the errors. Most of the relative errors of Rb and Sr concentrations, $^{87}Rb/^{86}Sr$ ratios, Sm and Nd concentrations and $^{147}Sm/^{144}Nd$ ratios are within 0.7%, 0.7%, 0.8%, 0.4%, respectively. But, relative errors of Sm and Nd concentrations and $^{147}Sm/^{144}Nd$ ratios of KG-1, KG-2 and KGB-1 are clearly high. This is due to same reason as stated in case of GSJ rock reference samples.

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Table1. Analytical results for Rb, Sr, Sm and Nd concentrations of BCR-1.

	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$
BCR-1	48.84	331.0	0.42685	6.658	29.04	0.13865
	48.74	328.4	0.42930	6.642	28.96	0.13870
	48.61	331.6	0.42406	6.654	29.01	0.13868
Average	48.73	330.3	0.42674	6.651	29.00	0.13868
S.D.	±0.12	±1.7	±0.00262	±0.008	±0.04	±0.00003
R.E.(%)	0.25	0.51	0.62	0.12	0.14	0.02
	47.2*	330*		6.59*	28.8*	

*published data by Glandney and Roelands (1990).

S.D. : standard deviation, R.E. : relative error.

Table 2. Sm and Nd concentrations of BCR-1 based on isotope dilution method.

Sm(ppm)	Nd(ppm)	Reference
6.74	28.8	Gast et al. (1970)
6.62	28.6	Philpotts and Schnetzler (1970)
6.57	27.5	Schnetzler and Nava (1971)
6.22	29.9	Loubet et al. (1972)
7.11	28.9	O'Nions and Clarke (1972)
6.52	28.8	Philpotts et al. (1972)
6.73	28.9	Nakamura and Masuda (1973)
6.72	28.8	Nakamura (1974)
6.77	29	Winzer et al. (1974)
6.41	27.8	Arth and Hanson (1975)
6.67	29.2	Hooker et al. (1975)
6.67	29.4	Hooker et al. (1975)
6.74	29.0	Shimizu (1975)
6.59	29.1	Sun and Hanson (1975)
6.70	28.9	Tanaka (1975)
6.67	29.3	Hawkesworth and O'Nions (1977)
6.62	29.1	Sun and Nesbitt (1978)
6.66	28.6	Whitford and Arndt (1978)
-	28.38	Gill and Bridgwater (1979)
6.69	29.4	Simmons et al. (1980)
6.56	29.2	Elderfield et al. (1981)
6.53	28.39	Futa (1981)
6.77	28.7	Fujimaki (1982)
6.6205	29.042	Thirlwall (1982)
6.6208	29.037	Thirlwall (1982)
6.54	28.6	Bender et al. (1984)
6.63	28.7	Roden et al. (1984)
6.45	28.54	Stern and Bibee (1984)
6.59	28.80	White and Patchett (1984)
6.59	28.84	Chauvel et al. (1985)
6.59	28.74	McDonough et al. (1985)
6.61	28.88	Kagami et al. (1987)
6.61	28.9	Kagami et al. (1992)
6.63	28.82	Average Value
±0.14	±0.44	Standard Deviation

Table 3. Analytical results for $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of JB-1b.

	$^{87}Sr/^{86}Sr$	2σ	$^{143}Nd/^{144}Nd$	2σ
JB-1b	0.704104	±0.000014	0.512788	±0.000010
	0.704077	±0.000012	0.512784	±0.000012
	0.704088	±0.000012	0.512791	±0.000012
	0.704109	±0.000012	0.512772	±0.000011
	0.704119	±0.000012	0.512794	±0.000013
	0.704096	±0.000012	0.512770	±0.000009
	0.704095	±0.000012	0.512790	±0.000013
	0.704089	±0.000013	0.512798	±0.000008
	0.704107	±0.000012		
	0.704094	±0.000013		
	0.704082	±0.000010		
	0.704099	±0.000009		
	0.704109	±0.000011		
Average	0.704098	±0.000012(S.D.)	0.512786	±0.000010(S.D.)

S.D. : standard deviation.

