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K-Ar dates measured in the geochronology laboratory of Yamagata University—Rocks from the Himekami pluton of northwestern Kitakami Mountains, northeastern Japan arc

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Abstract

This report presents K-Ar dating results of plutonic rocks from the Himekami pluton in the northwestern Kitakami Mountains, northeastern Japan arc, as measured by geochronology laboratory of the Yamagata University. Six biotite separates of plutonic rocks from North sub-pluton of the Himekami pluton yielded K-Ar dates ranged from 114 to 110 Ma. A biotite separate of South sub-pluton shows a K-Ar date of ca. 118 Ma. The cooling rate of North sub-pluton in Himekami pluton is calculated as approximately 30−180°C / m.y. at temperatures of 900°C to 350−400°C.

Introduction

The geochronology laboratory of the Yamagata University continued K-Ar and ^{40}Ar-^{39}Ar dating for rocks from plutonic bodies in eastern Japan to elucidate the spatiotemporal distribution of plutonism in the target region and cooling history in each plutonic body. These projects were conducted by former members of the faculty: Prof. Kazuo Saito and the late Dr. Kazuya Fukunaga with their graduate and undergraduate students. Measured K-Ar dates were summarized as their graduate and master theses. Some 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; northwestern part of Abukuma Highland, Iwata et al., 2020). However, certain data among the K-Ar dating results have not been published.

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Successive to earlier descriptions in the literature, this report presents K-Ar dating results from Yamagata University: K-Ar dates of Himekami pluton in the northwestern Kitakami Mountains, northeastern Japan arc. The K-Ar dating experiments for plutonic rock of Himekami pluton were conducted as part of an undergraduate research project (Sasaki, 2001MS) supervised by one author (KS).

As described herein, radiometric dates reported by Sasaki (2001MS) and others (Kawano and Ueda, 1965, Tsuchiya et al., 2015 and Osozawa et al., 2019) were compiled and compared by one author (NI). Quoted dates are valuable for an overview of the duration of the cooling processes in the Himekami pluton.

K-Ar dating

Himekami pluton is situated in Zone IV of the northern Kitakami Belt, where it intruded into pre-Cretaceous sedimentary rocks (Katada, 1974). Yoshida et al. (1984) reported the boundary of the Himekami pluton and surrounding pre-Cretaceous rocks (Figure 1).

Katada et al. (1991a, 1991b) summarized the geology and petrology of Himekami pluton. Based on lithofacies, Katada et al. (1991a) classified the major parts of Himekami pluton as North sub-pluton and South sub-pluton (Figure 1). North sub-pluton is a felsic-zoned pluton of quartz monzonite, granite, and granodiorite. South sub-pluton is a felsic and mafic complex composed of monzonite, monzogabbro, quartz monzonite, and quartz monzodiorite. South sub-pluton intrusion occurred earlier than North sub-pluton intrusion (Katada et al., 1991a). Both sub-plutons might be derivatives of a gabbroic magma (Katada et al., 1991b).

For Himekami pluton, Kawano and Ueda (1965) reported two biotite K-Ar ages: 112 Ma (G-7, the value was recalculated by Steiger and Jäger, 1977 constants) and 118 Ma (Gd-105, ditto). Tsuchiya et al. (2015) reported a zircon U-Pb age, 124 ± 1 Ma (NS17; *n*=11 of 12, 2 sigma level error). Osozawa et al. (2019) reported two zircon U-Pb ages. A sample, KTKM-06 (quartz monzodiorite), yields a spread age distribution, 117–216 Ma. A weighted mean age of the most concentrated part was calculated as 120.6 ± 1.2 Ma (*n*=25 of 31, 2 sigma level error). The rests are 157 ± 4, 159 ± 4, 173 ± 4, 178 ± 4, 184 ± 4, and 216 ± 5 Ma ($^{206}Pb/^{238}U$ ages, 1 sigma level error). Another sample, KTKM-07 (diorite) yielded a concentrated age distribution with weighted mean age of 121.4 ± 1.3 Ma (*n*=20 of 20, 2 sigma level error).

