Bull. of Yamagata Univ., Nat. Sci., Vol.19, No.4, Feb. 2021

K-Ar dates measured in the geochronology laboratory of Yamagata University — Rocks from the Nekoma volcano, Fukushima Prefecture

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Abstract

This report presents groundmass K-Ar dating results obtained for volcanic rocks from Nekoma volcano, Fukushima Prefecture that were measured at the geochronology laboratory of Yamagata University. Seven of eight K-Ar dates of Old Nekoma Volcano are ca. 0.6 Ma. The K-Ar dates of Old Nekoma Volcano support paleomagnetic constraints of Nekoma volcano, which erupted during the Brunhes Normal Epoch.

Introduction

K-Ar dating is invaluable to ascertain the spatiotemporal distribution of Quaternary volcanic activity in northeastern Japan. Furthermore, dating to different stratigraphic formations in a target volcano is valuable to construct an evolutional history of the volcano. The geochronology laboratory of Yamagata University has applied K-Ar dating for many rocks from some Quaternary volcanoes. These projects were undertaken in particularly in the 1980s–1990s by graduate and undergraduate students of former faculty members: Prof. Nobuo Takaoka and Prof. Kazuo Saito. Measured K-Ar dates were presented in their theses. Some dates have been published (e.g. Zaozan, Takaoka et al., 1989; Murayama-Hayama, Saito and Kamei, 1995; Shiratakayama, Ishii and Saito, 1997; Myojinyama, Iwata and Takaoka, 2019; Nanatsumori, Iwata et al., 2019; Omoshiroyama and Gantoyama, Iwata et al., 2020).

Successive to earlier reports, this report presents unpublished K-Ar dates measured at Yamagata University: K-Ar dates from Nekoma volcano, Fukushima Prefecture. K-Ar dating experiments for Nekoma volcano are

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part of an undergraduate research project (Iwatare, 1992MS) supervised by one author: KS. Compilation and recalculation of K-Ar dates in Iwatare (1992MS) were done by one author: NI.

K-Ar dates presented in this report were obtained using mass fractionation correction. The initial $^{40}Ar/^{36}Ar$ ratios of the samples are estimated from the $^{38}Ar/^{36}Ar$ ratios with an assumption that the initial argon isotope ratios of all samples are expected to lie on a mass fractionation line of argon in the atmosphere. Application of this procedure is desirable for date determination of Quaternary volcanic rocks younger than 1 Ma (e.g. Matsumoto et al., 1989; Takaoka, 1989; Matsumoto and Kobayashi, 1995) because the influence of non-radiogenic ^{40}Ar abundances among all ^{40}Ar abundances are significant in their rocks.

Stratigraphic details of Nekoma volcano were reported by Nakamura (1978), New Energy and Industrial Technology Development Organization (NEDO) (1991), Kimura et al. (2001), and Mimura (2002). Yamamoto (2005) presented an explanation of volcanic products of the western side of the Nekoma volcano. Nakamura (1978), in addition to defining 18 lava flows, 9 pyroclastic flows, and 5 lava domes, classified the volcanic activities of Nekoma volcano to five stages: I−V. Nakamura (1978) estimated that the summit area of Nekoma volcano collapsed at the end of stage IV. Then, Oguni caldera was formed. Subsequently, post-caldera lava dome forming activity occurred on the eastern interior part of the caldera and on the rim in the stage V. NEDO (1991) classified the volcanic activity in Nekoma volcano and easterly Bandai volcano into three stages: older, middle, and younger. NEDO (1991) indicated that the active period of Nekoma volcano occurred during older and middle stages before the Oguni caldera forming event. Kimura et al. (2001) recognized three stages of volcanic activities of Nekoma volcano. Kimura et al. (2001) reported that the first two stages consist of Low-K volcanic materials. The third stage, which began with formation of Oguni collapse caldera, consists predominately of medium-K with lesser low-K volcanic materials. Details of stratigraphy in NEDO (1991) and Kimura et al. (2001) rely fundamentally on those reported by Nakamura (1978), with some refinement.