Table 4. Analytical results for Rb, Sr, Sm and Nd concentrations of JB-1a and JB-1b.

	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$
JB-1a	39.13	447.5	0.25290	5.122	26.42	0.11723
(1/65)	39.18	449.2	0.25228	5.131	26.48	0.11716
	39.23	450.5	0.25189	5.140	26.51	0.11726
	39.26	450.1	0.25226	5.138	26.50	0.11722
	39.21	452.6	0.25060	5.118	26.50	0.11677
	39.39	450.0	0.25318	5.129	26.59	0.11663
	38.94	449.7	0.25043	5.122	26.53	0.11674
	38.82	449.1	0.24998	5.119	26.53	0.11670
	38.97	448.7	0.25119	5.219	27.01	0.11686
	39.00	448.6	0.25147	5.113	26.44	0.11694
	38.85	449.3	0.25003	5.103	26.39	0.11699
	39.26	450.2	0.25221	5.113	26.38	0.11719
	38.80	448.9	0.25004	5.106	26.40	0.11694
	38.66	447.1	0.25010			
Average	39.05	449.4	0.25133	5.129	26.51	0.11697
S.D.	±0.22	±1.3	±0.00114	±0.029	±0.16	±0.00022
R.E.(%)	0.56	0.29	0.45	0.57	0.60	0.19
R.V.	39.2	442		5.07	26.0	
JB-1b	36.04	444.1	0.23471	5.080	26.85	0.11444
(6/1195)	35.93	443.8	0.23418	5.072	26.80	0.11445
	36.12	443.3	0.23568	5.080	26.86	0.11436
	36.15	444.3	0.23533	5.074	26.83	0.11437
	36.07	443.4	0.23531	5.076	26.85	0.11434
				5.064	26.75	0.11449
				5.069	26.78	0.11445
Average	36.06	443.8	0.23504	5.073	26.82	0.11441
S.D.	±0.09	±0.4	±0.00059	±0.006	±0.04	±0.00006
R.E.(%)	0.25	0.09	0.25	0.12	0.15	0.05

( ) : split / position number, R.V. : recommended value of Imai et al. (1995).
S.D. : standard deviation, R.E. : relative error.

Table 5. Analytical results for Rb, Sr, Sm and Nd concentrations of GSJ rock reference samples.

