Rb-Sr isochron ages of Cretaceous-Paleogene granitoid rocks in the central part of the Chugoku district, Southwest Japan

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Abstract

Rb-Sr whole rock and internal isochron ages and initial Sr isotope ratios were determined for four granitoid rocks near the boundary of the San-yo and San-in Belts in the central part of the Chugoku district, SW Japan. The Shikijiki and Oasa Granites in the San-yo Belt have Rb-Sr internal isochron ages of 80.5 ± 3.9 (2σ) and 72.9 ± 2.8 (2σ) Ma with initial Sr isotope ratios of 0.70590 ± 35 (2σ) and 0.70733 ± 64 (2σ), respectively. The age of the former granitoid is comparable with previously reported K-Ar biotite ages, but the latter is younger than a K-Ar biotite age by several million years. The Ombara Granite in the San-in Belt has a Rb-Sr internal isochron age of 58.0 ± 1.5 (2σ) Ma with an initial Sr isotope ratio of 0.70617 ± 19 (2σ), which is consistent with K-Ar biotite and muscovite ages. The Asuna Granite in the San-in Belt is mainly composed of tonalite, granophyre and granite porphyry, which show gradational contacts in the field. However, these rocks do not plot on a Rb-Sr whole rock isochron. The tonalite has a whole rock isochron age of 44.3 ± 6.1 (2σ) Ma, and the internal isochron age of the granophyre is 40.4 ± 2.9 (2σ) Ma. The granite porphyry, on the other hand, has a much younger whole rock isochron age of 28.9 ± 5.8 (2σ) Ma. These age data suggest that the Asuna Granite solidified over at least 3.5 million years. All three initial Sr isotope ratios of the Asuna Granite are lower than 0.7050 and are similar to Miocene volcanic rocks in the central part of the San-in region, but slightly different to Cretaceous-Paleogene granitoid rocks.

Key words: Cretaceous-Paleogene, granitoids, Rb-Sr isochron, Sr isotope, Southwest Japan

Introduction

Cretaceous-Paleogene volcanic and intrusive rocks are widely distributed in the Oasa-Asuna-Akana area in the central part of the Chugoku district of SW Japan (Fig. 1). This area sits astride the boundary of the San-in and San-yo Belts, delineated by Murakami (1974) on the basis of petrography and radiometric ages of intrusive rocks. Cretaceous-Paleogene igneous activity in this area can be divided into three stages: late Cretaceous volcanism and plutonism, early Paleogene plutonism, and middle to late Paleogene volcanism and plutonism (Iizumi et al., 1985; Matsuura, 1989, 1990). Igneous rocks of all stages are mostly felsic in composition, composed mainly of rhyolite-dacite lavas and pyroclastic rocks, granite and granodiorite. There are small occurrences of gabbroic rocks, andesite lavas and pyroclastic rocks

(Fig. 1). Thus, this area is well suited to examine the geochemical evolution of both felsic magma and the magma source(s) with time, because felsic magmatism has occurred at least three times during the Cretaceous-Paleogene.

In a wider program to examine geochemistry of these igneous rocks, we determined Rb-Sr whole rock and internal (whole rock and separated mineral fractions) isochron ages, and initial Sr isotope ratios for four granitic bodies (the Shikijiki, Oasa, Ombara and Asuna Granites) in this area. Although some K-Ar and fission track age data have already been reported for these four granites (Kawano and Ueda, 1966; Shibata and Ishihara 1974; Matsuda, 1982; Hattori et al., 1983; Matsuura, 1989; Kitagawa et al., 1988), there are no Rb-Sr isochron ages and initial Sr isotope data. In this report we evaluate the new Rb-Sr geochronological data and initial Sr isotope ratios,

Paleogene:

- Late Cretaceous to Paleogene dikes
- Ishitanigawa Diorite
- Kambatagawa Granodiorite
- Ijimi Granite
- Asuna Granite (Granite Porphyry)
- Asuna Granite (Granophyre)
- Asuna Granite (Tonalite)
- Yagami Granite
- Kuchiba Diorite
- Sakugi Volcanic Rocks
- Ombara Granite
- Akana Granodiorite

