LETTER

Sr and Nd isotope ratios of twelve GSJ rock reference samples

TAKASHI MIYAZAKI¹ and KENJI SHUTO²

¹Graduate School of Science and Technology, Niigata University, Ikarashi 2-8050, Niigata 950-2181, Japan

²Department of Geology, Faculty of Science, Niigata University, Ikarashi 2-8050, Niigata 950-2181, Japan

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⁸⁷Sr/⁸⁶Sr and ¹⁴³Nd/¹⁴⁴Nd ratios for twelve GSJ rock reference samples (GSJ-RRS), together with the chemical standards NBS987, La Jolla and JNdi-1, have been measured on a MAT262 mass spectrometer in the Department of Geology, Niigata University. Measurements of five to nine aliquots for each GSJ-RRS gave small standard deviations of both Sr and Nd isotopic ratios.

INTRODUCTION

The standard samples of "igneous rock series" provided by the Geological Survey of Japan (GSJ rock reference samples, GSJ-RRS) are widely used for analytical references of geological samples, and their Sr and Nd isotopic ratios have been reported from several laboratories (e.g., Shibata and Adachi, 1972; Nohda and Wasserburg, 1981; Kagami *et al.*, 1982, 1987, 1989; Kurasawa, 1984; Zhang Zichao, 1987; Ando and Shibata, 1988; Okano *et al.*, 1989; Arakawa, 1992; Iizumi *et al.*, 1994, 1995; Yamamoto and Maruyama, 1996). However, there are still few isotopic data for some GSJ-RRS, and Nd isotope ratios have not yet been reported for some samples, such as JA-3 and JR-2. Also, as pointed out by some authors (e.g., Kagami *et al.*, 1989; Arakawa, 1992), some GSJ-RRS exhibit systematic differences in Sr and Nd isotopic ratios between laboratories even if normalization has been done using standard samples of chemicals.

We measured ⁸⁷Sr/⁸⁶Sr and ¹⁴³Nd/¹⁴⁴Nd ratios for JB-1a, JB-2, JB-3, JA-1, JA-2, JA-3, JG-1a, JG-3, JGb-1 and JR-1, ⁸⁷Sr/⁸⁶Sr ratios for JF-1 and JF-2, and ¹⁴³Nd/¹⁴⁴Nd ratios for JG-2 and JR-2. Strontium and Nd isotopic ratios were measured for five to nine separate aliquots of each GSJ-RRS. These data were compared with previously

reported data which were normalized using chemical standards.

ANALYTICAL PROCEDURES

Separation of Sr and Nd was carried out in the Department of Geology, Niigata University, essentially following the method described by Kagami *et al.* (1982, 1987). Each powdered sample (about 100 mg) was decomposed in a sealed teflon vessel using a HF, HCl, HNO₃ and HClO₄ mixture. Five to nine decomposed samples were prepared for each GSJ-RRS and extraction of Sr and Nd from these samples were made using different columns filled with cation exchange resin (Dowex AG 50W-X8, 200–400 mesh). The extracted Sr and Nd were loaded on Ta filaments with 2.5N HCl and 2.5N HNO₃, respectively.

The measurements were made with a Ta filament for evaporation and Re filament for ionization, using a Finnigan MAT 262 thermal ionization mass spectrometer equipped with nine Faraday collectors, which was installed in the Department of Geology, Niigata University. The data were obtained in so-called "static mode" in which ion beam of each mass number is collected by a fixed Faraday cup. These data were computed from 150–500 repeated measurements, comprising ten scans

in each of ten to fifty blocks.

The measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to a $^{86}\text{Sr}/^{88}\text{Sr}$ ratio of 0.1194, and the measured $^{143}\text{Nd}/^{144}\text{Nd}$ to a $^{146}\text{Nd}/^{144}\text{Nd}$ ratio of 0.7219. Since ^{85}Rb and ^{147}Sm were not detected during the course of this study, contribution from ^{87}Rb and ^{144}Sm were negligible. The total blanks of Sr and Nd in the whole procedure are less than 0.4 ng and 0.3 ng, respectively.

