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Unpublished K-Ar dates measured in the geochronology laboratory of Yamagata University—Rocks from the Abukuma Highland in Nihonmatsu area, Fukushima Prefecture

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Abstract

This report presents K-Ar dating results for biotite separates of granites from the Abukuma Highland in Nihonmatsu area, Fukushima Prefecture, as measured at the geochronology laboratory of Yamagata University. The K-Ar dates of rocks from a batholith-like plutonic body (Gd) were 111 – 105 Ma. The K-Ar dates of rocks from neighboring small plutonic bodies (Gr_2 and Gr_3) are, respectively, 102 – 99 Ma and 93 – 90 Ma. The K-Ar dating result of ca. 74 Ma from Gr_4 in the Dake-Onsen area is apparently 20–30 m.y. younger. The spatiotemporal distribution of K-Ar dates portrays the sequence of timing by which each plutonic rock reached the biotite closure temperature during the cooling process.

Introduction

The geochronology laboratory of Yamagata University has continued K-Ar and ^{40}Ar-^{39}Ar dating for rocks from plutonic bodies in eastern Japan to ascertain the spatiotemporal distribution of plutonism in the region and to elucidate the cooling history in each plutonic body. These projects were undertaken by former member of the faculty: Prof. Kazuo Saito along with their graduate and undergraduate students. Measured K-Ar dates were summarized in their theses. Some theses have been published (e.g. Tanzawa tonalite, Saito, 1989, Saito et al., 1991 and Saito, 1993; Kinpu-San plutonic body, Saito and Kato, 1996; Chichibu quartz diorite, Saito et al., 1996; Tokuwa granodiorite body, Saito et al., 1997). Unfortunately, some K-Ar dating results have not been published.

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This document presents unpublished K-Ar dating results measured at Yamagata University: K-Ar dates from Abukuma Highland in Nihonmatsu area, Fukushima Prefecture. The K-Ar dating experiments for plutonic rock in the Nihonmatsu area were conducted as part of an undergraduate research project (Kanno, 2001MS) supervised by one of the authors: KS.

In the Nihonmatsu area, Abukuma granites are distributed along the Abukuma River and around the Dake-Onsen area. The Abukuma granites are divisible into a batholith-like body and four small intrusive bodies based on mineral and chemical compositions (Sakaguchi, 1995). Radiometric dating has been applied only to the batholith-like body. No date has been reported for other small intrusive bodies.

Compilation and comparison of K-Ar dates presented by Kanno (2001MS) and in other reports (Kawano and Ueda, 1966; Tomizuka et al., 1991) were undertaken by one of the authors: NI. The quoted dates are invaluable for constraining the intrusion order and for surveying the duration of cooling processes affecting the Abukuma granites.

K-Ar dating

Sakaguchi (1995) summarized the geology of the Nihonmatsu area on a 1 :50,000 scale geological map of the Nihonmatsu District. A simplified geological map of the Nihonmatsu area is presented in Figure 1. Sakaguchi (1995) reported descriptions of the Cretaceous granitic rocks of this district. Abukuma granitic rocks are divisible into five bodies: medium-grained to coarse-grained hornblende-biotite granodiorite (hereinafter Gd), porphyritic K-feldspar bearing medium-grained biotite granite (Gr_1), medium-grained biotite granite (Gr_2), medium to fine-grained muscovite-biotite granite (Gr_3) and fine-grained to medium-grained muscovite-biotite granite (Gr_4). Gd is a major lithofacies of the batholith-like plutonic body. Results show that the Gr_3 and Gr_1 respectively intruded into the Gd. In this area, Gr_2 and Gr_4 intruded into metamorphic rocks. Relations between Gd-Gr_2 and Gd-Gr_4 are unclear because they have no contact in this area.

In the Nihonmatsu area, Kawano and Ueda (1966) reported a biotite K-Ar age, 92 Ma (G-274; Takizawa in the Nihonmatsu City, the value was recalculated by Steiger and Jäger, 1977 constants). Tomizuka et al. (1991) reported a whole rock K-Ar age of 110 Ma (91051701; Wada-Ushigahara, Shirasawa village).