We use the latest detailed stratigraphy and geological map by Mimura (2002) herein (Figure 1). Mimura (2002) established a new stratigraphy of Nekoma volcano based on detailed field observations, geological descriptions, and radiometric dating results (Figure 2). Mimura (2002) divided Nekoma volcano into two stages, Old Nekoma Volcano and New Nekoma Volcano, separated by the caldera forming event. Old Nekoma Volcano is subdivided into six formations from lower to upper: Oguninuma north lava, Hayama lavas, Hagidaira pyroclastic flow deposit (hereinafter Hagidaira PFD), Main cone lavas, Oguniyama lavas, and Ougigamine lavas.

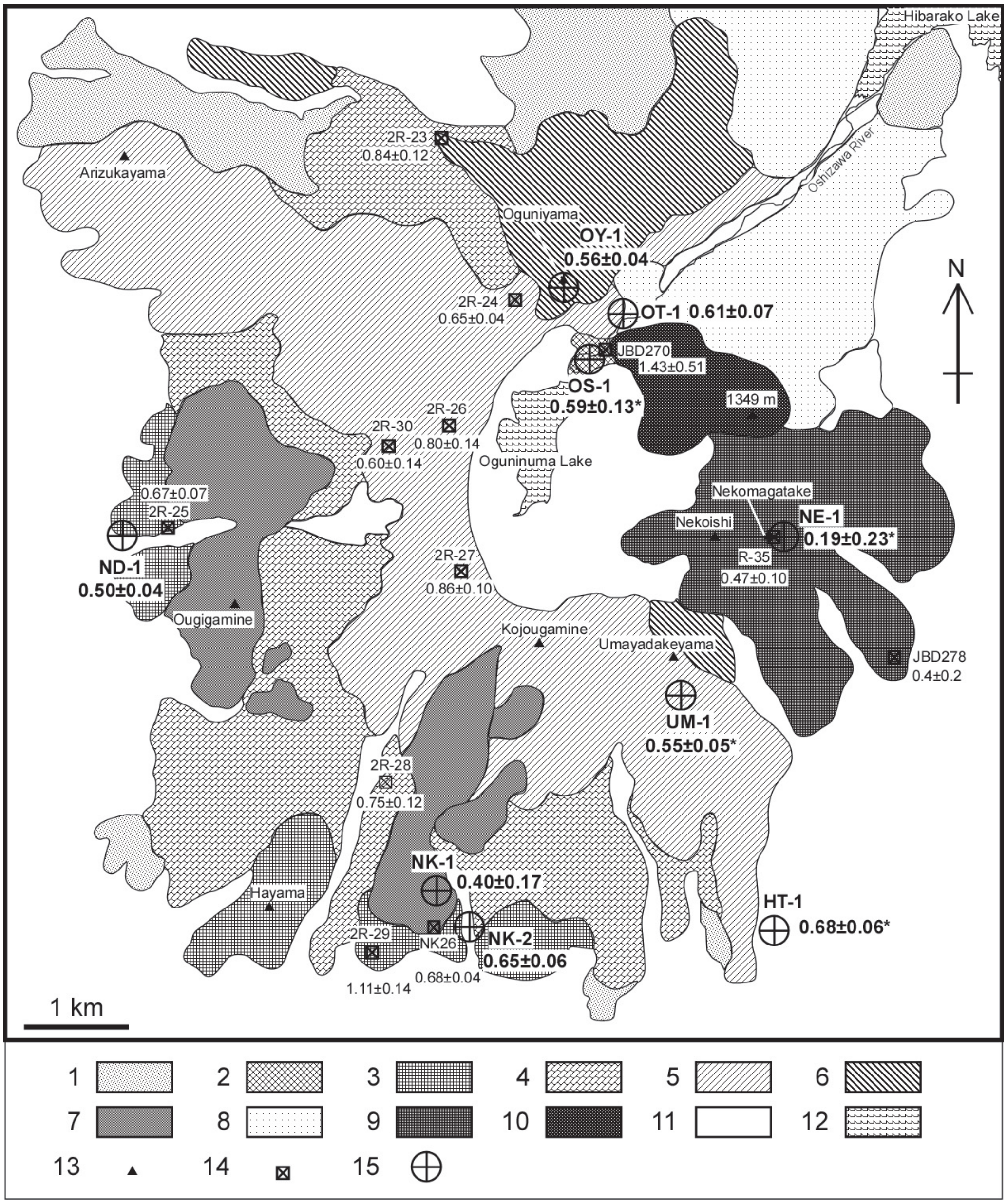

Figure 1. Simplified geological map of Nekoma volcano. The geological map is modified from Mimura et al. (2002): 1, Tertiary; 2, Oguninuma north lava; 3, Hayama lavas; 4, Hagidaira pyroclastic flow deposit, 5: Main cone lavas, 6: Oguniyama lavas, 7: Ougigamine lavas, 8: Oshizawa debris avalanche deposit, 9: Nekomagatake lavas, 10: 1349 m lavas, 11: Other Quaternary, 12: Lake, 13: Mountain summit, 14: K-Ar dates by previous works, 15: K-Ar dates by this work (* denotes weighted average date of duplicate measurements).

New Nekoma Volcano is subdivided into three formations: Oshizawa debris avalanche deposit (hereinafter Oshizawa DAP), Nekomagatake lavas, and 1349 m lavas in ascending order. The Oshizawa DAP is related to the caldera forming event. The erupted volume of the Old Nekoma Volcano is estimated as 15 km^3. The sum of the erupted volume of the Nekomagatake lavas and the 1,349 m lavas is estimated as 1.2 km^3.