RESULTS

$^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of the standard chemical samples, NBS987, La Jolla and JNdi-1

The NBS987 standard determined during this study gave a mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.710251 ± 0.000004 ($2\sigma_m$, $N = 51$). During the course of this study, we also measured $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of two standard samples, La Jolla and JNdi-1. The latter a new standard provided by Geological Survey of Japan. The La Jolla standard gave a mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.511851 ± 0.000006 ($2\sigma_m$, $N = 17$) whereas JNdi-1 gave a mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.512106 ± 0.000003 ($2\sigma_m$, $N = 44$). Tanaka *et al.* (1997) reported $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.512116 ± 0.000008 for standard sample JNdi-1, which was corrected by normalizing to La Jolla as reported in Lugmair and Carlson (1978). Our mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratio for the JNdi-1 standard corrected in the same manner gives 0.512113 ± 0.000003 , which is almost identical to the value of Tanaka *et al.* (1997).

$^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of GSJ rock reference samples

Strontium isotopic ratios of five or eight separately decomposed samples of each GSJ-RRS are listed with average values and the standard deviations in Table 1. Kurasawa (1984), Zhang Zichao (1987), Kagami *et al.* (1989), Iizumi *et al.* (1994) and Yamamoto and Maruyama (1996) also reported Sr isotope values of GSJ-RRS with the value of NBS987. The NBS987 values in these reports are 0.710278 ± 0.000009 ($2\sigma_m$), 0.71030 ± 0.00003 ($2\sigma_m$), 0.710252 ± 0.000018 ($2\sigma_m$), 0.710275 ± 0.000007 ($2\sigma_m$) and $0.710241 \pm$

0.000022 ($2\sigma_m$), respectively. Hereafter, we will compare our data on GSJ-RRS to the previously reported data normalized using NBS987 values of 0.710251.

Eight separate aliquots of JB-1a gave an average $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.704107 ± 0.000008 ($2\sigma_m$). Previously reported values for JB-1a exhibit a large variation from 0.704082 to 0.70415 (Zhang Zichao, 1987; Kagami *et al.*, 1989; Iizumi *et al.*, 1994; Yamamoto and Maruyama, 1996). Our value is slightly higher than that of 0.704082 ± 0.000016 ($2\sigma_m$) reported by Kagami *et al.* (1989), but very close to the value of 0.704109 ± 0.000007 ($2\sigma_m$) by Iizumi *et al.* (1994) and the value of 0.704116 ± 0.000012 ($2\sigma_m$) by Yamamoto and Maruyama (1996).

Mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of JB-2, JA-1 and JG-1a are within the range of previously reported data (JB-2; $0.703667 \sim 0.703727$; Kurasawa, 1984; Zhang Zichao, 1987; Iizumi *et al.*, 1994, JA-1; $0.703506 \sim 0.70362$; Kurasawa, 1984; Zhang Zichao, 1987; Kagami *et al.*, 1989; Iizumi *et al.*, 1994, JG-1a; $0.71093 \sim 0.710972$; Zhang Zichao, 1987; Kagami *et al.*, 1989; Iizumi *et al.*, 1994; Yamamoto and Maruyama, 1996). Mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of JB-3 and JR-1 are within the deviation of the lowest values previously reported (JB-3; 0.703415 ± 0.000005 ($2\sigma_m$); Iizumi *et al.*, 1994, JR-1; 0.70413 ± 0.00003 ($2\sigma_m$); Zhang Zichao, 1987). A mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of JA-3 is close to the lowest value previously reported (0.704173 ± 0.000009 ($2\sigma_m$); Iizumi *et al.*, 1994). Mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of JA-2, JF-1 and JGb-1 obtained by us are within the deviation of reported values (JA-2; 0.70632 ± 0.00003 ($2\sigma_m$), JF-1; 0.71353 ± 0.00004 ($2\sigma_m$); Zhang Zichao, 1987, JGb-1; 0.705220 ± 0.000017 ($2\sigma_m$); Kurasawa, 1984). Our mean Sr isotopic data for JG-3 and JF-2 are lower than values reported by Zhang Zichao (1987) (JG-3; 0.70547 ± 0.00005 ($2\sigma_m$), JF-2; 0.70982 ± 0.00002 ($2\sigma_m$)).

