NOTE

High initial Sr-isotopic ratios of gabbro and metadiabase in the Ryoke Belt, Southwest Japan

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Rb and Sr contents and Sr-isotopic ratios as well as SiO₂ and K₂O contents were determined for basic rocks (gabbro, cortlandite, anorthosite and metadiabase) from the Ryoke Belt in the Kinki and Setouchi Inland Sea districts, Southwest Japan. The basic rocks are characterized by lower K₂O and Rb contents and by higher initial Sr-isotopic ratios than the mantle-derived igneous rocks in the oceanic region. The high initial Sr-isotopic ratios of the basic rocks are explained by the high isotopic ratios of their source materials.

INTRODUCTION

The Ryoke Belt consists mainly of granitoids of 77 to 91 Ma K-Ar age, with sporadic occurrences of metamorphic rocks of the amphibolite facies. Diabase and gabbroic rocks accompanied by small amounts of cortlandite and anorthosite are scattered in small masses ranging in size from several tens of meters to several kilometers. The diabase shows metamorphic granular texture, and is usually called metadiabase in the Ryoke Belt. As regards gabbro, the metamorphic effect is not always discernible, for its original coarse-grained texture. In this paper metadiabase and gabbroic rocks are collectively called basic rocks. In the Kinki and Setouchi Inland Sea districts, the basic rocks occur frequently in relatively large masses with diameters up to 7 km (Yoshizawa *et al.* 1966; Ochi, 1982). Most of them occur as masses captured in granitoids. Then the basic rocks are surely older than the Cretaceous Ryoke granitoids.

Initial Sr-isotopic ratios (SrI) of the Ryoke granitoids are high, ranging from 0.707 to 0.711 (Kagami, 1973; Shigeno and Yamaguchi,

1976; Shibata and Ishihara, 1979). Kagami (1973) ascribed this high SrI in the Ryoke granitoids to the source materials of the magma. Shibata and Ishihara (1979) have shown that the gabbroic rocks in the Ryoke Belt have high SrI ranging from 0.7076 to 0.7096, and ascribed this to the Sr-isotopic re-equilibration with the Ryoke granitoids, which were considered to have been emplaced contemporaneously with or later than gabbroic rocks.

The high SrI in the basic igneous rocks have been frequently explained by contamination of the magma with the upper crustal materials or by isotopic exchange with the host rocks (Faure and Powell, 1972). In order to re-examine whether the high SrI of the basic rocks in the Ryoke Belt are explained by such mechanism, we have determined Sr isotopic ratios for 47 samples of metadiabase and gabbroic rocks in the Ryoke Belt of the Kinki and Setouchi Inland Sea districts.

PETROGRAPHY

Metadiabase and gabbroic rocks generally form separate masses, but the former is some-

times accompanied by small amounts of gabbroic rocks, which comprise usually hornblende gabbro but rarely norite. Metadiabase occurs as lenses, shulieren, or slender xenolithic blocks in gneissose granitoids. Metadiabase is dark green and massive, but is sometimes weakly schistose. It usually shows fine-grained metamorphic granular texture, but rarely the original ophitic nature. The rock is composed mainly of hornblende, plagioclase (An_{40-60}), quartz and a small amount of biotite. Rarely, relict augite and/or hypersthene are observed.

Gabbroic rocks occur as xenolithic blocks in granitoids. The masses are classified into the following three types: a) composed mainly of hornblende gabbro, b) of norite and c) of both. They are sometimes accompanied by cortlandite and anorthosite. Hornblende gabbro and norite are gradational in the masses of the type c). Hornblende gabbro consists of hornblende, plagioclase, augite, hypersthene and a small amount of biotite, and norite of olivine, hypersthene, hornblende and plagioclase.

The norite in the Ryoke Belt have highly calcic plagioclase (An_{90}) and olivine, hypersthene and hornblende with low $Mg/Mg+Fe$ ratios (0.6-0.7) (Tainosho, in preparation). Kutsukake (1974, 1975) and Tezuka (1979) suggested that the parent magmas of the gabbroic rocks and metadiabase belong to the tholeiitic series.

The mode of occurrence of the analyzed basic rocks are referred in Table 1, and their localities are shown in Fig. 1. Of these, the Haibara, the Kajishima and the Ikomayama masses are briefly described as representatives of the types a), b) and c), respectively.

Haibara mass This is a small mass of 2km in diameter enclosed in granitoids. Main rock types are hornblende gabbro consisting of hornblende-biotite-relic pyroxene. Rarely, olivine-norite or cortlandite are observed in the gabbroic body.