Samples for K-Ar dating were collected from the respective sites: FB04 and FB05 from Gd; FB03 from Gr_1; FB08 and FB09 from Gr_2; FB01 and FB02 from Gr_3; and FB07 from Gr_4. For K-Ar dating, samples were then prepared using the following procedure. The roughly broken rock samples were crushed in a stainless steel mortar and were sieved to 0.25 – 0.60 mm

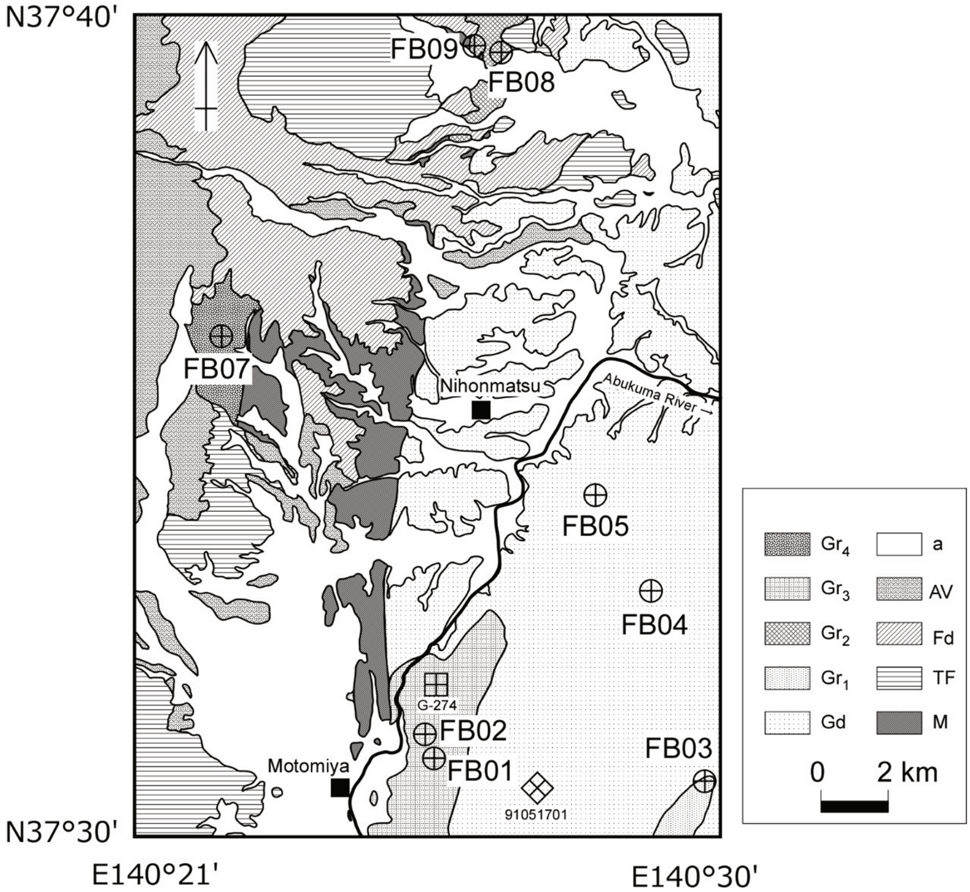

Figure 1. Simplified geological map of the Nihonmatsu area and sampling locations. The geological map is modified from a 1:50,000 geological map of Nihonmatsu area by Sakaguchi (1995): FB01 – FB09 represent sample positions of this report; G-274 denotes the sample position of Kawano and Ueda (1966); 91051701 denotes the sample position of Tomizuka et al. (1991); Gd, medium-grained to coarse-grained hornblende-biotite granodiorite; Gr_1, porphyritic K-feldspar bearing medium-grained biotite granite; Gr_2, medium-grained biotite granite; Gr_3, medium to fine-grained muscovite-biotite granite; Gr_4, fine-grained to medium-grained muscovite– biotite granite; M, Pre-Cretaceous Metamorphic rocks; TF, Takahata Formation; Fd, Early Pleistocene Fushiogami Debris avalanche deposits; AV, products of Adatara volcano; a, alluvium.

diameter. After washing the sieved fractions in distilled water in an ultrasonic bath, we dried them in an oven. Subsequently, we used a Franz type isodynamic magnetic separator to separate the biotite fraction magnetically. Tapping and handpicking were also done to separate biotite from other minerals. Finally, samples were washed in acetone using ultrasonic treatment. The biotite fraction purity was found to be > 95% after completion of the procedures described above.