Neodymium isotopic ratios of analyzed samples are listed in Table 2. Our data in Table 2 show $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of either five or nine separate analyses for each reference sample and their average values with the standard deviations. Arakawa

Table 1. Analytical results for $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of twelve GSJ rock reference samples and standard sample NBS987

Samples	$^{87}\text{Sr}/^{86}\text{Sr} \pm 2\sigma_m$		Samples	$^{87}\text{Sr}/^{86}\text{Sr} \pm 2\sigma_m$	
JB1a-1	0.704117 $\pm$ 4		JG1a-1	0.710962 $\pm$ 5	
JB1a-2	0.704115 $\pm$ 4	(n=2)*	JG1a-2	0.710967 $\pm$ 8	
JB1a-3	0.704119 $\pm$ 3		JG1a-3	0.710964 $\pm$ 6	
JB1a-4	0.704101 $\pm$ 7	(n=6)*	JG1a-4	0.710989 $\pm$ 7	
JB1a-5	0.704097 $\pm$ 5	(n=2)*	JG1a-5	0.710967 $\pm$ 6	
JB1a-6	0.704094 $\pm$ 5	(n=2)*		0.710970 $\pm$ 11	(s.d.) (N=5)**
JB1a-7	0.704102 $\pm$ 5	(n=2)*		$\pm$ 13	(2 σ_m) (N=5)**
JB1a-8	0.704110 $\pm$ 8				
	0.704107 $\pm$ 10	(s.d.) (N=8)**	JG3-1	0.705350 $\pm$ 6	
	$\pm$ 8	(2 σ_m) (N=8)**	JG3-2	0.705379 $\pm$ 8	
JB2-1	0.703673 $\pm$ 5	(n=2)*	JG3-3	0.705352 $\pm$ 6	
JB2-2	0.703679 $\pm$ 8		JG3-4	0.705373 $\pm$ 5	
JB2-3	0.703657 $\pm$ 6		JG3-5	0.705344 $\pm$ 5	
JB2-4	0.703663 $\pm$ 5			0.705360 $\pm$ 15	(s.d.) (N=5)**
JB2-5	0.703665 $\pm$ 6			$\pm$ 19	(2 σ_m) (N=5)**
	0.703668 $\pm$ 9	(s.d.) (N=5)**	JGb1-1	0.705225 $\pm$ 10	
	$\pm$ 11	(2 σ_m) (N=5)**	JGb1-2	0.705204 $\pm$ 9	
JB3-1	0.703406 $\pm$ 5	(n=2)*	JGb1-3	0.705205 $\pm$ 7	
JB3-2	0.703412 $\pm$ 5	(n=2)*	JGb1-4	0.705196 $\pm$ 5	
JB3-3	0.703407 $\pm$ 5	(n=2)*	JGb1-5	0.705195 $\pm$ 5	
JB3-4	0.703410 $\pm$ 5	(n=2)*		0.705205 $\pm$ 12	(s.d.) (N=5)**
JB3-5	0.703416 $\pm$ 5	(n=2)*		$\pm$ 15	(2 σ_m) (N=5)**
	0.703410 $\pm$ 4	(s.d.) (N=5)**	JR1-1	0.704127 $\pm$ 13	
	$\pm$ 5	(2 σ_m) (N=5)**	JR1-2	0.704125 $\pm$ 8	
JA1-1	0.703546 $\pm$ 8	(n=2)*	JR1-3	0.704119 $\pm$ 7	
JA1-2	0.703537 $\pm$ 5	(n=2)*	JR1-4	0.704138 $\pm$ 8	
JA1-3	0.703548 $\pm$ 7	(n=2)*	JR1-5	0.704123 $\pm$ 7	
JA1-4	0.703541 $\pm$ 5	(n=2)*		0.704127 $\pm$ 7	(s.d.) (N=5)**
JA1-5	0.703541 $\pm$ 5	(n=2)*		$\pm$ 9	(2 σ_m) (N=5)**
	0.703543 $\pm$ 4	(s.d.) (N=5)**	JF1-1	0.713482 $\pm$ 8	
	$\pm$ 6	(2 σ_m) (N=5)**	JF1-2	0.713500 $\pm$ 9	
JA2-1	0.706329 $\pm$ 5	(n=2)*	JF1-3	0.713492 $\pm$ 8	
JA2-2	0.706339 $\pm$ 5	(n=2)*	JF1-4	0.713501 $\pm$ 8	
JA2-3	0.706342 $\pm$ 5	(n=2)*	JF1-5	0.713487 $\pm$ 9	
JA2-4	0.706326 $\pm$ 5			0.713493 $\pm$ 8	(s.d.) (N=5)**
JA2-5	0.706335 $\pm$ 5			$\pm$ 10	(2 σ_m) (N=5)**
	0.706334 $\pm$ 7	(s.d.) (N=5)**	JF2-1	0.709709 $\pm$ 8	
	$\pm$ 8	(2 σ_m) (N=5)**	JF2-2	0.709699 $\pm$ 8	
JA3-1	0.704163 $\pm$ 5	(n=2)*	JF2-3	0.709703 $\pm$ 8	
JA3-2	0.704147 $\pm$ 6		JF2-4	0.709702 $\pm$ 9	
JA3-3	0.704161 $\pm$ 5	(n=2)*	JF2-5	0.709710 $\pm$ 7	
JA3-4	0.704165 $\pm$ 8	(n=2)*		0.709705 $\pm$ 5	(s.d.) (N=5)**
JA3-5	0.704165 $\pm$ 6			$\pm$ 6	(2 σ_m) (N=5)**
	0.704160 $\pm$ 8	(s.d.) (N=5)**	NBS987	0.710251 $\pm$ 4	(n=51)*
	$\pm$ 10	(2 σ_m) (N=5)**			

