NOTE

Fission track ages of the Omine Acidic Rocks, Kii Peninsula, Southwest Japan

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Fission track (FT) ages of the Omine Acidic Rocks, one of the Tertiary granitic rocks which occurs in the Outer Zone of the Median Tectonic Line, Southwest Japan, are determined in order to assess the timing of intrusion. Nine FT zircon (ZR) ages and one apatite (AP) age are obtained for igneous rocks, and four ZR ages for basement sandstone. Data for each pluton are concordant within a body representing the time of intrusion. The ZR ages from sandstone are concordant with the nearest pluton. The ages of plutons are classified into two groups statistically, suggesting that the Omine Acidic Rocks formed by two intrusive events. The Dorogawa, Tenguyama, Shiratani and Katago-Mukuro Dike are the older group with the weighted mean age of 16.8 ± 0.8 Ma, and the Kose pluton are the younger with an age of 14.2 ± 1.7 Ma.

INTRODUCTION

More than fifteen Tertiary intrusive granitic rocks are known as the "Outer Zone Granite" in the Shimanto Belt, Outer Zone of the Median Tectonic Line in Southwest Japan. These igneous activities were considered to be contemporaneous at around 14 Ma (Shibata, 1978; Shibata and Nozawa, 1967), and were attributed to a tectonic event which widely affected the thermal regime of the forearc area of ~1200 km long, from the Kii peninsula to Kyushu. Considering their timing, it was deduced that the tectonic framework of southwest Japan region at Miocene, remarked by the opening of the Shikoku Basin plate (Chamot-Rooke *et al.*, 1987) and the clockwise rotation of the Southwest Japan block (Otofuji *et al.*, 1985), might be responsible for these igneous events.

A precise determination of the age-space distribution of granites is a fundamental need to understand the relationship between the granitic

magma intrusion and tectonic framework at the time. Because of their possible complicated histories, the emplacement ages of granites should be estimated after investigation of their cooling histories by means of an age mapping and a combination of several dating techniques. At the beginning of studies on ages of the Outer Zone Granites, however, an age of each granite was estimated using data from one locality without investigation of its cooling history (Shibata and Nozawa, 1967). Recent researches (e.g., Murakami *et al.*, 1989; Iwaya and Mimura, 1992; Dai *et al.*, 1993; Hasebe *et al.*, 1993; Tagami and Shimada, 1996; Sumii *et al.*, 1998) re-estimate their emplacement ages carefully, still supporting the contemporaneity of the Outer Zone Granite intrusion.

In this study the fission-track (FT) ages were determined on zircon and apatite crystals to assess the time of intrusion of the Omine Acidic Rocks (OARs). The OARs are one of the Outer Zone Granites occurring at north of the eastern end of the region. Because the OARs were inter-

preted as one large body (Kawasaki, 1980), the age of the OARs had been discussed using data from only one of the bodies (e.g., Shibata and Nozawa, 1968a; Hayase and Ishizaka, 1967). However, later chemical and petrological studies revealed that it consists of several small plutons rather than one large pluton (Kawasaki, 1980; Murata *et al.*, 1983; Murata, 1984). This study contributes the discussion on age difference (or concordance) between the bodies (Itaya *et al.*, 1982; Sumii *et al.*, 1997) of the OARs, and further on contemporaneity of the Outer Zone Granites.

GEOLOGICAL SETTING AND SAMPLING

The OARs occur in the central mountainous land of the Kii peninsula intruding into the Permian Chichibu Belt, the Cretaceous and Paleogene Shimanto Belt, and the Miocene Kumano Group (Fig. 1). It consists of seven plutons with diameters less than 5 km across, named Dorogawa, Shirakura, Kose, Tenguyama, Asahi, Shiratani and Katago-Mukuro Dike. The plutons generally consist of granodiorite, granite and granite porphyry (Kawasaki, 1980). Murata *et al.* (1983) divided the plutons into two types of

Fig. 1. Sampling localities are shown as solid circles along with obtained ages (Ma, $\pm 2\sigma$). All data are FT zircon ages except for one with "AP" which is an apatite age. Previously reported data are also shown in rectangles. *Hayase and Ishizaka, 1967; **Shibata and Nozawa, 1968a; ***Itaya *et al.*, 1982; ****Sumii *et al.*, 1997. Abbreviation for mineral names are as follows: bt = biotite, hbl = hornblende, Kf = K-feldspar. Map is modified based on Tokuoka *et al.* (1981), Shiida *et al.* (1989), Yamada *et al.* (1990) and Kurimoto *et al.* (1998).