Late Cretaceous:

- Mitsumori Granite
- Shikijiki Granite
- Oasa Granite
- Kanbikisan Gabbro
- Sakamoto Granite Porphyry
- Late Cretaceous volcanic rocks

Pre-Cretaceous:

- Pre-Cretaceous sedimentary rocks

Fault

Tectonic boundary

Fig. 1. Geological map of the Oasa-Asuna-Akana area. Based on Kano et al. (1988), Takagi et al. (1989), Matsuura (1990), Murakami and Komuro (1993).

and present a discussion on the solidification history of the Asuna Granite.

Geological setting

The basement rocks to the Cretaceous-Paleogene igneous rocks in this area are pre-Cretaceous sedi-

mentary rocks, distributed in two separate areas (Fig. 1). In the eastern part of the study area, these rocks are called the Hasumi Formation (Matsuura, 1990), comprising sandstone overlain by shale, which contains blocks of chert, basalt and limestone (Matsuura, 1990; Sugiyama et al., 1990). Matsuura (1990) and

Table 1. Geochronological data and initial Sr isotope ratios of granitic rocks.

	Method	Sample type	Age (Ma)	SrI	References
San-in Belt	Rb-Sr	WR (Granite Porphyry)	28.9±5.8	0.70489±60	This study
	Rb-Sr	INT (Granophyre)	40.4±2.9	0.70405±28	This study
	Rb-Sr	WR (Tonalite)	44.3±6.1	0.70449±12	This study
	K-Ar	Kf	34.4		Kawano & Ueda (1966)
	K-Ar	Bt	41.2±1.9		Shibata & Ishihara (1974)
	K-Ar	Bt	38.7±1.8		Shibata & Ishihara (1974)
	K-Ar	Bt	36.0±1.8		Matsuura (1989)
	K-Ar	Ser	36.4±1.8		Kitagawa et al. (1988)
	F.T.	Zir	51±4		Matsuda (1982)
	Rb-Sr	INT	58.0±1.5	0.70617±19	This study
	K-Ar	Bt	65.2±2.7		Shibata & Ishihara (1974)
	K-Ar	Bt	60.0±3.0		Hattori et al. (1983)
San-yo Belt	K-Ar	Ms	56.1±2.8		Hattori et al. (1983)
	F.T.	Zir	52		Matsuda (1982)
	Rb-Sr	INT	72.9±2.8	0.70733±64	This study
	K-Ar	Bt	82.4±3.2		Shibata & Ishihara (1974)
	F.T.	Zir	87		Matsuda (1982)
	Rb-Sr	INT	80.5±3.9	0.70590±35	This study
	K-Ar	Bt	73.3		Kawano & Ueda (1966)
	K-Ar	Bt	84.7±4.2		Matsuura (1989)

Rb-Sr : Rb-Sr method, K-Ar : K-Ar method, F.T. : fission track method, WR : whole rock samples, INT : whole rock and separated mineral fractions, Kf : alkali feldspar samples, Bt : biotite samples, Ser : sericite samples, Ms : muscovite samples, Zir : zircon samples.

Sugiyama et al. (1990) suggested a Carboniferous or Permian age for the Hasumi Formation, since the limestone contains fossil rugose corals from the Middle Carboniferous. The Tsunotani Formation in the northern part of this area is composed of thermally metamorphosed wacke-type sandstone and shale (Matsuura, 1990).

Cretaceous-Paleogene igneous activity can be grouped into three stages : Cretaceous volcanism and plutonism (1st stage), early Paleogene plutonism (2nd stage) and middle-late Paleogene volcanism and plutonism (3rd stage). The Cretaceous volcanic rocks of the first stage consist mainly of dacitic to rhyolitic pyroclastic rocks, with thin intercalations of lacustrine sediments, and lavas, totaling more than 2,000 m in thickness. The pyroclastic rocks have a fission track zircon age of 92 ± 4 (2 σ) Ma (Matsuda 1982).