*Number of measurements; **Number of samples which are separately decomposed and extracted.
s.d.: standard deviation.

Table 2. Analytical results for $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of twelve GSJ rock reference samples and standard samples La Jolla and JNdi-1

Samples	$^{143}\text{Nd}/^{144}\text{Nd} \pm 2 \sigma_m$	Samples	$^{143}\text{Nd}/^{144}\text{Nd} \pm 2 \sigma_m$
JB1a-1	0.512779 $\pm$ 9	JG1a-1	0.512385 $\pm$ 12
JB1a-2	0.512795 $\pm$ 10	JG1a-2	0.512378 $\pm$ 12
JB1a-3	0.512789 $\pm$ 9	JG1a-3	0.512373 $\pm$ 6
JB1a-4	0.512781 $\pm$ 9	JG1a-4	0.512392 $\pm$ 10
JB1a-5	0.512771 $\pm$ 11	JG1a-5	0.512386 $\pm$ 13
JB1a-6	0.512779 $\pm$ 10		0.512383 $\pm$ 7 (s.d.) (N=5)**
JB1a-7	0.512785 $\pm$ 9		$\pm$ 9 (2 σ_m) (N=5)**
JB1a-8	0.512785 $\pm$ 9		
JB1a-9	0.512773 $\pm$ 11		
	0.512782 $\pm$ 7 (s.d.) (N=9)**	JG2-1	0.512218 $\pm$ 13
	$\pm$ 6 (2 σ_m) (N=9)**	JG2-2	0.512210 $\pm$ 14
		JG2-3	0.512193 $\pm$ 13
JB2-1	0.513081 $\pm$ 15	JG2-4	0.512212 $\pm$ 10
JB2-2	0.513087 $\pm$ 19	JG2-5	0.512227 $\pm$ 14
JB2-3	0.513095 $\pm$ 14		0.512212 $\pm$ 12 (s.d.) (N=5)**
JB2-4	0.513097 $\pm$ 14		$\pm$ 15 (2 σ_m) (N=5)**
JB2-5	0.513089 $\pm$ 10		
	0.513090 $\pm$ 6 (s.d.) (N=5)**	JG3-1	0.512611 $\pm$ 15
	$\pm$ 8 (2 σ_m) (N=5)**	JG3-2	0.512611 $\pm$ 18
		JG3-3	0.512630 $\pm$ 14
JB3-1	0.513030 $\pm$ 7	JG3-4	0.512631 $\pm$ 11
JB3-2	0.513043 $\pm$ 8	JG3-5	0.512600 $\pm$ 13
JB3-3	0.513038 $\pm$ 11		0.512617 $\pm$ 13 (s.d.) (N=5)**
JB3-4	0.513035 $\pm$ 10		$\pm$ 17 (2 σ_m) (N=5)**
JB3-5	0.513040 $\pm$ 8		
	0.513037 $\pm$ 5 (s.d.) (N=5)**	JGb1-1	0.512647 $\pm$ 13
	$\pm$ 6 (2 σ_m) (N=5)**	JGb1-2	0.512628 $\pm$ 12
		JGb1-3	0.512635 $\pm$ 13
JA1-1	0.513101 $\pm$ 10	JGb1-4	0.512667 $\pm$ 16
JA1-2	0.513090 $\pm$ 9	JGb1-5	0.512661 $\pm$ 10
JA1-3	0.513103 $\pm$ 14		0.512648 $\pm$ 16 (s.d.) (N=5)**
JA1-4	0.513084 $\pm$ 7		$\pm$ 20 (2 σ_m) (N=5)**
JA1-5	0.513081 $\pm$ 10		
	0.513092 $\pm$ 10 (s.d.) (N=5)**	JR1-1	0.512911 $\pm$ 14
	$\pm$ 12 (2 σ_m) (N=5)**	JR1-2	0.512912 $\pm$ 14
		JR1-3	0.512912 $\pm$ 14
JA2-1	0.512518 $\pm$ 15	JR1-4	0.512899 $\pm$ 13
JA2-2	0.512528 $\pm$ 9	JR1-5	0.512906 $\pm$ 12
JA2-3	0.512538 $\pm$ 17		0.512908 $\pm$ 6 (s.d.) (N=5)**
JA2-4	0.512540 $\pm$ 11		$\pm$ 7 (2 σ_m) (N=5)**
JA2-5	0.512525 $\pm$ 13		
	0.512530 $\pm$ 9 (s.d.) (N=5)**	JR2-1	0.512909 $\pm$ 11
	$\pm$ 11 (2 σ_m) (N=5)**	JR2-2	0.512917 $\pm$ 10
		JR2-3	0.512903 $\pm$ 13
JA3-1	0.512855 $\pm$ 17	JR2-4	0.512927 $\pm$ 12
JA3-2	0.512863 $\pm$ 14	JR2-5	0.512911 $\pm$ 13
JA3-3	0.512858 $\pm$ 11		0.512913 $\pm$ 9 (s.d.) (N=5)**
JA3-4	0.512867 $\pm$ 11		$\pm$ 11 (2 σ_m) (N=5)**
JA3-5	0.512851 $\pm$ 16		
	0.512859 $\pm$ 6 (s.d.) (N=5)**	LaJolla	0.511851 $\pm$ 6 (n=17)*
	$\pm$ 8 (2 σ_m) (N=5)**	JNdi-1	0.512106 $\pm$ 3 (n=44)*