Kajishima mass Kajishima, an islet of 700m in diameter in the Setouchi Inland Sea (Fig. 1), is occupied by norite. The mass appears to be a large xenolithic block enclosed in gneissose granitoids. The main rock-type is augite-bearing hornblende norite (nos. 31 and 32 in Table 1 and Fig. 1), and is associated with hornblende norite (no. 33), hornblende-olivine norite and augite-bearing hornblende-olivine norite. Cortlandite (no. 34) and cortlanditic melanocratic norite (no. 36) occur as a band about 10m wide, always associated with anorthosite band of similar width with a sharp boundary. Melanocratic olivine-hypersthene hornblende norite (no. 37) occurs in a xenolithic form in augite-bearing-hornblende norite.

Ikomayama mass This is a large mass of 7km in diameter enclosed in granitoids, and is composed of many rock-types. Hornblende

Fig. 1. Sample localities of gabbro and metadiabase in the Kinki and Setouchi Inland Sea districts.

Table 1. Mode of occurrence of gabbro and metadiabase in the Kinki and Setouch Inland Sea districts

<i>Metadiabase</i>		
1	Kamitaki	Opx-Hb metadiabase: Coarse-grained facies of 3km-long, 500m-wide metadiabase lens concordant in gneissose granite
2	Kamitaki	Hb metadiabase: Coarse-grained facies of 2km-long, 500m-wide metadiabase lens concordant in metamorphic rocks
3	Kayumi	Hb metadiabase: 400m-long, 100m-wide sheet-like metadiabase mass concordant in gneissose granite
4	Sanposan	Bt-Hb-Qz metadiabase: Main facies of 6km-long, 1.5km-wide metadiabase lens in augen granite
5	Sanposan	Bt-Hb-Qz metadiabase: Main facies in central part of 6km-long, 1.5m-wide metadiabase lens concordant in augen granite
6	Tsuehityabara	Bt-Hb-Qz metadiabase: Central facies of 6km-long, 500m-wide metadiabase lens concordant in augen granite
7	Hirao	Hb metadiabase: Main facies in central part of 4km-long, 500m-wide metadiabase lens concordant in gneissose granite
8	Uda	Hb metadiabase: Porphyritic facies of 7km-long, 4km-wide metadiabase lens concordant in gneissose granite
9	Awaji-Ōiso	Hb metadiabase: Main facies of 500m-long, 300m-wide stock like metadiabase mass in schistose granite
10	Awaji-Shizuki	Hb metadiabase
11	Awaji-Shizuki	Bt-Hb metadiabase
12	Awaji-Shizuki	Hb metadiabase
} : 300m-long, 100m-wide stock-like metadiabase mass in gneissose granite		
<i>Masses composed mainly of hornblende gabbro (Type a)</i>		
13	Ieki	Cpx-Hb gabbro: Main facies in central part of 700m-long, 500m-wide stock-like gabbro mass in gneissose granite
14	Haibara	details in text
15	Miwayama	Bt-Hb gabbro: Main facies of 3km-long, 1.5km-wide sheet-like gabbro mass in schistose granite
16	Takayasuyama	Bt-Hb Qz gabbro: Gabbroic facies of 1.5km-long, 1km-wide quartz diorite stock in schistose granite
17	Awaji-Yamada	Bt-Hb gabbro: 300m-long, 200m-wide gabbro lens in schistose granite
18	Yashima	Hb-Qz gabbro: 700m-long, 500m-wide gabbro lens in schistose granite
19-20	Mategata	Hb-gabbro: 500m-wide gabbro mass in schistose granite
21	Kuroboshi	Cpx-Hb gabbro: Melanocratic facies of 500m-wide gabbro sheet in metadiabase
<i>Masses composed mainly of norite and related rocks (Type b)</i>		
22	Awashima	Ol-Hb norite: 400m-wide, Small stock-like gabbro mass in schistose granite
23	Awashima	Ol-Opx-Hb cortlanditic gabbro: Melanocratic facies of the above mass
24	Motodori	Hb norite: Main facies in central part of 2.5km-long, 1km-wide stock-like gabbro mass in gneissose granite
25	Fukudayama	Hb norite: Main facies in central part of 2km-long, 1km-wide stock-like gabbro mass in gneissose granite
26	Kozue	Ol-Opx-Hb cortlandite: 100m-wide cortlandite mass in metadiabase
27	Takinohara	Hb norite: Main facies in central part of 3km-long, 1.5km-wide stock-like gabbro mass in gneissose granite
28-29	Konoyama	Hb-Ol norite: Main facies in central part of 1.5km-long, 1km-wide stock gabbro mass at the boundary between gneiss and gneissose granite
30	Ichidaisan	Hb-Ol norite: Main facies in central part of 1.5km-long, 0.7km-wide stock-like gabbro mass in gneissose granite
31-37	Kajishima	details in text
<i>Masses composed mainly of norite and hornblende gabbro (Type c)</i>		
38	Ōsumibana	Opx-Hb gabbro: 1km-long, 800m-wide stock-like gabbro mass in schistose granite
39	Amenokaguyama	Hb norite: 300m-wide gabbro lens in gneissose granite
40	Nijyosan	Bt-Hb norite: Melanocratic facies of 1km-long, 0.5km-wide stock-like gabbro mass in gneissose granite
41-45	Ikomayama	details in text
46-47	Ikomayama	Opx-Hb metadiabase: Main facies of 100m-wide xenolithic form in hornblende gabbro