Using a flame photometer (FP-33D; Hekisa Kagaku), we measured the potassium contents of samples with a lithium internal standard and the peak integration method. To verify the accuracy of potassium analyses, we took measurements of an age standard sample (HD-B1, Hess and Lippolt, 1994) and unknown samples simultaneously. Measured potassium contents of the HD-B1 were 7.96 ± 0.02 wt.%, which is consistent with the reference value of HD-B1: 7.956 wt.% (Hess and Lippolt, 1994). Because no duplicate analyses were conducted for unknown samples, we estimated large (3%) relative uncertainty of the potassium content analyses.

Abundances of radiogenic ^{40}Ar were measured using the isotope dilution method with ^{38}Ar spikes. Samples were degassed at 1500°C in a Mo crucible using a resistance furnace. After purification of the extracted gases using two Ti-Zr getters and a Zr-Al alloy getter, we introduced them into the mass spectrometer. Argon isotopes were analyzed using a 15 cm radius and 60° deflection sector type of a mass spectrometer. To calculate the amount of radiogenic ^{40}Ar, we conducted corrections of mass discrimination and hot blanks during argon isotope analyses. The amount of ^{38}Ar in a spike is often calibrated using an international age standard sample: HD-B1 (Hess and Lippolt, 1994).

The following constants were used for K-Ar date calculation: λ_e=0.581 $\times 10^{-10}$, λ_β=4.962$\times 10^{-10}$, and $^{40}K/K$=0.0001167 (Steiger and Jäger, 1977). We calculated uncertainty related to the K-Ar date from the propagation of analytical errors in potassium and radiogenic ^{40}Ar contents (1 sigma level).

Results and Discussion

Table 1 and Figure 2 present results of K-Ar dating of plutonic rocks from the Nihonmatsu area. For Gd, FB04 and FB05 respectively yield 110.9 ± 3.1 Ma and 106.5 ± 2.9 Ma. Tomizuka et al. (1991) reported the whole rock K-Ar age of 110 Ma (91051701) for this granodiorite body. For Gr_3, FB01 and FB02 respectively yield 92.4 ± 2.5 Ma and 90.0 ± 2.7 Ma. Kawano and Ueda (1966) earlier reported K-Ar age of 92 Ma (G-274) for this granitic body. Newly obtained K-Ar dates show good agreement with earlier results.

Table 1. K-Ar dating results of granitic rocks from the Nihonmatsu area

Sample No.	Type	Sampling Locations		K (wt.%)	Rad. ^{40}Ar[2] (10^{-5} cm^3/g)	AC[3] (%)	Date (Ma)
		Longitude[1]	Latitude[1]				
FB01	Gr_3	37°31′9.14″	140°25′24.34″	6.79 ± 0.14	2.50 ± 0.05	5.2	92.4 ± 2.5
FB02	Gr_3	37°31′27.64″	140°25′16.46″	7.29 ± 0.15	2.61 ± 0.06	5.7	90.0 ± 2.7
FB03	Gr_1	37°30′53.58″	140°29′33.07″	7.35 ± 0.15	3.15 ± 0.09	5.5	107.2 ± 3.6
FB04	Gd	37°33′10.86″	140°28′40.39″	6.33 ± 0.15	2.81 ± 0.06	6.2	110.9 ± 3.1
FB05	Gd	37°34′22.01″	140°27′48.02″	7.28 ± 0.15	3.10 ± 0.06	4.8	106.5 ± 2.9
FB07	Gr_4	37°36′15.80″	140°22′13.15″	6.57 ± 0.13	1.92 ± 0.05	6.8	73.8 ± 2.4
FB08	Gr_2	37°39′43.86″	140°26′30.00″	7.09 ± 0.14	2.88 ± 0.04	7.2	101.7 ± 2.4
FB09	Gr_2	37°39′43.86″	140°26′30.00″	7.04 ± 0.14	2.78 ± 0.06	7.6	99.0 ± 2.8

N.B.