*Number of measurements; **Number of samples which are separately decomposed and extracted.
s.d.: standard deviation.

(1992), Iizumi *et al.* (1994) and Yamamoto and Maruyama (1996) reported Nd isotope values of GSJ-RRS with the value of La Jolla. The La Jolla values in their reports are 0.511864 ± 0.000006 ($2\sigma_m$), 0.511848 ± 0.000003 ($2\sigma_m$) and 0.511829 ± 0.000024 ($2\sigma_m$) respectively. Like $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, our data were compared with the previously reported data normalized using La Jolla value of 0.511851.

Previously reported Nd isotopic ratios for JB-1a sample range from 0.512758 to 0.512807 (Arakawa, 1992; Iizumi *et al.*, 1995; Yamamoto and Maruyama, 1996). Our average $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of 0.512782 ± 0.000006 ($2\sigma_m$) lies within this range. Mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of JB-3 is also within the range of previously reported data (0.513033–0.513038; Arakawa, 1992; Iizumi *et al.*, 1995). Our average $^{143}\text{Nd}/^{144}\text{Nd}$ ratio of JG-1a is within the deviation of the highest values previously reported (0.512365 ± 0.000018 ($2\sigma_m$); Arakawa, 1992).

Mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of JA-2, JG-2 and JG-3 obtained by us are close to the values reported by Arakawa (1992) (JA-2; 0.512537 ± 0.000012 ($2\sigma_m$), JG-2; 0.512219 ± 0.000007 ($2\sigma_m$), JG-3; 0.512606 ± 0.000007 ($2\sigma_m$)). But our mean Nd isotopic data for JB-2, JA-1, JGb-1 and JR-1 are higher than value reported by Arakawa (1992) (JB-2; 0.513042 ± 0.000008 ($2\sigma_m$), JA-1; 0.513073 ± 0.000005 ($2\sigma_m$), JGb-1; 0.512611 ± 0.000008 ($2\sigma_m$), JR-1; 0.512893 ± 0.000006 ($2\sigma_m$)).

Neodymium isotopic ratios for JA-3 and JR-2 have not been previously reported, and the mean $^{143}\text{Nd}/^{144}\text{Nd}$ ratios of our measurements are 0.512859 ± 0.000008 ($2\sigma_m$) for JA-3 and 0.512913 ± 0.000011 ($2\sigma_m$) for JR-2.

In summary, five to nine aliquots for each GSJ-RRS measurements reported here gave small standard deviations of both Sr and Nd isotopic ratios. Most Sr and Nd isotopic ratios reported here are within previously reported data range, but some present Nd isotopic ratios are higher than previously reported data.

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