	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$
JB-2	6.554	180.3	0.10514	2.298	6.391	0.21743
(4/45)	6.505	180.0	0.10455	2.305	6.401	0.21778
	6.544	180.6	0.10478	2.297	6.389	0.21744
	6.505	180.0	0.10457	2.302	6.406	0.21738
	6.514	180.7	0.10466	2.305	6.413	0.21741
Average	6.524	180.3	0.10474	2.301	6.400	0.21749
S.D.	±0.023	±0.3	±0.00024	±0.004	±0.010	±0.00016
R.E.(%)	0.35	0.18	0.23	0.16	0.16	0.08
R.V.	7.37	178		2.31	6.63	
JB-3	14.88	414.8	0.10375	4.332	15.99	0.16387
(8/95)	14.89	415.0	0.10375	4.319	15.95	0.16373
	14.86	413.2	0.10400	4.322	15.96	0.16380
	14.97	413.8	0.10464	4.317	15.94	0.16380
	14.93	414.5	0.10420	4.319	15.96	0.16364
Average	14.91	414.3	0.10407	4.322	15.96	0.16377
S.D.	±0.04	±0.7	±0.00037	±0.006	±0.02	±0.00009
R.E.(%)	0.29	0.18	0.36	0.14	0.12	0.05
R.V.	15.1	403		4.27	15.6	
JA-1	11.32	261.5	0.12522	3.445	11.03	0.18899
(4/45)	11.42	261.6	0.12621	3.453	11.05	0.18889
	11.33	261.3	0.12537	3.447	11.03	0.18897
	11.34	261.6	0.12536	3.445	11.03	0.18898
	11.30	261.3	0.12502	3.447	11.03	0.18900
Average	11.34	261.5	0.12544	3.447	11.03	0.18897
S.D.	±0.05	±0.2	±0.00046	±0.003	±0.01	±0.00004
R.E.(%)	0.41	0.06	0.36	0.10	0.08	0.02
R.V.	12.3	263		3.52	10.9	
JA-2	74.66	250.6	0.86179	3.157	14.68	0.13004
(9/15)	74.65	250.7	0.86154	3.153	14.69	0.12982
	74.81	250.9	0.86253	3.151	14.67	0.12986
	74.74	250.9	0.86174	3.157	14.70	0.12986
	74.72	250.8	0.86192	3.159	14.71	0.12987
Average	74.72	250.8	0.86190	3.155	14.69	0.12989
S.D.	±0.07	±0.1	±0.00038	±0.003	±0.02	±0.00009
R.E.(%)	0.09	0.05	0.04	0.10	0.11	0.07
R.V.	72.9	248		3.11	13.9	
JA-3	36.75	287.0	0.37037	3.142	12.56	0.15131
(6/14)	36.96	288.1	0.37103	3.149	12.59	0.15126
	36.85	287.3	0.37098	3.140	12.55	0.15130
	36.87	288.1	0.37016	3.140	12.56	0.15122
	36.91	287.8	0.37100	3.142	12.56	0.15131
Average	36.87	287.7	0.37078	3.143	12.56	0.15128
S.D.	±0.08	±0.5	±0.00041	±0.004	±0.02	±0.00004
R.E.(%)	0.21	0.17	0.11	0.12	0.12	0.03
R.V.	36.7	287		3.05	12.3	
JG-1a	185.6	183.8	2.9229	4.427	19.46	0.13758
(8/91)	184.5	183.3	2.9129	4.591	20.36	0.13634
	184.9	183.7	2.9127	4.463	19.69	0.13705
	184.6	184.2	2.9001	4.315	18.79	0.13886
Average	184.9	183.8	2.9122	4.449	19.57	0.13746
S.D.	±0.5	±0.4	±0.0093	±0.114	±0.65	±0.00106
R.E.(%)	0.27	0.20	0.32	2.6	3.3	0.77
R.V.	178	187		4.53	20.4	
JG-2	308.4	16.43	54.570	8.117	25.34	0.19364
(5/14)	306.8	16.57	53.841	8.096	25.54	0.19167
	310.0	16.53	54.539	8.384	26.50	0.19128
	307.8	16.55	54.081	8.193	25.92	0.19107
	308.3	16.57	54.093			
Average	308.3	16.53	54.223	8.198	25.83	0.19192
S.D.	±1.2	±0.06	±0.318	±0.131	±0.51	±0.00118
R.E.(%)	0.38	0.35	0.59	1.6	2.0	0.61
R.V.	301	17.9		7.78	26.4	
JG-3	69.71	369.6	0.54554	3.304	16.97	0.11775
(3/22)	69.70	369.7	0.54541	3.327	17.24	0.11671
	69.75	370.2	0.54494	3.356	17.35	0.11698
	69.75	369.5	0.54610	3.333	17.26	0.11678
Average	69.73	369.8	0.54550	3.330	17.21	0.11706
S.D.	±0.03	±0.3	±0.00048	±0.021	±0.16	±0.00048
R.E.(%)	0.04	0.08	0.09	0.64	0.95	0.41
R.V.	67.3	379		3.39	17.2	
JGb-1	6.131	330.6	0.053669	1.480	5.410	0.16545
(7/77)	5.992	331.8	0.052262	1.439	5.252	0.16572
	6.143	331.4	0.053641	1.466	5.352	0.16563
				1.459	5.322	0.16572
				1.439	5.258	0.16552
Average	6.087	331.3	0.053191	1.457	5.319	0.16561
S.D.	±0.084	±0.6	±0.000804	±0.018	±0.066	±0.00012
R.E.(%)	1.4	0.18	1.5	1.2	1.3	0.07
R.V.	6.87	327		1.49	5.47	
JR-1	263.9	28.37	26.906	5.873	23.81	0.14918
(4/45)	264.0	28.53	26.762	5.884	23.84	0.14929
	264.7	28.88	26.501	5.887	23.85	0.14928
Average	264.2	28.59	26.723	5.881	23.83	0.14925
S.D.	±0.4	±0.26	±0.205	±0.007	±0.02	±0.00006
R.E.(%)	0.16	0.91	0.77	0.13	0.09	0.04
R.V.	257	29.1		6.03	23.3	
JR-2	314.1	7.871	115.44	5.462	19.69	0.16780
(9/70)	314.6	7.897	115.24	5.465	19.69	0.16788
	314.8	7.950	114.54	5.461	19.67	0.16792
				5.473	19.72	0.16783
Average	314.5	7.906	115.07	5.465	19.69	0.16786
S.D.	±0.4	±0.040	±0.47	±0.005	±0.02	±0.00005
R.E.(%)	0.11	0.51	0.41	0.10	0.10	0.03
R.V.	303	8.11		5.63	20.4	