Earlier reported K-Ar dates of Nekoma volcano are presented in Table 1. Nine K-Ar dates of 1.11 ± 0.14 Ma to 0.47 ± 0.10 Ma from Nekoma volcano were reported by NEDO (1991). Mimura (2002) reported two K-Ar dates of 1.43 ± 0.51 Ma and 0.68 ± 0.04 Ma from Oguninuma north lava and Ougigamine lavas, with one fission track date of 0.4 ± 0.2 Ma from Nekomagatake lavas. The K-Ar dates reported in NEDO (1991) and Mimura (2002) are measured without mass fractionation correction for the whole rock form samples.

Paleomagnetic constraints for the active volcanic period of Nekoma volcano were reported in two documents. NEDO (1991) presented that eight of nine rocks of Hayama lavas through Oguniyama lavas in Nekoma volcano have normal magnetic polarity. One exception is that the paleomagnetic orientation of rocks of Nekomagatake lavas was scattered. The normal

Table 1 Radiometric dates and their sample locations at Nekoma volcano by NEDO (1991) and Mimura (2002)

Sample No.	Formation	Latitude (N)	Longitude (E)	Date (Ma)	M. P.	Ref.
JBD278	Nekomagatake lavas	37° 36′ 04.86″	140° 02′ 32.01″	0.40 ± 0.20		M02
R-35	Nekomagatake lavas	37° 36′ 41.85″	140° 01′ 43.01″	0.47 ± 0.10	S	N91
NK26	Ougigamine lavas	37° 34′ 41.17″	139° 59′ 31.74″	0.68 ± 0.04		M02
2R-23	Oguniyama lavas	37° 38′ 44.84″	139° 59′ 35.02″	0.84 ± 0.12	N	N91
2R-30	Main cone lavas	37° 37′ 09.85″	139° 59′ 14.03″	0.60 ± 0.14	N	N91
2R-24	Main cone lavas	37° 37′ 54.84″	140° 00′ 04.02″	0.65 ± 0.04	N	N91
2R-26	Main cone lavas	37° 37′ 16.85″	139° 59′ 38.03″	0.80 ± 0.14	N	N91
2R-27	Main cone lavas	37° 36′ 30.86″	139° 59′ 42.03″	0.86 ± 0.10	N	N91
2R-28	Hagidaira PFD	37° 35′ 25.86″	139° 59′ 13.03″	0.75 ± 0.12	N	N91
2R-25	Hayama lavas	37° 36′ 44.85″	139° 57′ 49.04″	0.67 ± 0.07	N	N91
2R-29	Hayama lavas	37° 34′ 32.87″	139° 59′ 08.04″	1.11 ± 0.14	N	N91
JBD270	Oguninuma north lavas	37° 37′ 39.85″	140° 00′ 39.02″	1.43 ± 0.51		M02

N.B.