1) Longitude and latitude are in Japan Geodesic Datum 2000 (JGD2000).

2) Rad. ^{40}Ar represents the radiogenic ^{40}Ar content.

3) AC denotes the air contamination ratio (non-radiogenic ^{40}Ar / total ^{40}Ar).

Based on the model of the closure temperature concept (Dodson, 1973), the K-Ar biotite date indicates the timing at which the plutonic rock reached the closure temperature of biotite for the K-Ar system during cooling. Based on the compilation of closure temperatures for various minerals and radiometric dating methods by Reiners et al. (2005), the closure temperature of biotite for K-Ar system can be estimated as 350 – 400°C (Grove and Harrison, 1996; Harrison et al., 1985). Provided that plutonic bodies in the Nihonmatsu area experienced a similar cooling history, the order of the K-Ar biotite dates for granitic rocks of each lithofacies indicates the order of timing by which each rock reached the biotite's closure temperature during cooling.

A K-Ar date of Gr_1 ca. 107 Ma (FB03) is comparable to the K-Ar dates of Gd (111 – 105 Ma) within the error range. These results indicate that a small plutonic body located inside of the batholith-like plutonic body cooled simultaneously with the surrounding batholith-like plutonic body.

Compared to K-Ar dates from the batholith-like plutonic body (Gd, 111 – 105 Ma), K-Ar dates from small plutonic bodies (Gr_2, 102–99 Ma and Gr_3, 93–90 Ma) are apparently younger (Figure 2). This result indicates that the batholith-like plutonic body (Gd) reached the biotite's closure temperature earlier than the small plutonic bodies (Gr_2 and Gr_3). Because small plutonic bodies (Gr_2 and Gr_3) are peripheral parts of the batholith-like plutonic body, these lithofacies cooled faster than a small plutonic body inside of the batholith-like plutonic body (Gr_1) because of cooling by adjacent metamorphic rocks. Given that intrusion of small plutonic bodies (Gr_1, Gr_2 and Gr_3) occurred simultaneously, K-Ar dates from small plutonic bodies in peripheral parts (Gr_2 and Gr_3) must be older than those of inside of the batholith-like plutonic body (Gr_1) because of prior cooling of peripheral parts. The K-Ar date difference between younger small plutonic bodies in peripheral areas (Gr_2 and Gr_3) and older small plutonic body from inside of the batholith-like plutonic body (Gr_1) lead to our inference that the intrusion of the small plutonic bodies in those peripheral parts (Gr_2 and Gr_3) apparently occurred later that of the small plutonic body from inside of the batholith-like plutonic body (Gr_1). Relations whereby Gd was intruded by Gr_3 and Gr_1 are consistent with the order of intrusion found from field observations (Sakaguchi, 1995).