Sample locations of G-7, Gb-105, and NS17 are presented in Figure 1. Although no sample location information was reported by Osozawa et al. (2019), one can assume that KTKM-06 was from South sub-pluton and that KTKM-07 was from North sub-pluton, based on their lithofacies.

Figure 1 presents positions of our samples for K-Ar dating. Samples Himikami01−05 and Himekami08 were collected from North sub-pluton. Samples Himikami06−07 were collected from South sub-pluton.

Samples for K-Ar dating were prepared using the following procedure. Roughly broken rock samples were crushed in a stainless-steel mortar and were sieved to 0.25−0.50 mm diameter. The sieved fractions were washed in distilled water in an ultrasonic bath. Then they were dried in an oven. Subsequently, the biotite fraction was separated magnetically using a Franz-type isodynamic magnetic separator. To separate biotite from other minerals, tapping and handpicking were also conducted. Finally, samples were washed in acetone with ultrasonic treatment.

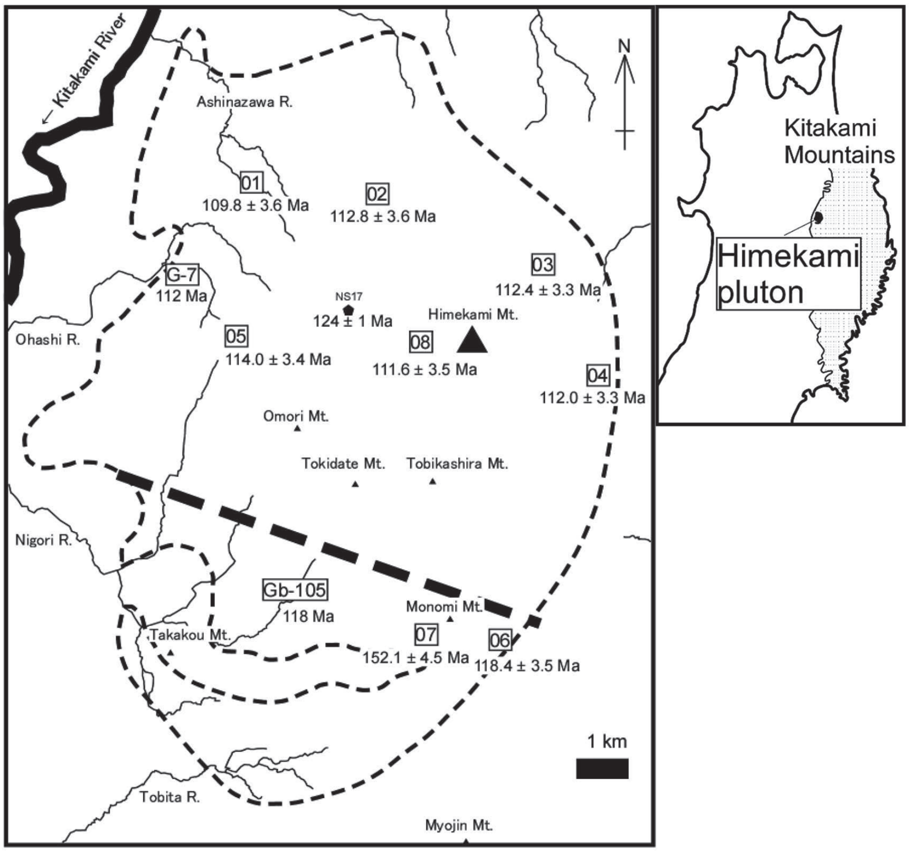

Figure 1. Locations of samples for K-Ar dating and dates from the Himekami pluton in the northwest Kitakami Mountains. The outline of the Himekami pluton (dashed line) is quoted from Geological Map of Japan 1:200,000 Series "Morioka" (Yoshida et al., 1984). The bold dashed line shows the estimated boundary of North and South Plutons (Katada, 1991a). Numbers of 01−08 respectively denote sample numbers of Himekami01−Himeakmi08. G-7 and Gb-105 denote sample locations and K-Ar ages that were measured by Kawano and Ueda (1965). NS17 indicates a sample location and zircon U-Pb age measured by Tsuchiya et al. (2015).

