Letter

Bull. Volcanol. Soc. Japan
Vol. 50 (2005) No. 2, pp. 143–148

K-Ar Ages of the Lavas from Kirigamine Volcano, Central Japan

Teruki OIKAWA* and Kuniaki NISHIKI**

(Received July 23, 2004; Accepted January 16, 2005)

The Late Pliocene to Early Pleistocene volcanic rocks in the Suwa area, central Japan, comprising an enormous quantity of volcanic rocks, are named the Enrei Volcanic Rocks. The authors will report two K-Ar ages of volcanic rocks from the Kirigamine Volcano, which composes the uppermost part of the Enrei Volcanic Rocks. Based on the newly obtained ages, previously reported radiometric ages, and volcanostratigraphic data, we identify activity periods of 1.3 to 0.75 Ma for Kirigamine Volcano. We point out the possibility that the Oiwake Volcanic Graben partly covered by Kirigamine Volcano was mainly formed at ca. 0.85 Ma. From the previous studies and this study, the duration of the activity of the Enrei Volcanic Rocks is mainly from ca. 1.5 to 0.75 Ma. This duration of activity of the Enrei Volcanic Rocks almost corresponds to the active period in the Early Pleistocene of the Yatsugatake Volcanoes that adjoined Suwa area. Thus, in the Suwa and Yatsugatake areas in the Early Pleistocene, volcanic activity occurred with enormous volumes, covering a large area (800 km^2).
Key words: K-Ar dating, Kirigamine Volcano, Enrei Volcanic Rocks, Yatsugatake Volcano, Early Pleistocene

1. Introduction

The Late Pliocene to Early Pleistocene volcanic rocks in the Suwa area, central Japan, comprising an enormous quantity of volcanic rocks covering over 400 km^2 area, are named the Enrei Formation (Momose *et al.,* 1959) or the Enrei Volcanic Rocks (Makimoto *et al.,* 1996). In the area adjoining the Suwa area, the Older Yatsugatake Volcanoes (Kawachi, 1974 and 1977), also comprising an enormous volume (ca. 100 km^3) of Early Pleistocene volcanic rocks, are distributed (Fig. 1). Thus, the Suwa and Yatsugatake areas are the location in which outstanding and enormous volcanism occurred in central Japan. However, in these areas, chronological studies were insufficient and the relationship in time and space of the enormous volcanism was not clear. The chronology of the Enrei Volcanic Rocks was previously studied by Momose *et al.* (1966), Kaneoka and Suzuki (1970), Kitada *et al.* (1994), Kawachi (1997), Uchiumi *et al.* (1998), Miwa and Hoshi (2002) and Sato (2004). However, these studies were insufficient to clarify the volcanic history of the Enrei Volcanic Rocks.

Because of the active structural movements in and around the Suwa area, especially related to the Itoigawa-Shizuoka Tectonic Line active fault system (Fujimori, 1991) and the Oiwake Volcanic Graben (Kawachi, 1974), the Enrei Volcanic Rocks has been considerably deformed. Therefore, the chronological study of the Enrei Volcanic Rocks is important to clarify not only the volcanic history but also the relationship between the structural movements and the volcanic activity.

In this paper, the authors will report two K-Ar ages of volcanic rocks from the Kirigamine Volcano (definition after Compilation Group of Natural History in Suwa, 1975), which composes the uppermost part of the Enrei Formation (Momose *et al.,* 1959), and will discuss the temporal relationships with the adjoining volcanoes.

2. Outline of Geology

The Kirigamine Volcano, with the highest summit being Mt. Kurumayama; (1,925 m), 10 km (N-S) × 8 km (E-W), 900 m relative height and ca. 15 km^3 volume, has gentle slopes of less than 10 degree. The basement rocks of the Kirigamine Volcano consist of Miocene granite and the Lower Enrei Volcanic Rocks (Compilation Group of Natural History in Suwa, 1975). The Kirigamine Volcanic Rocks, Takayama Volcanic Rocks, Wadatoge Volcanic Rocks, and Mitsumine Volcanic Rocks compose the upper Enrei Volcanic Rocks (Compilation Group of Natural History in Suwa, 1975). These volcanic rocks are distributed in and around the Oiwake Volcanic Graben (Fig. 1). Kawachi (1974) considered that the Enrei Volcanic Rocks is the base-

* Tono Geoscience Center, Japan Nuclear Cycle Development Institute, 959–31, Jorinji, Izumi, Toki 509–5102, Japan.
** Graduate School of Science and Technology, Shinshu University, 3–1–1 Asahi, Matsumoto 390–8621, Japan.