I- and S-type granitoid following the definition by Chappel and White (1974). The Dorogawa and Shirakura plutons are I-type granodiorite probably generated from igneous source materials and the others (Kose, Tenguyama, Asahi, Shiratani and Katago-Mukuro Dike) are S-type granite that could be generated in sedimentary source material. A couple of rock samples were collected from each pluton except for the Shirakura pluton that shows small distribution near Dorogawa pluton. Some samples are sandstone hornfels or complex rock of granitic and basement parts. The locations of rock samples are shown in Fig. 1 as solid circles. Rock facies of samples are explained in Table 1.

EXPERIMENTAL PROCEDURE

Zircon and apatite crystals were analysed by FT method using the external detector method (e.g., Naeser, 1976) and zeta calibration approach (Hurford and Green, 1983; Hurford, 1990). The experimental procedure used in this work was described by Tagami *et al.* (1988) in detail. For zircon samples, etching took 20–50 hours in NaOH:KOH eutectic etchant. Apatite samples were etched in 0.6% HNO₃ at 32.0 ± 0.5°C for 1.5 minutes. A low-uranium muscovite sheet was used as an external detector to record the induced tracks of minerals and to measure the thermal neutron flux. They were attached to the mounts of

Table 1. Fission track analytical results

Pluton	Code	Rock	ρ_s (10 ⁶ cm ⁻²)	N_s	ρ_i (10 ⁶ cm ⁻²)	N_i	ρ_d (10 ⁶ cm ⁻²)	N_d	$T \pm 2\sigma$ (Ma)	N	$P(\chi^2)$ (%)
Dorogawa	OMG02	GD	2.61	336	2.43	313	0.0976	2268	18.8 ± 3.1	7	80
	OMG04	GD	3.79	2573	3.82	2598	0.0960	2231	17.0 ± 1.4	19	84
	Weighted mean of OMG02 and OMG04								17.4 ± 1.3		
Kose	OMG08	G	2.47	506	2.75	563	0.0882	2049	14.2 ± 1.9	15	7
	OMG08AP	G	0.34	42	1.70	207	0.4512	2097	14.1 ± 4.9	6	69
	Weighted mean of OMG08 and OMG08AP								14.2 ± 1.7		
Tenguyama	OMG10	GwS	2.26	205	2.49	226	0.0976	2268	15.9 ± 3.2	8	69
	OMG11	GwS	3.05	383	2.78	350	0.0882	2049	17.3 ± 2.8	6	3
	OMG25	G	2.90	508	3.08	541	0.0976	2268	16.4 ± 2.2	13	93
Asahi	OMG27	G	3.23	357	3.04	336	0.0882	2049	16.8 ± 2.7	9	26
	Weighted mean of OMG25 and OMG27								16.6 ± 1.7		
Shiratani	OMG12	GP	1.56	145	1.76	164	0.0960	2231	15.2 ± 3.6	6	24
	OMG16	G	2.28	883	2.25	874	0.0882	2049	16.0 ± 1.8	16	6
	OMG17	SS	2.84	185	2.56	167	0.0882	2049	17.5 ± 3.9	5	90
	Weighted mean of OMG12 and OMG16								15.9 ± 1.6		
K-M Dike	OMG18	SS	3.77	348	3.63	333	0.0882	2049	16.4 ± 2.7	7	5
	OMG22	GP	3.33	406	3.43	419	0.0976	2268	16.9 ± 2.6	8	45
	OMG24	GP	2.15	195	2.26	205	0.0960	2231	16.4 ± 3.4	6	31
	Weighted mean of OMG22 and OMG24								16.7 ± 2.1		

Note: ρ_s = density of spontaneous tracks; N_s = number of spontaneous tracks counted to determine ρ_s ; ρ_i = density of induced tracks in a sample; N_i = number of induced tracks counted on a muscovite external detector to determine ρ_i ; ρ_d = density of induced tracks in NBS-SRM612 dosimeter glass; N_d = number of induced tracks counted in muscovite external detector to determine ρ_d ; T = FT age calculated from pooled N_s and N_i for all grains counted; N = number of counted grains; $P(\chi^2)$ = probability of χ^2 for $N - 1$ degrees of freedom (Galbraith, 1981); K-M Dike means Katago-Mukuro Dike. AP in code represents the data for apatite. Others are for zircon. GD = granodiorite; GwS = complex rock of granitic and basement sandstone parts collected from boundary of an intrusion and basement rocks; G = granite; SS = sandstone hornfels; GP = granite porphyry.