Potassium contents of samples were measured using a flame photometer (FP-33D; Hekisa Kagaku) with a lithium internal standard and the peak integration method. To verify the accuracy of potassium analyses, we measured an age standard sample (HD-B1; Hess and Lippolt, 1994) and unknown samples simultaneously. Measured potassium contents of the HD-B1 were 7.77 ± 0.16 wt.%, which are 2.3% lower than the reference values of HD-B1, 7.956 wt. % (Hess and Lippolt, 1994). For this experiment, large (3%) uncertainty of the potassium content analyses was estimated because 1) no duplicate analysis was performed for unknown samples and 2) K measurement of HD-B1 yielded a 2.3% lower value relative to the reference value.

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

For K-Ar age calculation, the following constants were used: $\lambda_e = 0.581 \times 10^{-10}$ year^{-1}, $\lambda_\beta = 4.962 \times 10^{-10}$ year^{-1}, and ^{40}K/K = 0.0001167 (Steiger and Jäger, 1977). Uncertainty related to the K-Ar date was calculated from propagation of analytical errors in potassium and radiogenic ^{40}Ar contents (1 sigma level).

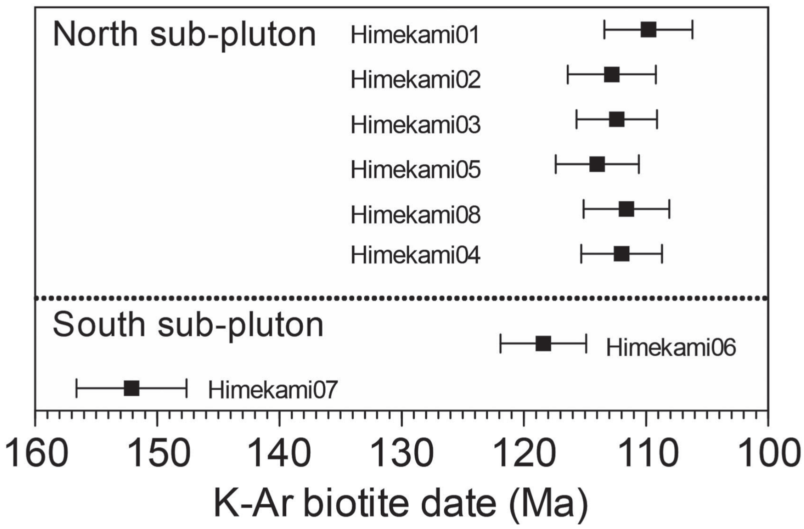

Figure 2. K-Ar dates distribution of the Himekami pluton. Dates are sorted from north to south.

Table 1. K-Ar dating results of granitic rocks from the Himekami pluton

Sample No.	K (wt. %)	Rad. ^{40}Ar (10^{-6} cm^3/g)	AC (%)	K-Ar Date (Ma)
Himekami01	5.79 ± 0.17	25.43 ± 0.39	4.1	109.8 ± 3.6
Himekami02	6.15 ± 0.18	27.78 ± 0.38	3.3	112.8 ± 3.6
Himekami03	4.81 ± 0.14	21.64 ± 0.14	2.1	112.4 ± 3.3
Himekami04	6.37 ± 0.19	28.56 ± 0.18	6.9	112.0 ± 3.3
Himekami05	4.08 ± 0.12	18.63 ± 0.13	11.0	114.0 ± 3.4
Himekami06	6.37 ± 0.19	30.25 ± 0.13	8.4	118.4 ± 3.5
Himekami07	5.59 ± 0.17	34.45 ± 0.22	11.7	152.1 ± 4.5
Himekami08	5.64 ± 0.17	25.22 ± 0.31	14.8	111.6 ± 3.5

N.B.
Rad. ^{40}Ar represents the abundance of radiogenic ^{40}Ar. AC represents the air contamination ratio (non-radiogenic ^{40}Ar / total ^{40}Ar). Errors are quoted at the 1 sigma level.