Intrusive rocks of the first stage are the Kanbikisan Gabbro, Sakamoto Granite Porphyry, Oasa, Shikijiki and Mitsumori Granites. These intrusive rocks are distributed in the San-yo Belt except for the Mitsumori Granite, which is in the San-in Belt (Fig. 1). The Kanbikisan Gabbro (predominantly clinopyroxene-hornblende gabbro) occurs as a xenoblock in the Oasa Granite at the boundary between the San-yo and San-in Belts. The Shikijiki Granite is a medium-grained massive hornblende-biotite granite, whereas the predominant rock type of the Oasa Granite is coarse- to medium-grained biotite granite. The Shikijiki Granite has K-Ar biotite ages of 73.3 Ma (Kawano and Ueda, 1966) and 84.7 ± 4.2 (2 σ) (Matsuura, 1989), and the Oasa Granite has a K-Ar biotite age of 82.4 ± 3.2 (2 σ) (Shibata and Ishihara, 1974) and a fission track zircon age of 87 Ma (Matsuda, 1982). The Mitsumori Granite consists of granodiorite porphyry, granite porphyry, granophyre and aplitic granite, and

has a Rb-Sr internal isochron age of 80.4 ± 3.3 (2 σ) Ma (Takagi et al., 1989). Based on a fission track zircon age of 80.1 ± 5.6 (2 σ) Ma (Murakami et al., 1982), Matsuura (1989) included the Sakamoto Granite Porphyry along with the first stage intrusive rocks.

The Akana Granodiorite and Ombara Granite in the northern part of the area (Fig. 1) are intrusive rocks of the second stage. The Akana Granodiorite is mainly composed of medium- to coarse-grained hornblende-biotite granodiorite, and the Ombara Granite is a coarse- to medium-grained biotite granite. The former is intruded by the latter with a sharp contact. The Ombara Granite has K-Ar biotite and muscovite ages ranging from 56.1 ± 2.8 (2 σ) to 65.2 ± 2.7 (2 σ) Ma (Shibata and Ishihara, 1974 ; Hattori et al., 1983) and a fission track zircon age of 52 Ma (Matsuda, 1982).

The Sakugi Volcanic Rocks (Yoshida, 1961) (third stage igneous rocks) unconformably overlie the Mitsumori Granite (Takagi et al., 1989) and is in turn intruded by the Asuna Granite. The Sakugi Volcanic Rocks are composed mainly of andesite to rhyolite lavas and pyroclastic rocks with intercalations of lacustrine sedimentary rocks (Matsuura, 1990 ; Murakami and Komuro, 1993) (Fig. 1). The Sakugi Volcanics are intruded in several places by the Kuchiba Diorite, which is mainly composed of clinopyroxene-hornblende-quartz diorite and orthopyroxene-hornblende diorite. The Kuchiba Diorite has a K-Ar hornblende age of 49.3 ± 7.5 (2 σ) Ma (Matsuura, 1989). Based on its intimate relationship with the Sakugi Volcanics, the Kuchiba Diorite is considered to be comagmatic with the Sakugi Volcanics.

The Asuna, Ijimi and Yagami Granites (Fig. 1) are the main intrusive rocks of the third stage. The Asuna Granite in the central part of this area intrudes

Table 2. Rb and Sr concentrations, Sr isotope ratios and ages of granitic rocks.