minerals and dosimeter glass NBS-SRM612, and irradiated in Thermal Column Pneumatic Tube facility of Kyoto University Research Reactor (KUR-1). The induced tracks were revealed by etching the mica sheet in 47% HF at $32.0 \pm 0.5^\circ\text{C}$ for four minutes. Etched tracks (spontaneous tracks in a mineral and induced tracks recorded on mica detectors for both mineral and dosimeter glass) were counted under a Nikon Biophot transmitted microscope with 100 $\times$ dry objective and 10 $\times$ eye pieces that result in the true measured magnification of 925 $\times$. The ζ values of 358.9 ± 14.0 (2σ) for zircon and 309.6 ± 23.4 (2σ) for apatite were adopted for age calculation (e.g., Hasebe *et al.*, 1993, 1997).

RESULTS

FT ages were obtained from 13 sites. The analytical results are shown in Table 1. All of granodiorite, granite and granite porphyry samples passed the χ^2 -test at the 5% criterion (Galbraith, 1981; Green, 1981). This result suggests that the age variations between grains in samples are within that allowed for under the conventional Poissonian statistics and that these ages are considered as cooling ages of the plutons. Other samples also passed the χ^2 -test except for OMG11 from the Tenguyama pluton, showing concordant ages with the age of the nearest plutons. This means that the age of the basement rock samples has been reset by the intrusion of the granite. The OMG11, which did not pass the test ($P(\chi^2) = 3\%$), contains a few zircon grains of rounded shape having higher spontaneous track densities. The age may not been reset completely by the intrusive event.

The weighted mean age is calculated to represent a cooling age of each pluton because obtained ages for each pluton are concordant. For Kose pluton, FT ages of zircon and apatite are concordant, suggesting the rapid cooling of the body through the zircon and apatite closure temperatures. Tenguyama and Asahi plutons yield concordant ages. On the basis of chemical and petrographical studies, Kawasaki (1980) inter-

preted that the Asahi pluton is a part of the Tenguyama pluton. Obtained ages also support this interpretation. Hence a weighted mean age of samples from the Asahi and Tenguyama is calculated to represent cooling time of the pluton.

Following lines of reasoning, i.e., the relatively small size of these plutons, rapid cooling revealed on the Kose pluton, and existence of age unresetting part in nearby basement rocks even by the largest Tenguyama pluton, lead us to the idea that plutons intruded at shallow level and cooled rapidly. Thus obtained cooling ages should nearly represent the emplacement age for each pluton. These ages are consistent with the data by K-Ar method (Shibata and Nozawa, 1968a; Sumii *et al.*, 1997), giving one more evidence for rapid cooling. Although K-Ar ages by Itaya *et al.* (1982) were slightly younger than obtained data here, this could be attributed to the unstable condition of the K-Ar laboratory at the very beginning of its history (Itaya, personal communication). The Rb-Sr ages from the Tenguyama pluton (Hayase and Ishizaka, 1967) are significantly older than the FT and K-Ar ages. Although the FT ages are considered here to represent the time of pluton emplacement, the Rb-Sr ages do not necessarily express the same time with FT ages because of low mobility of the elements applied for this technique. The Rb-Sr age could offer the oldest limit for the intrusive time. Or, considering that the Kose pluton is the S-type granite, the Rb-Sr age could be older than the true age because of possible contamination of radiogenic daughter delivered from original sedimentary material which produce the granitic magma.

THE AGES OF THE OARS

Among five plutons, one pluton (Kose) seems to be slightly younger than others. Whether all plutons belong to the same age population or not is considered statistically using the χ^2 -test. The possibility that all five plutons belong to one age population, which is represented by the weighted mean age and error of all plutons, is less than 0.1%. On the other hand, the probability of χ^2

value is 10% for the assumption that four bodies except for the Kose pluton belong to the one age population, giving no evidence to reject the assumption of the synchronous intrusion of the other four plutons. When one of the other plutons (Dorogawa, Tenguyama, Shiratani, or Katago-Mukuro Dike) is excluded from the population, the χ^2 -test demonstrates that the possibilities of four plutons to belong to one age population are still less than 0.1%. Based on these statistical tests, at least the Kose pluton yields the intrusive age different from the others. It is difficult to state that the intrusive ages for other four plutons are different, and the weighted mean age of four is calculated as 16.8 ± 0.8 (2σ) Ma to represent the time of intrusive event. The Kose pluton intruded at 14.2 ± 1.7 (2σ) Ma slightly later than others. This

result indicates that magma chemistry (I-type and S-type) is not associated with the time of intrusion, which is shown by the concordant age of intrusion between Dorogawa (I-type) and other S-type plutons except for the Kose.