M. P. stands for magnetic polarity. S denotes scattered. N denotes normal polarity.

Ref. denotes references; N91, NEDO (1991); M02, Mimura (2002).

Longitude and latitude are in JGD2000.

Date of JBD278 was measured using fission track dating method.

magnetic polarities indicate that the Old Nekoma Volcano erupted in the Brunhes Normal Epoch (0.781–0 Ma; Ogg, 2012), or Jaramillo Event (1.072–0.988 Ma) in the Matsuyama Reversed Epoch (2.581–0.781 Ma). However, Yamamoto (2005) reported reverse magnetic polarity from ten outcrops of the western part of Nekoma volcano, which were measured on site using a portable magnetometer. Although Yamamoto (2005) pointed out that the Nekoma volcanic materials erupted during the early Pleistocene (Matsuyama Reversed Epoch), this estimation is inadequate because on-site measurement using a portable magnetometer show a sum of primary and secondary remanent magnetization. To estimate the direction of primary remanent magnetization of a rock sample that is useful for fitting to the geomagnetic polarity time scale, demagnetization of secondary remanent magnetization of the rock sample is necessary.

As described in this report, nine rock samples from five formations were collected for K-Ar dating (Figure 1 and Table 2). The dates quoted herein are useful for elucidating the volcanic history of Nekoma volcano.

K-Ar dating

NE-1 was collected from a brownish-red colored weathered outcrop at the top of Nekomagatake (1,404 m altitude). NK-1 and NK-2 were collected from lava flows with a platy joint. The sampling position of NK-1 was 680 m distant northeast from a roadside quarry at the position of NK-2. OY-1 was

Table 2 Position and rock type of dated samples from Nekoma volcano

Sample No.	Formation	Latitude (N)	Longitude (E)	Rock type
NE-1	Nekomagatake lavas	37° 36′ 41.85″	140° 01′ 47.02″	Hy-Aug And
NK-1	Ougigamine lavas	37° 34′ 51.87″	139° 59′ 33.03″	Hy-Aug And
OY-1	Oguniyama lavas	37° 37′ 58.84″	140° 00′ 23.02″	Hy-Aug And
HT-1	Main cone lavas	37° 34′ 39.87″	140° 01′ 45.02″	Qz bg Ol-Hy-Aug And
OT-1	Main cone lavas	37° 37′ 50.85″	140° 00′ 46.02″	Hy-Aug And
UM-1	Main cone lavas	37° 35′ 52.86″	140° 01′ 08.02″	Hy-Aug And
ND-1	Hayama lavas	37° 36′ 41.85″	139° 57′ 31.04″	Hy-Aug And
NK-2	Hayama lavas	37° 34′ 40.87″	139° 59′ 46.03″	Hy-Aug And
OS-1	Oguninuma north lavas	37° 37′ 36.85″	140° 00′ 33.02″	Ol bg Qz-Hy-Aug And

N.B.

Rock type abbreviations: Hy, hypersthene; Aug, augite; Ol, olivine; Qz, quartz; And, andesite; bg, bearing.

Longitude and latitude are in JGD2000.

collected from Oguniyama summit (1,271 m). HT-1 was collected from a 15-m-thick lava flow with platy joint around Fudotaki fall. We inferred that HT-1 belongs to the nearest formation of Main cone lavas, whereas the sampling location of HT-1 is outside of the formations in the geological map (Figure 1). Kubo et al. (2003) also describe using a 1:200,000 geological map of Fukushima that the Fudotaki falls area should be included among the Nekoma volcano products. OT-1 was collected from a 20-m-thick lava flow with a platy joint at a point of 980 m in altitude along the Oshizawa River. UM-1 was collected from a point of south of Umayadakeyama summit (1,140 m). ND-1 was collected from a massive lava flow at a roadside point of 500 m in altitude. NK-2 was collected from a lava flow with platy joint at a roadside quarry. We estimated that the NK-2 belongs to the Hayama lavas, not Hagidaira PFD, because NK-2 is collected from the lava flow. OS-1 was collected from 10-m-thick lava flows at the Oshizawa-otaki fall in the Oshizawa River (1,080 m).