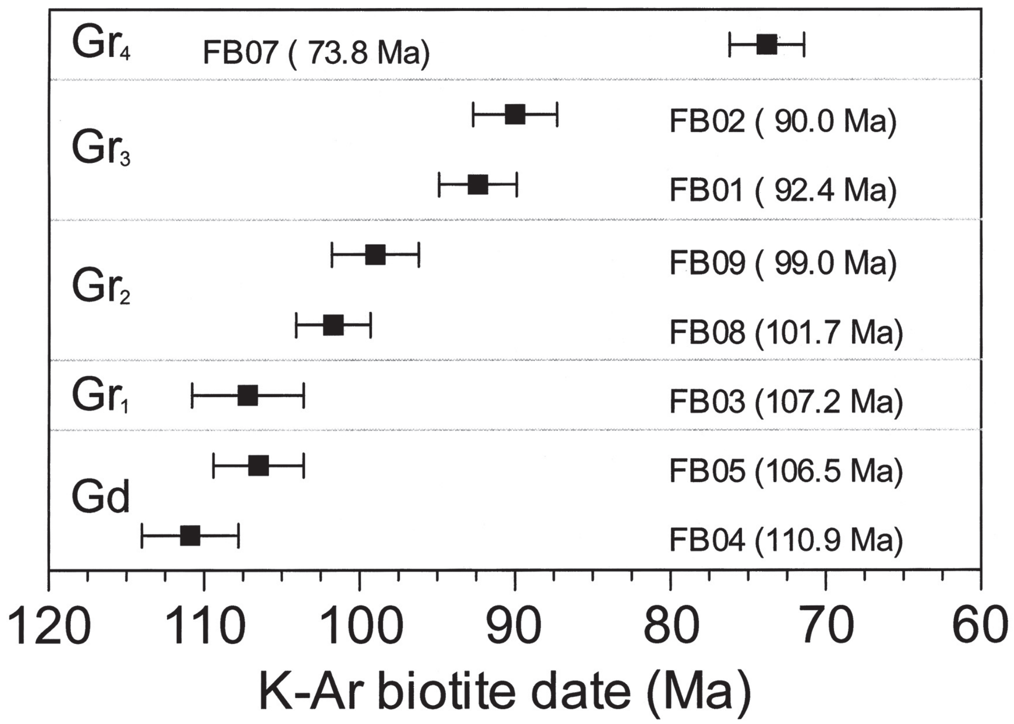

Figure 2. K-Ar date distribution of plutonic rocks in the Nihonmatsu area. Abbreviations of the respective plutonic bodies are the same as those in Figure 1.

A K-Ar date of 73.8 ± 2.4 Ma for FB07 from a small Gr_4 body around Dake-Onsen area is 20 – 30 m.y. younger than K-Ar dates from Gd, Gr_1, Gr_2, and Gr_3. Similar to the discussion presented above, this result also indicates that the intrusion timing of the small plutonic body around Dake-Onsen (Gr_4) differs from that of the batholith-like plutonic body, rather than another possibility; the small plutonic bodies around Dake-Onsen (Gr_4) experienced different cooling processes (very slow cooling) compared to the batholith-like plutonic body.

Matsumoto et al. (2007) reported two biotite K-Ar dates of 72.4 ± 0.8 Ma (AZ-021) and 73.4 ± 0.8 Ma (AZ-022) from Abukuma granites within the Azumayama district. The K-Ar date of 73.8 ± 2.4 Ma for FB07 found from the results presented herein provides explanatory support for the presence of young (approximately 70 Ma) plutonic rocks at different parts of the Abukuma granites.

Summary

For the batholith-like plutonic body (Gd), K-Ar dating of the Abukuma granites in the Nihonmatsu conducted by Kanno (2001MS) shows a date duration of 111–105 Ma. However, K-Ar dating of neighboring small plutonic bodies yields younger date durations of 102–99 Ma for Gr_2 and 93–90 Ma for Gr_3. The K-Ar dating result of ca. 74 Ma from Gr_4 in the Dake-Onsen area is 20–30 m.y. younger than that of other plutonic bodies. The sequence of K-Ar biotite dates of each of the respective types of granitic rock represents the sequence of timing during which each rock reached the biotite's closure temperature during the cooling process.

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References

[Dodson,1973] Dodson, M.H. (1973): Closure temperature in cooling geochronological and petrological systems, Contrib. Mineral. Petrol., **40**, 259-274.

[Grove and Harrison, 1996] Grove, M. and Harrison, T.M. (1996): $^{40}Ar^*$ diffusion in Fe-rich biotite, Amer. Mineral., **81**, 940-951.

[Harrison et al., 1985] Harrison, T.M., Duncan, I. and McDougall, I. (1985): Diffusion of ^{40}Ar in biotite: temperature, pressure and compositional effects, Geochim. Cosmochim. Acta, **49**, 2461-2468.