			Sample	Rb ppm	Sr ppm	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr (2σ)	Age (Ma) (2σ)
San-in Belt	Asuna Granite	Granite Porphyry	WR	123	55	6.47	0.707524±14	28.9±5.8
			WR	139	61	6.59	0.707623±14	
			WR	147	57	7.46	0.707919±14	
			WR	139	51	7.89	0.708237±13	
			WR	144	47	8.87	0.708449±14	
		Granophyre	WRL	84.0*	147*	1.66	0.704901±14	40.4±2.9
			WR	104	112	2.69	0.705893±14	
			WRM	151*	29.0*	14.9	0.712642±16	
			BRF	250*	14.0*	50.3	0.732551±14	
		Tonalite	WR	56	501	0.323	0.704586±14	44.3±6.1
			WR	76	282	0.780	0.704976±12	
			WR	75	276	0.792	0.705072±13	
			WR	76	249	0.883	0.705127±16	
			WR	103	134	2.22	0.705830±14	
			WR	106	133	2.31	0.705957±13	
		Ombara Granite	WR	99	121	2.37	0.705928±13	58.0±1.5
	WRL		125*	69.0*	5.25	0.710455±14		
	WR		133	61	6.27	0.711313±14		
	WRM		237*	58.0*	11.8	0.716034±14		
	BRF		567*	9.88*	168	0.843374±16		
San-yo Belt	Oasa Granite	WRL	175*	40.3*	12.7	0.720143±14	72.9±2.8	
		WR	195	42	13.3	0.721248±14		
		WRM	289*	47.3*	17.7	0.725829±14		
		BRF	442*	21.4*	60.1	0.769275±14		
	Shikijiki Granite	WRL	137*	156*	2.53	0.708895±15	80.5±3.9	
		WR	170	144	3.42	0.709386±14		
		WRM	392*	27.8*	41.0	0.752419±14		
		BRF	478*	12.8*	109	0.832448±14		

* concentrations were determined by isotope dilution.

BRF: biotite rich fractions, WRM: melanocratic fractions of whole rock samples, WR: whole rock samples, WRL: leucocratic fractions of whole rock samples.

Cretaceous volcanic rocks, the Oasa Granite, the Ombara Granite, the Sakugi Volcanics and the Kuchiba Diorite. As will be described later, the Asuna Granite is a slender stock, composed of tonalite, granophyre and granite porphyry. K-Ar biotite, K-feldspar and sericite ages of the Asuna Granite range from 41.2 $\pm$ 1.9 (2 σ) to 34.4 Ma (Kawano and Ueda, 1966; Shibata and Ishihara, 1974; Kitagawa et al., 1988; Matsuura, 1989) (Table 1), but Matsuda (1982) reported an older fission track zircon age of 51 $\pm$ 4 (2 σ) Ma (Table 1). The Ijimi and Yagami Granites are composed of granite porphyry, granophyre and aplitic granite. The Ijimi Granite has similar K-Ar biotite and muscovite ages around 31 Ma (Hattori et al., 1983; Matsuura, 1989).

Analytical procedures

Rb and Sr concentrations of whole rock samples were determined by X-ray fluorescence spectrometry (GEOL JSX60S7) in the Geology Department, Faculty of Science, Shimane University, following the methods described by Kobayashi et al. (1981) and Ichikawa et al. (1987). An error of 5% for the Rb/Sr ratio of each sample is estimated, based on reproducibility of the data for the standard samples JG-1a and JB-1a. Mineral fractions were prepared using an isodynamic separator.

Isotope work was carried out at the Institute for

Study of the Earth's Interior, Okayama University, using a MAT-261 mass spectrometer. Extraction methods for Rb and Sr from rock powders have been described by Kagami et al. (1987). Mass spectrometric analyses were made following the procedure of Kagami et al. (1987, 1989). The measured $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.1194$. Blanks for the whole procedure were 0.60 ng Rb and 0.55 ng Sr. Sr isotope ratios for NBS987 were measured five times during this study, with a mean ratio of 0.710236 $\pm$ 0.000012 (2 σ mean). Rb and Sr contents of mineral samples were determined by isotope dilution using a ^{87}Rb - ^{86}Sr mixed spike. Measured Rb and Sr contents of BCR-1 were 46.5 ppm and 328 ppm, respectively. An error of 2% for the Rb/Sr ratio of each sample is estimated for the isotope dilution method, based on reproducibility of the data for BCR-1. Ages were calculated after York (1966).