gabbro (no. 41) and hornblende norite (no. 42) are dominant. Hornblende-olivine norite (no. 43) occurs sporadically in hornblende gabbro. These rock-types have a gradational relation to one another. Metadiabase (nos. 46 and 47) occurs as a xenolith in hornblende gabbro. Cortlandite (no. 44) and anorthosite (no. 45) occur as lenses of about 100m width in hornblende gabbro.

ANALYTICAL PROCEDURE

The isotopic ratio was determined by the mass spectrometer Varian MAT 261. The analytical procedure of Kagami *et al.* (1982) was followed. The analysis, which was repeated 60 times, gave the average value of $0.710239 \pm 0.000007(2\sigma)$ for the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of the standard sample NBS-SRM 987. The average error of each determination was 0.0038% at 2 level. All the measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$. Rb- and Sr-contents were determined by the isotopic dilution method. The determined $^{87}\text{Rb}/^{86}\text{Sr}$ ratio has the average error of 0.68%. In this study the decay constant of $1.42 \times 10^{-11} \text{y}^{-1}$ is used for ^{87}Rb (Steiger and Jäger, 1977). We determined SiO_2 and K_2O contents by X-ray fluorescence following Kobayashi *et al.* (1981).

RESULT AND DISCUSSION

Rb- and Sr-contents and Sr-isotopic ratios analyzed in this study are listed in Table 2, together with SiO_2 and K_2O contents. They are characterized by low K_2O and Rb contents, especially in norite and related rocks. Sr-isotopic ratios fall in a limited range from 0.7067 to 0.7083. Among them norite and the related rocks have relatively higher Sr-isotopic ratios and lower $^{87}\text{Rb}/^{86}\text{Sr}$ ratios than the hornblende gabbro and metadiabase.

As the ages of the basic rocks are not known, it is impossible to determine their SrI. The two gabbroic masses, the Kajishima and Ikomayama masses, from which several samples were analyzed, yield no reliable isochrons owing to the limited range in Rb/Sr ratios. Shibata and Ishihara (1979) calculated SrI (0.7076-0.7096) of gabbroic rocks in the Ryoke Belt, assuming their ages to be Cretaceous. As already mentioned, however, gabbroic rocks in the Ryoke Belt are surely older than Cretaceous granitoids, and we calculated the SrI in this paper, assuming the age of gabbroic rocks to be 400Ma, which are the peak of the radiometric ages shown by the oldest plutonic rocks in Southwest Japan (Nozawa, 1983). The gabbroic rocks have higher SrI than the mantle derived

Fig. 2. $^{87}\text{Sr}/^{86}\text{Sr}$ - $^{87}\text{Rb}/^{86}\text{Sr}$ diagram for metadiabase. Solid triangle: Metadiabase in the Southern part of the Kinki district, triangle: Metadiabase in the Northern part of the Kinki and Setouchi Inland Sea districts, solid circle: Masses composed mainly of hornblende gabbro (Type a), open circle: Masses composed mainly of norite and related rocks (Type b), square: Masses composed mainly of norite and hornblende gabbro (Type c).