To avoid the influence of excess argon in phenocryst, the groundmass concentration was used for K-Ar dating. Rock tips of a sample were crushed and sieved into 0.15−0.20 mm (48-60 mesh) size fractions. Phenocryst fragments were separated magnetically from the groundmass fraction.

Potassium contents of samples were measured using an atomic absorption photometer (Type 208; Hitachi Ltd.) in flame photometer mode. Measurements of unknown and reference samples were taken simultaneously. Measured potassium contents of the reference samples (JA-3, igneous rock series; Geological Survey of Japan Geochemical Reference samples, Imai et al., 1995) are consistent with the reference values within 3% relative differences. The relative uncertainty of the potassium content analyses was estimated as 5% because no replicate measurement was performed for any unknown sample.

The abundances of radiogenic ^{40}Ar were measured using peak comparison without an ^{38}Ar spike according to standard procedures: argon isotopes were analyzed using a single-focus sector type mass spectrometer of 20 cm radius and 90° deflection (Takaoka, 1976). To calculate the amount of radiogenic ^{40}Ar, corrections of mass discrimination and a hot blank were conducted during argon isotope analyses in this procedure.

For K-Ar date 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 the propagation of analytical errors in potassium and radiogenic ^{40}Ar contents (1 sigma level). Mass fractionation correction (e.g. Matsumoto et al., 1989; Takaoka, 1989; Matsumoto and Kobayashi, 1995) was applied for the K-Ar dating result of this report using the following atmospheric argon ratios: $^{40}Ar/^{36}Ar=295.5$ and $^{38}Ar/^{36}Ar=0.187$ (Nier, 1950).

Results and Discussion

The K-Ar dating results of rocks from Nekoma volcano are presented in Table 3. Figure 2 depicts K-Ar dates related to stratigraphy by this and earlier works.

Compared to earlier K-Ar dates reported by NEDO (1990) and Mimura (2002), our dates are younger and less scattered. Especially, our new K-Ar dates indicate two major discrepancies with K-Ar dating results reported earlier. First, NEDO (1991) reported an old K-Ar date of 1.11 ± 0.14 Ma (2R-29) from Hayama lavas. However, our K-Ar dates from this formation are < 1 Ma, 0.65 ± 0.06 Ma (NK-2), and 0.50 ± 0.04 Ma (ND-1). Second, Mimura

Table 3 K-Ar dating results of rocks from Nekoma volcano

Sample No.	K	^{36}Ar	$^{38}Ar/^{36}Ar$	$^{40}Ar/^{36}Ar$	$^{40}Ar^*$	AC	Date
NE-1a	0.68 ± 0.03	3.50 ± 0.12	0.186 ± 0.006	306.5 ± 1.7	0.50 ± 0.61	0.954	0.19 ± 0.23
NE-1b	0.68 ± 0.03	11.40 ± 0.24	0.188 ± 0.010	301.6 ± 1.3	0.34 ± 3.61	0.990	0.13 ± 1.37
				weighted mean of NE-1a and NE-1b			**0.19 ± 0.23**
NK-1	0.75 ± 0.04	6.00 ± 0.15	0.188 ± 0.003	318.3 ± 1.5	1.18 ± 0.48	0.938	**0.40 ± 0.17**
OY-1a	0.71 ± 0.04	1.11 ± 0.04	0.187 ± 0.006	435.9 ± 3.2	1.55 ± 0.22	0.678	0.56 ± 0.08
OY-1b	0.71 ± 0.04	1.29 ± 0.03	0.184 ± 0.003	406.2 ± 2.4	1.55 ± 0.11	0.704	0.56 ± 0.05
				weighted mean of OY-1a and OY -1b			**0.56 ± 0.04**
HT-1a	0.69 ± 0.03	1.47 ± 0.05	0.185 ± 0.005	403.4 ± 3.4	1.68 ± 0.22	0.717	0.63 ± 0.09
HT-1b	0.69 ± 0.03	1.68 ± 0.04	0.181 ± 0.003	391.1 ± 2.4	1.92 ± 0.17	0.707	0.72 ± 0.07
				weighted mean of HT-1a and HT-1b			**0.68 ± 0.06**
OT-1	0.79 ± 0.04	1.38 ± 0.04	0.187 ± 0.004	430.8 ± 3.3	1.87 ± 0.19	0.686	**0.61 ± 0.07**
UM-1a	0.89 ± 0.04	1.54 ± 0.04	0.185 ± 0.004	408.8 ± 3.2	1.84 ± 0.18	0.707	0.53 ± 0.06
UM-1b	0.89 ± 0.04	3.49 ± 0.11	0.185 ± 0.004	351.3 ± 1.9	2.17 ± 0.45	0.823	0.63 ± 0.13
				weighted mean of UM-1a and UM-1b			**0.55 ± 0.05**
ND-1a	0.86 ± 0.04	1.70 ± 0.06	0.188 ± 0.005	403.1 ± 3.7	1.78 ± 0.26	0.741	0.53 ± 0.08
ND-1b	0.86 ± 0.04	1.44 ± 0.04	0.189 ± 0.003	416.1 ± 2.8	1.65 ± 0.15	0.725	0.49 ± 0.05
				weighted mean of ND-1a and ND-1b			**0.50 ± 0.04**
NK-2	0.69 ± 0.03	1.64 ± 0.04	0.185 ± 0.003	394.8 ± 2.1	1.73 ± 0.14	0.732	**0.65 ± 0.06**
OS-1a	0.53 ± 0.03	3.31 ± 0.10	0.187 ± 0.004	324.5 ± 1.9	0.96 ± 0.42	0.911	0.47 ± 0.21
OS-1b	0.53 ± 0.03	4.14 ± 0.09	0.182 ± 0.003	313.3 ± 1.4	1.39 ± 0.33	0.893	0.68 ± 0.17
				weighted mean of OS-1a and OS-1b			**0.59 ± 0.13**