( ) : split / position number; S.D. : standard deviation; R.E. : relative error.
R.V. : recommended value of Imai et al. (1995).

Table 6. Analytical results for $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of KIGAM rock reference samples.

	$^{87}Sr/^{86}Sr$	2σ	$^{143}Nd/^{144}Nd$	2σ
KB-1	0.705166	±0.000008	0.512557	±0.000009
	0.705177	±0.000009	0.512568	±0.000008
	0.705180	±0.000008	0.512568	±0.000008
			0.512570	±0.000008
			0.512577	±0.000007
			0.512571	±0.000009
Average	0.705174	±0.000007(S.D.)	0.512569	±0.000007(S.D.)
KG-1	0.737651	±0.000007	0.511865	±0.000007
	0.737670	±0.000007	0.511877	±0.000009
	0.737643	±0.000011	0.511856	±0.000008
Average	0.737655	±0.000014(S.D.)	0.511866	±0.000011(S.D.)
KG-2	0.718130	±0.000013	0.511681	±0.000010
	0.718132	±0.000007	0.511681	±0.000010
	0.718146	±0.000007	0.511700	±0.000008
			0.511693	±0.000007
			0.511693	±0.000008
Average	0.718136	±0.000009(S.D.)	0.511690	±0.000008(S.D.)
KD-1	0.707306	±0.000006	0.512376	±0.000008
	0.707309	±0.000007	0.512383	±0.000008
	0.707287	±0.000008	0.512341	±0.000009
			0.512383	±0.000008
Average	0.707301	±0.000012(S.D.)	0.512371	±0.000020(S.D.)
KT-1	0.704995	±0.000007	0.512748	±0.000008
	0.704979	±0.000007	0.512754	±0.000008
	0.705018	±0.000008	0.512756	±0.000009
			0.512755	±0.000009
Average	0.704997	±0.000020(S.D.)	0.512753	±0.000004(S.D.)
KGB-1	0.708721	±0.000010	0.512099	±0.000006
	0.708746	±0.000007	0.512116	±0.000006
	0.708710	±0.000009	0.512098	±0.000007
	0.708727	±0.000007		
	0.708710	±0.000008		
Average	0.708723	±0.000015(S.D.)	0.512104	±0.000010(S.D.)

S.D. : standard deviation.

Table 7. Analytical results for Rb, Sr, Sm and Nd concentrations of KIGAM rock reference samples.