[Hess and Lippolt, 1994] Hess, J.C. and Lippolt, H.J. (1994): Compilation of K-Ar measurements on HD-B1 standard biotite 1994 status report, Phanerozoic Time Scale, **12**, 19-23.

[Kanno, 2001MS] Kanno, F. (2001MS): K-Ar dating of Abukuma plutonic rocks from Kita-Nihonmatsu area, Fukushima Prefecture, Undergraduate thesis of Department of Earth and Environmental Sciences, Faculty of Science, Yamagata University, 29 p. (in Japanese)

[Kawano and Ueda, 1966] Kawano, Y. and Ueda, Y. (1966): K-A dating on the igneous rocks in Japan (IV) -Granitic rocks in northeastern Japan-. Jour. Min. Petr. Econ. Geol., **56**, 41-55. (in Japanese with English abstract)

[Matsumoto et al., 2007] Matsumoto, A., Ohta, Y., Hoshizumi, H., Takahashi, Y., Nishioka, Y., Miyake, Y.,Tsunoda, K. and Shimizu, M. (2007): K-Ar age determinations of age-unknown rocks in Japanese Islands – volcanic and plutonic rocks in the areas associated with Geological Map Project (during fiscal 2005) – , Bull. Geol. Surv. Japan, **58**, 33-43. (in Japanese with English abstract)

[Reiners et al., 2005] Reiners, P.W., Ehlers, T.A. and Zeitler, P.K. (2005): Past, present, and future of thermochronology, in) Low Temperature Thermochronology: Techniques, Interpretations, and Applications (Reiners, P.W. and Ehlers, T.A. eds.), Rev. Mineral. Geochem., **58**, 1-18.

[Saito, 1989] Saito, K. (1989): Potassium-argon dates for plutonic bodies in the South Fossa Magna, Modern Geol., **14**, 145-152.

[Saito, 1993] Saito, K. (1993): ^{40}Ar-^{39}Ar studies on some Tanzawa tonalite samples, Jour. Geomag. Geoelectr., **45**, 261-272.

[Saito and Kato, 1996] Saito, K. and Kato, K. (1996): A high density sampling K-Ar dating of the Kinpu-San plutonic body and the initiation of the Philippine Sea plate subduction, Jour. Geomag. Geoelectr., **48**, 233-246.

[Saito et al., 1997] Saito, K., Kato, K. and Sugi, S. (1997): K-Ar dating studies of Ashigawa and Tokuwa granodiorite bodies and plutonic geochronology in the South Fossa Magna, central Japan, Island Arc, **6**, 158-167.

[Saito et al., 1991] Saito, K., Otomo, I. and Takai, T. (1991): K-Ar Dating of the Tanzawa Tonalitic Body and Some Restrictions on the Collision Tectonics in the South Fossa Magna, Central Japan, Jour. Geomag. Geoelectr., **43**, 921-935.

[Saito et al., 1996] Saito, K., Takahashi, M. and Onozuka, N. (1996): A K-Ar investigation of the Chichibu quartz diorite and some discussions on its cooling history, Jour. Geomag. Geoelectr., **48**, 1103-1109.

[Sakaguchi, 1995] Sakaguchi, K. (1995): Geology of the Nihonmatsu District, with Geological sheet Map at 1:50,000. Geological Survey of Japan, 79 p.

(in Japanese with English abstract)
[Steiger and Jäger, 1977] Steiger, R.H. and Jäger, E. (1977): Subcomission on geochronology: Convention on the use of decay constants in geo- and cosmo-chronology, Earth Planet. Sci. Lett., **36**, 359-362.
[Tomizuka et al., 1991] Tomizuka, R., Yashima, R. and Kadosawa, Y. (1991): K-Ar ages of granitic rocks from the Miharu district in the middle Abukuma Mountains, northeast Japan, Sci. Rep. Fac. Edu., Fukushima Univ., **48**, 19-23. (in Japanese with English abstract)