Table 2. Analytical results of Rb and Sr contents and $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, with SiO_2 and K_2O content. Srl was calculated assuming the age of basic rocks to be 400Ma

	Locality	$^{87}\text{Sr}/^{86}\text{Sr}$	2σ	Sr initial ratio ($4 \times 10^8 \text{y}$)	$^{87}\text{Rb}/^{86}\text{Sr}$	Rb (ppm)	Sr (ppm)	SiO_2 wt%	K_2O wt%
<i>Metadiabase</i>									
1	Kamitaki	0.70762	0.00002	0.70632	0.0713	10.59	429.4	45.14	0.56
2	Kamitaki	0.70747	0.00007	0.70614	0.2335	34.12	422.7	48.47	0.92
3	Kayumi	0.70693	0.00003	0.70645	0.0838	15.87	547.6	44.47	0.44
4	Sanposan	0.70764	0.00005	0.70633	0.2305	36.18	454.1		
5	Sanposan	0.70757	0.00004	0.70600	0.2758	37.36	391.8		
6	Tsuchiyabara	0.70739	0.00007	0.70686	0.0928	17.87	557.2		
7	Hirao	0.70740	0.00002	0.70678	0.1095	14.09	372.5	47.36	0.33
8	Uda	0.70792	0.00007	0.70626	0.2923	37.36	369.8	49.99	1.03
9	Awaji-Oiso	0.70816	0.00002	0.70690	0.2226	21.12	274.4	49.04	0.45
10	Awaji-Shizuki	0.70758	0.00003	0.70724	0.0600	8.175	393.9	46.16	0.33
11	Awaji-Shizuki	0.70735	0.00004	0.70707	0.0496	6.927	404.3	48.79	0.28
12	Awaji-Shizuki	0.70734	0.00010	0.70704	0.0529	8.347	456.5	49.16	0.18
<i>Masses composed mainly of hornblende gabbro (Type a)</i>									
13	Ieki	0.70736	0.00003	0.70690	0.0815	10.94	388.4	47.16	0.36
14	Haibara	0.70783	0.00003	0.70776	0.0308	4.766	447.1	47.74	0.12
15	Miwayama	0.70708	0.00004	0.70653	0.0972	13.72	408.3		
16	Takayasuyama	0.70720	0.00002	0.70716	0.0066	1.304	572.0	46.74	0.09
17	Awaji-Yamada	0.70814	0.00004	0.70749	0.1138	10.33	262.7	50.89	0.23
18	Yashima	0.70715	0.00002	0.70665	0.0882	10.46	343.1	52.47	0.48
19	Mategata	0.70694	0.00002	0.70657	0.0655	7.275	321.6	36.39	0.21
20	Mategata	0.70690	0.00002	0.70654	0.0637	7.278	330.6	46.51	0.31
21	Kuroboshi	0.70723	0.00002	0.70652	0.1242	19.14	445.9	46.89	0.89
<i>Masses composed mainly of norite and related rocks (Type b)</i>									
22	Awashima	0.70740	0.00004	0.70708	0.0568	6.698	341.4	44.37	0.72
23	Awashima	0.70755	0.00005	0.70736	0.0342	1.271	107.6	45.20	0.35
24	Motodori	0.70744	0.00002	0.70738	0.0113	1.837	569.5	46.48	0.09
25	Fukudayama	0.70828	0.00002	0.70823	0.0082	1.524	538.5	50.37	0.24
26	Kozue	0.70694	0.00008	0.70674	0.0357	1.456	117.9		
27	Takinohara	0.70776	0.00002	0.70771	0.0086	0.747	251.2	44.72	0.08
28	Konoyama	0.70800	0.00003	0.70778	0.0218	2.115	280.4	47.41	0.16
29	Konoyama	0.70806	0.00003	0.70792	0.0244	3.623	430.4	47.26	0.11
30	Ichidaisan	0.70830	0.00002	0.70820	0.0174	2.707	450.6	43.27	tr.
31	Kajishima	0.70753	0.00007	0.70748	0.0082	1.091	383.3		
32	Kajisima	0.70765	0.00001	0.70744	0.0370	5.967	466.6	46.37	0.22
33	Kajisima	0.70749	0.00002	0.70741	0.0149	2.079	404.4		
34	Kajisima	0.70756	0.00006	0.70750	0.0108	0.637	171.1	42.64	0.10
35	Kajisima	0.70752	0.00003	0.70741	0.0187	3.651	564.5		
36	Kajisima	0.70774	0.00003	0.70770	0.0076	0.586	222.9	42.56	tr.
37	Kajisima	0.70758	0.00002	0.70748	0.0184	3.040	478.8	46.31	0.18
<i>Masses composed mainly of norite and hornblende gabbro (Type c)</i>									
38	Ōsumibana	0.70730	0.00002	0.70710	0.0346	4.382	3666.2	47.54	0.31
39	Amanokaguyama	0.70787	0.00003	0.70758	0.0511	8.728	458.0	48.47	0.13
40	Nijyōsan	0.70754	0.00003	0.70741	0.0223	5.039	652.7	50.64	0.19
41	Ikomayama	0.70776	0.00002	0.70761	0.0265	4.708	514.3	46.77	0.18
42	Ikomayama	0.70755	0.00005	0.70749	0.0111	2.409	630.9		
43	Ikomayama	0.70761	0.00008	0.70749	0.0207	1.252	174.8		
44	Ikomayama	0.70767	0.00003	0.70767	0.0007	0.129	543.6	45.57	0.15
45	Ikomayama	0.70791	0.00002	0.70773	0.0318	5.844	531.6	47.03	0.23
46	Ikomayama	0.70831	0.00002	0.70829	0.0038	0.717	548.0	49.94	0.20
47	Ikomayama	0.70736	0.00003	0.70714	0.0388	7.752	578.6		