THE AGES OF THE OUTER ZONE GRANITES

The ages of granitic intrusions in the Outer Zone are listed in Table 2. Age varies between 11 to 17 Ma. This variation could depend on the quality and meaning of data, because the table includes data which meanings are not discussed by the original authors. The data by recent researches (e.g., researches in 1990's) still show significant scattering in spite that they indicate the age of intrusion after the considerable discussion. The older

Table 2. The radiometric ages of granitic intrusions in the Outer Zone, Southwest Japan. The ages of Omine Acidic Rocks (OAR) are restricted those obtained in this study. For other granites, ages obtained recently are listed in case that there are several studies by the same method. Ages in parenthesis include data obtained from several rock facies. The question marks in the age column denote data with no information about that error represent σ or 2σ . See the cited references for the detailed description of stages of Cape Ashizuri.

Pluton	Method	Age $\pm 2\sigma$ (Ma)	References
<i>Kii Peninsula</i>			
OARs but Kose	FT; zr	16.8 ± 0.8	This work
Kose, OAR	FT; zr	14.2 ± 1.7	This work
Kumano Acidic Rocks	FT; zr, ap	14.3 ± 0.5	Hasebe <i>et al.</i> , 1993
	K-Ar; bt	$(14.2-14.4) \pm 0.4$	Sumii <i>et al.</i> , 1998
<i>Shikoku</i>			
Omogo	K-Ar; bt	14 ± 2 (?)	Shibata and Nozawa, 1968b
Takatsukiyama	FT; zr	14.8 ± 0.9	Tagami and Shimada, 1996
	K-Ar; bt	12 ± 2 (?)	Shibata and Nozawa, 1968b
Kashiwajima	Rb-Sr; wr	16 ± 2	Dai <i>et al.</i> , 1993
<i>Cape Ashizuri</i>			
stage II	FT; zr	16.1 ± 0.7	Murakami <i>et al.</i> , 1989
	K-Ar; bt	12.9 ± 0.6 (?)	Murakami <i>et al.</i> , 1989
stage IV	FT; zr	11.3 ± 0.4	Murakami <i>et al.</i> , 1989
stage IV?	K-Ar; bt	13 ± 2 (?)	Shibata and Nozawa, 1968b
<i>Kyushu</i>			
Osuzuyama	FT; zr	14.9 ± 1.4	Iwaya and Mimura, 1992
	K-Ar; bt, wr	$(15.1-16.6) \pm 1.6$	Iwaya and Mimura, 1992
Okueyama	K-Ar; bt	13.8 ± 0.9 (?)	Shibata, 1978
Minami Osumi	K-Ar; bt	14.4 ± 0.7 (?)	Shibata, 1978
	FT; zr	$(13.9-15.3) \pm (1.3-1.5)$	Miyachi, 1990

Note: FT: fission track method, zr: zircon, ap: apatite, K-Ar: K-Ar method, bt: biotite, wr: whole rock.

age of the OARs appears to be excluded from the contemporaneous timing of granitic activities in the Outer Zone, indicating the existence of igneous activity prior to the contemporaneous granitic intrusion. Granitic activities could occur twice or repeatedly in the Outer Zone. Ages of the intrusions could have some relationships with their locations. The future geochronological studies on other Outer Zone Granite would give a guide to understand the significance of age difference found in this study.

CONCLUSIVE REMARKS

(1) FT age determination, along with the χ^2 statistical test, reveals that the OARs have two intrusive times; one is 16.8 ± 0.8 Ma for Dorogawa, Tenguyama, Shiratani and Katago-Mukuro Dike, and the other is 14.2 ± 1.7 Ma for Kose pluton.

(2) The difference in magma chemistry of I- and S-type in the OARs does not correspond to the difference in the time of intrusion, which was demonstrated by concordant ages between Dorogawa (I-type) and Tenguyama, Shiratani and Katago-Mukuro Dike (S-type).

(3) The correlation of intrusive ages between the OARs and the other Outer Zone Granites indicates that the parts of OARs intruded earlier than the others.

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