Results and Discussion

Table 1 and Figure 2 present the results of K-Ar dating of Himekami pluton. For North sub-pluton, seven K-Ar dates of Himikami01－05 and Himekami08, and G-7 (Kawano and Ueda, 1965) concentrated to ca. 112 Ma. However, two of three K-Ar dates from South sub-pluton, Himekami06 and Gb-105 (Kawano and Ueda, 1965), were ca. 118 Ma. Himekami07 yielded an old K-Ar date of ca. 152 Ma.

Based on the model of closure temperature hypothesis, K-Ar biotite age represents the timing by which the plutonic rock reached to the closure temperature of biotite for the K-Ar system during cooling. From compilation of closure temperatures for various minerals and radiometric dating by Reiners et al. (2005), the closure temperature of biotite for K-Ar system was estimated to 350－400°C (Grove and Harrison, 1996; Harrison et al., 1985). Furthermore, this work indicated no difference within the error range in K-Ar dates from North sub-pluton. Therefore, North sub-pluton reached to 350－400°C simultaneously during cooling both in central (positions of Himekami01, 02, 05, and 08) and in marginal parts (positions of Himekami03, 04, and G-7) within North sub-pluton.

Because the closure temperature of zircon for U-Pb system is estimated as >900°C (Reiners et al., 2005), the zircon U-Pb date resembles the timing of magma intrusion in plutonism. Combining earlier reported zircon U-Pb dates of 124 ± 1 Ma (Tsuchiya et al., 2015) and 121.4 ± 1.3 Ma (Osozawa et al., 2019), and K-Ar dates of ca. 112 Ma from North sub-pluton in Himekami pluton, the cooling rate from 900°C to 350 – 400°C can be inferred as approximately 30–180°C / m.y. during cooling after magma intrusion.

A K-Ar date of 152.1 ± 4.5 Ma (Himekami07) in South sub-pluton is strange because this date is considerably older than either of two K-Ar dates (ca. 118 Ma; Himekami07 and Gb-105, Kawano and Ueda, 1965). A possible reason for this older date is the presence of precursory plutonism in South sub-pluton. Osozawa et al. (2019) pointed out the presence of older ages, 157, 159, 173, 178, 184, and 216 Ma, in zircon of the KTKM-06 (age of most concentrated part is 120.6 ± 1.2 Ma) and interpreted it as "recycled zircon". Providing the recycled zircon came from earlier plutonism in the Himekami pluton, an old K-Ar date of Himekami07 (152 Ma) might similarly be a result of this precursory plutonic rock intrusion (ca. 158 Ma?). The location of Himekami07 should not reheated to a closure temperature of biotite by thermal overprinting because of North sub-pluton intrusion.

Without Himekami07, K-Ar dates from South sub-pluton in Himekami pluton are concentrated to ca. 118 Ma, which is slightly older than K-Ar dates of the North sub-pluton (ca. 112 Ma). This spatiotemporal relation indicates that North sub-pluton reached to the closure temperature of biotite for the K-Ar system later than South sub-pluton. This relation is consistent with the order of intrusion: early South sub-pluton and later North sub-pluton intrusions (Katada et al., 1991a).

Summary

The K-Ar dates from North sub-pluton are ca. 112 Ma. Those from South sub-pluton are ca. 118 Ma without exception, with an old K-Ar date of ca. 152 Ma from South sub-pluton (Himikami07). These dates represent timings at which the plutonic rock reached the closure temperature of biotite for the K-Ar system during cooling.

Combining earlier reported zircon U-Pb dates of 124 ± 1 Ma (Tsuchiya et al., 2015) and 121.4 ± 1.3 Ma (Osozawa et al., 2019), and K-Ar dates of ca 112 Ma from North sub-pluton in Himekami pluton, the cooling rate from 900°C to 350–400°C can be calculated as approximately 30–180°C / m.y.

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