	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$
KB-1	20.58	510.2	0.11585	4.677	20.40	0.13865
(37/16)	20.50	510.8	0.11588	4.686	20.47	0.13844
	20.58	511.2	0.11644	4.688	20.46	0.13854
	20.84	510.1	0.11682	4.703	20.51	0.13869
				4.699	20.54	0.13829
Average	20.63	510.6	0.11625	4.691	20.48	0.13852
S.D.	±0.15	±0.5	±0.00047	±0.010	±0.05	±0.00016
R.E.(%)	0.72	0.10	0.40	0.22	0.26	0.12
KG-1	278.9	39.64	20.418	5.151	22.57	0.13795
(14/19)	276.6	39.36	20.390	5.754	24.26	0.14340
	278.9	39.66	20.407	5.028	23.22	0.13090
	279.1	39.86	20.322	5.442	22.77	0.14449
				5.357	24.25	0.13357
				5.428	24.27	0.13520
Average	278.4	39.63	20.384	5.360	23.56	0.13759
S.D.	±1.2	±0.21	±0.043	±0.253	±0.80	±0.00544
R.E.(%)	0.43	0.52	0.21	4.7	3.4	4.0
KG-2	173.1	153.1	3.2750	2.312	16.26	0.085997
(3/9)	171.0	152.8	3.2603	2.147	15.81	0.082111
	172.8	153.3	3.2646	2.243	16.07	0.084387
	171.9	152.5	3.2644	2.355	16.69	0.085312
	172.9	153.0	3.2722	2.284	16.63	0.083045
Average	172.3	152.9	3.2673	2.268	16.29	0.084170
S.D.	±0.9	±0.3	±0.0061	±0.079	±0.37	±0.001596
R.E.(%)	0.51	0.20	0.19	3.5	2.3	1.9
KD-1	71.22	442.7	0.47199	6.061	30.54	0.11998
(9/24)	71.61	441.4	0.46936	6.044	30.55	0.11961
	72.01	443.3	0.46999	5.994	30.31	0.11956
	71.58	443.7	0.46679	5.975	30.01	0.12038
	72.22	442.8	0.47189	5.997	30.07	0.12058
Average	71.73	442.8	0.47000	6.014	30.30	0.12002
S.D.	±0.39	±0.9	±0.00214	±0.036	±0.25	±0.00045
R.E.(%)	0.55	0.20	0.45	0.61	0.84	0.38
KT-1	125.2	713.0	0.50780	11.15	68.76	0.88021
(13/8)	125.0	711.3	0.50849	11.21	68.93	0.87891
	125.0	711.8	0.50788	11.13	68.63	0.88599
Average	125.1	712.0	0.50806	11.16	68.78	0.88170
S.D.	±0.1	±0.9	±0.00038	±0.04	±0.15	±0.00377
R.E.(%)	0.09	0.12	0.07	0.37	0.22	0.43
KGB-1	60.06	426.6	0.40742	5.983	29.56	0.58609
(36/11)	59.96	428.9	0.40450	6.141	30.87	0.58940
	60.26	426.6	0.40869	5.933	29.25	0.58436
	59.37	427.9	0.40146			
	59.78	427.4	0.40471			
Average	59.89	427.5	0.40536	6.019	29.89	0.58662
S.D.	±0.34	±1.0	±0.00282	±0.109	±0.86	±0.00256
R.E.(%)	0.56	0.23	0.69	1.8	2.9	0.44

( ) : split / position number; S.D. : standard deviation; R.E. : relative error.

Table 8. Rb and Sr concentrations of KIGAM rock reference samples reported by Murata (1993) and Kimura et al. (1996).

	Rb(ppm)	Sr(ppm)	method	reference
KB-1	21.4	496.1	P.XRF	Murata (1993)
	19.3	501.1	PAA	Kimura et al. (1996)
	19.7	491	B.XRF	Kimura et al. (1996)
KG-1	276.4	40.8	PAA	Kimura et al. (1996)
	266	39	B.XRF	Kimura et al. (1996)
KG-2	168.3	161.3	PAA	Kimura et al. (1996)
	165	152	B.XRF	Kimura et al. (1996)
KD-1	69.1	442.1	P.XRF	Murata (1993)
	68.0	432.4	PAA	Kimura et al. (1996)
	66	432	B.XRF	Kimura et al. (1996)
KT-1	121.6	697.4	P.XRF	Murata (1993)
	115.0	714.1	PAA	Kimura et al. (1996)
	119	697	B.XRF	Kimura et al. (1996)
KGB-1	59.3	418.4	P.XRF	Murata (1993)
	57.8	431	PAA	Kimura et al. (1996)
	55	412	B.XRF	Kimura et al. (1996)

Analytical methods, P.XRF : powder pellet XRF analysis, PAA : photon activation analysis, B.XRF : glass bead XRF analysis.