N.B.

$^{40}Ar^*$ means abundance of radiogenic ^{40}Ar. AC represents the air contamination ratio (non-radiogenic ^{40}Ar / total ^{40}Ar). Errors are quoted in 1 sigma.

Unit of K, ^{36}Ar, $^{40}Ar^*$ and Date are, respectively, wt. %, $10^{-10}cm^3STP/g$, $10^{-8}cm^3STP/g$ and Ma, respectively. STP denotes standard temperature and pressure.

Date in bold face represent weighted means of replicate dating results.

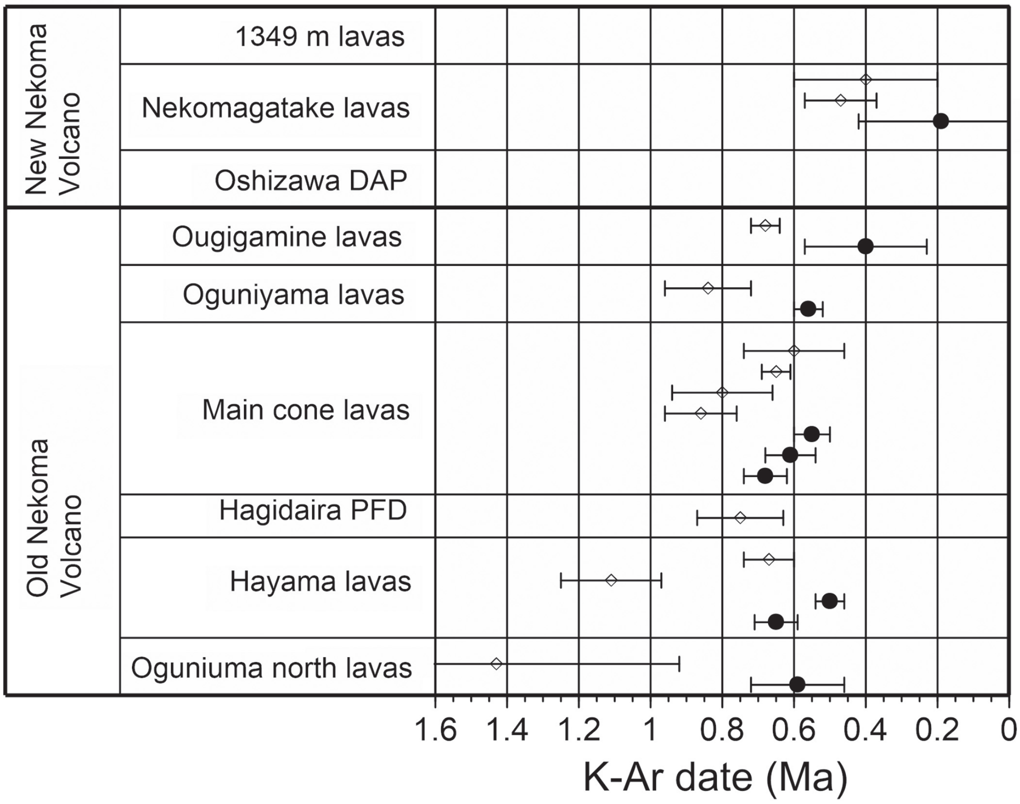

Figure 2 Stratigraphy of Nekoma volcano (Mimura, 2002, not to vertical scale) and K-Ar dates found from this his and earlier works. Solid circles represent our results. Open rhombic symbols represent earlier results. DAP and PFD respectively mean debris avalanche deposit and pyroclastic flow deposit. The Oshizawa DAP is related to the caldera forming event (Mimura, 2002).

(2002) reported the oldest K-Ar date for Nekoma volcano from the Oguninuma north lavas, 1.43 ± 0.51 Ma (JBD270). By contrast, our K-Ar date from this formation is 0.59 ± 0.13 Ma (OS-1). Possible reasons for the date difference are difference of the sample form for K-Ar dating and the presence of mass fractionated trapped argon component. We used the groundmass concentration, whereas the NEDO (1991) and Mimura (2002) used the whole rock form. The excess argon is expected to play a function in older and scattered K-Ar dates if a whole rock form sample contains phenocryst, which might have excess argon. The influence of a fractionated trapped argon component is pronounced for a younger rock sample that has a high non-radiogenic ^{40}Ar/total ^{40}Ar ratio, > 0.9 (e.g. Matsumoto et al., 1989; Takaoka, 1989; Matsumoto and Kobayashi, 1995). For example, non-radiogenic ^{40}Ar/total ^{40}Ar ratios of the JBD270 were high: 0.955 and 0.961 (Mimura, 2002). This sample is susceptible to fractionated trapped argon.