igneous rocks regardless of their age, for their extremely low Rb/Sr ratios. The calculated ratios are 0.7060 to 0.7083, which are only slightly lower not only than the present ratios but also than those calculated by Shibata and Ishihara (1979).

Initial Sr-isotopic ratios (SrI) from 400Ma are shown in Table 2. Norite and the related rocks are higher in Sr-isotopic ratio than 0.7073, with one exception (no. 26) which occurs as a small lens in metadiabase. Whereas, SrI for hornblende gabbro and metadiabase are lower than those for norite with some exceptions.

The analyzed metadiabases are plotted on a $^{87}\text{Sr}/^{86}\text{Sr}$ - $^{87}\text{Rb}/^{86}\text{Sr}$ diagram (Fig. 2). Metadiabases in the southern part of the Kinki district (nos. 1-8 in Table 1) have lower Sr-isotopic ratios than the rest, and are plotted nearly parallel to the 300Ma reference isochron (Fig. 2). Other metadiabases (nos. 9-12, 46, 47) are plotted also along the 300Ma reference isochron with higher SrI (Fig. 2). Most of the hornblende gabbros in the mass of type a) are plotted closely to the metadiabase, but most of gabbroic rocks of type b) and c) have distinctly higher Sr-isotopic ratios (Fig. 2).

It is concluded that the basic rocks in the Ryoke Belt of the Kinki and Setouchi Inland Sea districts have distinctly higher SrI than the mantle-derived igneous rocks. In order to raise the Sr-isotopic ratio in the Ryoke gabbro from 0.705, the highest value in the mantle-derived rocks, to the observed ratio by the isotopic equilibration, only Sr must have been selectively exchanged in a considerable amount between gabbro and granitoid without changing other components on a large scale. For example, to obtain 414ppm and 0.7075 for the Sr content and isotopic ratio of the Ryoke gabbro, respectively, about 330ppm of Sr must migrate from granitoid to gabbro and in turn about 370ppm from gabbro to granitoid, 330ppm of Sr reaches 1.4 times of the mean content in granitoid. This is unlikely to have taken place.

Honma *et al.* (1983) have shown that the tonalite, granodiorite, and granite around the Mategata hornblende gabbro mass (no. 19 in

Fig. 1) in the Takanawa Peninsula have isochron age of $92.6 \pm 3.8\text{Ma}$ with the SrI of 0.70773 ± 0.00008 . Two analyzed samples (SrI 0.70682) from the Mategata gabbro mass (nos. 19 and 20) have distinctly lower Sr isotopic ratios, and are not plotted on this isochron. This indicates that the Mategata gabbros were not isotopically re-equilibrated with the surrounding granitoids.

Moreover, the limited variation in the Sr-isotopic ratios and the low SiO_2 , K_2O and Rb contents of the basic rocks of the Ryoke Belt do not favor the isotopic re-equilibrium or contamination hypotheses. Accordingly, high SrI in the basic rocks are attributed to the high Sr-isotopic ratio in their source materials. Ishizaka and Carson (1983) have determined SrI of the mantle-derived Miocene basalts and high magnesian andesite in the Kinki and Setouchi Inland Sea districts giving the result of 0.70408 to 0.70537.

This may suggest that the source materials of the basic rocks must have constituted the lowermost crust under the Ryoke Belt at the time of their formation, although upper mantle materials had lower SrI.

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