Results and discussion

Analytical results and isochron ages are listed in Table 2. These Rb-Sr isochron ages for the four granites are also listed in Table 1, together with previously reported K-Ar and fission track ages. The Shikijiki and Oasa Granites in the San-yo Belt have Rb-Sr internal isochron ages of 80.5 $\pm$ 3.9 (2 σ) Ma and 72.9 $\pm$ 2.8 (2 σ) Ma, and initial Sr isotope ratios of 0.70590 $\pm$ 35 (2 σ) and 0.70733 $\pm$ 64 (2 σ), respectively (Figs. 2 and 3).

Fig. 2. Rb-Sr internal isochron diagram of the Shikijiki Granite. Symbols as in Table 2.

Fig. 3. Rb-Sr internal isochron diagram of the Oasa Granite. Symbols as in Table 2.

Fig. 4. Rb-Sr internal isochron diagram of the Ombara Granite. Symbols as in Table 2.

The Rb-Sr internal isochron age of the Shikijiki Granite is consistent with a K-Ar biotite age of 84.7 ± 4.2 (2 σ) Ma (Matsuura, 1989) within analytical error, but is older than a K-Ar biotite age of 73.3 Ma reported by Kawano and Ueda (1966). The Oasa Granite has a younger Rb-Sr internal isochron age than the K-Ar biotite age of 82.4 ± 3.2 (2 σ) Ma reported by Shibata and Ishihara (1974). The Ombara Granite in the San-in Belt has a Rb-Sr internal isochron age of 58.0 ± 1.5 (2 σ) Ma with an initial ratio of 0.70617 ± 19 (2 σ) (Fig. 4).

The Asuna Granite can be petrographically subdivided into tonalite, granophyre and granite porphyry (Fig. 1), which do not plot on an isochron. The tonalite shows a Rb-Sr whole rock isochron age of 44.3 ± 6.1 (2 σ) Ma with an initial Sr isotope ratio of 0.70449 ± 12 (2 σ) (Fig. 5). The granophyre shows an internal isochron age of 40.4 ± 2.9 Ma and an initial Sr isotope ratio of 0.70405 ± 28 (2 σ) (Fig. 6), whereas the granite

Fig. 5. Rb-Sr whole rock isochron diagram of the Asuna Granite (Tonalite and Granite Porphyry).

Fig. 6. Rb-Sr internal isochron diagram of the Asuna Granite (Granophyre). Symbols as in Table 2.

porphyry has a whole rock isochron age of 28.9 ± 5.8 (2 σ) Ma and an initial Sr isotope ratio of 0.70489 ± 60 (2 σ) (Fig. 5). The Granite Porphyry of the Asuna Granite has the youngest radiometric age amongst Paleogene granitoid rocks in the San-in Belt.

In the Rb-Sr isotope system, internal isochron ages of granitoid rocks are in some cases younger than the whole rock isochron ages, due to the time interval between differentiation-crystallization of the magma and cooling of constituent minerals to their closure temperatures. Therefore, ages determined by the internal isochron method should be treated carefully when comparing them with those determined by the whole rock isochron method. In the case of the Cretaceous-Paleogene granitoid rocks of SW Japan, the internal Rb-Sr isochron ages and K-Ar mineral ages are in some cases 5 to 9 million years younger than the Rb-Sr whole rock isochron ages (Shibata and Ishihara, 1979a; Kagami et al., 1988; Sudo et al., 1988). Thus, the granophyre of the Asuna Granite, with an internal isochron age of 40.4 ± 2.9 Ma may have an older whole rock isochron age. Tonalite, granophyre and granite porphyry, which make up the Asuna Granite, are gradational in the field. This, combined with the Rb-Sr isochron ages of the three rock types, means that the Asuna Granite could have crystallized over an interval of more than 3.5 million years. This is consistent with K-Ar biotite, K-feldspar and sericite ages reported by Kawano and Ueda (1966), Shibata and Ishihara (1974), Matsuura (1989) and Kitagawa et al. (1988), which range from 41.2 ± 1.9 to