Our K-Ar dates from Old Nekoma Volcano (Oguninuma north lava, Hayama lavas, Main cone lavas, and Oguniyama lavas) are ca. 0.6 Ma. A K-Ar date of Ougigamine lavas (NK-1), 0.40 ± 0.17 Ma, is younger than that from the lower part of Old Nekoma Volcano products. The K-Ar date relation between lower and upper formations is consistent with stratigraphy. However, because the large uncertainty of the date arises from a high air contamination ratio (non-radiogenic ^{40}Ar / total ^{40}Ar), it remains unclear whether this difference is meaningful or not. Similarly, a K-Ar date of Nekomagatake lavas from New Nekoma Volcano (NE-1), 0.19 ± 0.23 Ma, indicates the youngest date within the dates of rocks from Nekoma volcano. The K-Ar date appears to be consistent with results found for stratigraphy, but appears to less reliable because their large (> 100%) uncertainty of the date, which arises from the high air contamination ratio.

K-Ar dates obtained from this work (ca. 0.6 Ma) are younger than the Brunhes - Matasuyama magnetic boundary (0.78 Ma). This result supports an estimate indicating that Nekoma volcano erupted in the Brunhes Normal Epoch (0.781–0 Ma; Ogg, 2012), rather than during the Jaramillo Event (1.072–0.988 Ma) in the Matsuyama Reversed Epoch (2.581–0.781 Ma).

Summary

Groundmass K-Ar dates using mass fractionation correction of rocks from Older Nekoma Volcano were distributed around 0.6 Ma. The K-Ar dates found through our study support earlier estimates made for Nekoma volcano, which erupted in the Brunhes Normal Epoch.

Acknowledgments

KI acknowledge Dr. Masao Ban, Dr. Kazuya Fukunaga, and graduate students, then of Yamagata University, and his colleagues at investigations of the Nekoma volcano, for carrying out the undergraduate research project. We thank the anonymous reviewers for contributing suggestions that have improved earlier manuscripts.

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