34.4 Ma (Table 1).

The Rb-Sr isochron ages reported here indicate three phases of magmatism during the Cretaceous-Paleogene in this restricted area of the central Chugoku district. The first stage of felsic to intermediate volcanism was followed by intrusions of Late Cretaceous granitoid rocks, the Mitsumori, Shikijiki and Oasa Granites with Rb-Sr internal isochron ages of 80.5 ± 3.9 Ma (Takagi et al., 1989), 80.4 ± 3.3 Ma and 72.9 ± 2.8 Ma, respectively. After a hiatus of about 15 million years, this first stage was followed by the intrusion of the Eocene Ombara Granite and Akana Granodiorite (second stage), which are correlated with the Inbi Intrusive Rocks distributed widely in the San-in Belt. The third stage of magmatism started with intermediate to felsic volcanism (the Sakugi Volcanic Rocks), resulting in formation of a small-scale collapse-type cauldron (Murakami and Komuro, 1993), and terminated with the intrusion of the late Eocene-Oligocene Asuna and Izumi Granites.

As the internal isochron method gives in some cases higher initial Sr isotope ratios than the whole rock isochron method, it is not acceptable to compare initial Sr isotope ratios of the Oasa, Shikijiki and Ombara Granites with those of other granitoid rocks. However, it is reasonable to say that the Oasa Granite has a similar initial Sr isotope ratio to other granitoid rocks of the San-yo Belt, which are mostly in the range from 0.7060 to 0.7080, since the initial ratio is still high (0.7065), even if the initial ratio is recalculated assuming that the whole rock isochron age is older than the internal isochron age by five million years. The Shikijiki Granite, on the other hand, has a low initial isotope ratio for granitoid rocks of the San-yo Belt. As suggested by Kagami et al. (1992), different initial Sr isotope ratios of these two granitoid rocks may reflect geochemical heterogeneity of the source beneath the northern part of the San-yo Belt. The three rock types of the Asuna Granite have conformable initial Sr isotope ratios within analytical error, and the initial ratios are slightly lower than those (0.7050–0.7060) of most granitoid rocks in the San-in Belt (Shibata and Ishihara, 1979b; Iizumi et al., 1984; Sudo et al., 1988; Kagami et al., 1992). We note that the Asuna Granite has a similar initial Sr isotope ratio to Miocene volcanic rocks (0.7040–0.7053) (Sawada, personal communication) rather than Cretaceous-Paleogene granitoid rocks of the San-in Belt.

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** : in Japanese

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(要旨)

Rezanov, A.I., Kagami, H. and Iizumi, S., 1994, Rb-Sr isochron ages of Cretaceous-Paleogene granitoid rocks in the central part of the Chugoku district, Southwest Japan. *Jour. Geol. Soc. Japan*, 100, 651-657. (アンドレ レザノフ・加々美寛雄・飯泉 滋, 1994, 西南日本, 中国地方中央部に分布する白亜紀-古第三紀花崗岩類の Rb-Sr アイソクロン年代. 地質雑, 100, 651-657.)

中国地方中央部の山陽・山陰帯境界付近に分布する4つの花崗岩体について, Rb-Sr アイソクロン年代と Sr 同位体初生値を求めた. 山陽帯の式敷および大朝花崗岩はそれぞれ, 80.5 ± 3.9 Ma, 72.9 ± 2.8 Ma, 山陰帯の乙原花崗岩は 58.0 ± 0.5 Ma のインターナルアイソクロン年代を示す. また, 互いに漸移するトータル岩・文象斑岩・花崗斑岩から構成される山陰帯の阿須那花崗岩は, 一本のアイソクロンにはプロットされず, それぞれ, 44.3 ± 6.1 Ma, 40.4 ± 2.9 Ma, 28.9 ± 5.8 Ma, の年代を示す. これらの年代から, 本岩体は固結に少なくとも 350 万年以上を要したことが示唆される. 本地域では白亜紀末から古第三紀末にかけて約 15 Ma の間隔を置いて3回の花崗岩の活動があったことが示される. 式敷花崗岩は山陽帯の花崗岩としては低い Sr 同位体初生値を, また阿須那花崗岩は山陰帯の多くの花崗岩類より低く, むしろ新第三紀の火成岩類に匹敵する低い初生値を示す.