Corresponding author: Teruki Oikawa
e-mail: oikawa.teruki@jnc.go.jp

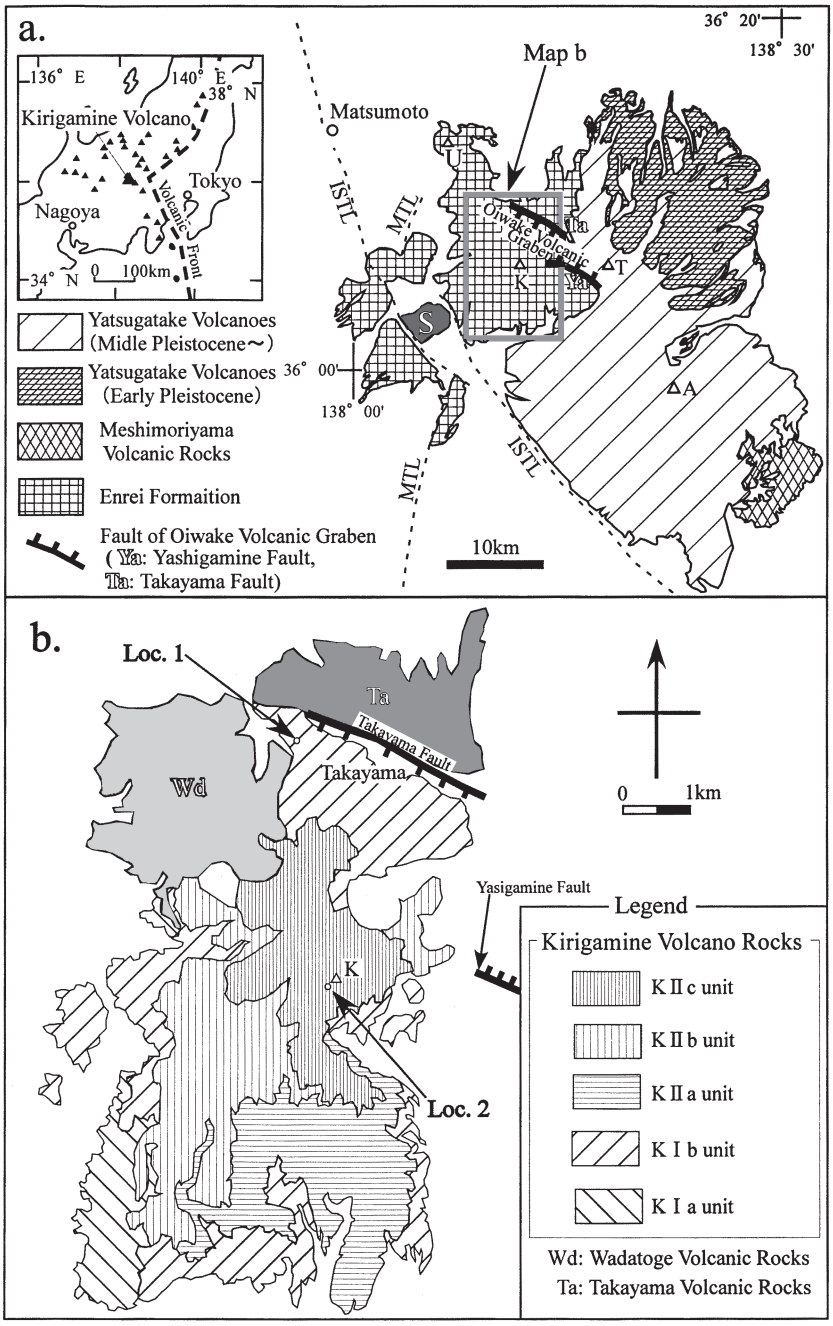

Fig. 1. a) Simplified geological map of Quaternary volcanic products in and around the Suwa and Yatsugatake areas. This map is simplified after Nakano *et al.* (1998), Ozaki *et al.* (2002) and Yamada *et al.* (1989). b) Simplified geological map of the Kirigamine Volcano, the Wadatoge Volcanic Rocks and the Takayama Volcanic Rocks. These Volcanic Rocks compose the upper Enrei Volcanic Rocks (Compilation Group of Natural History in Suwa, 1975). This map simplified after Compilation Group of Natural History in Suwa (1975) and Teshima and Kawachi (1994). Sampling localities for K-Ar dating are also shown. S: Suwako (Suwa Lake), U: Mt. Utsukushigahara, A: Yatsugatake (Mt. Akadake), T: Mt. Tateshinayama, K: Mt. Kurumayama, ISTL: Itoigawa-Shizuoka Tectonic Line active fault system, MTL: Median Tectonic Line.

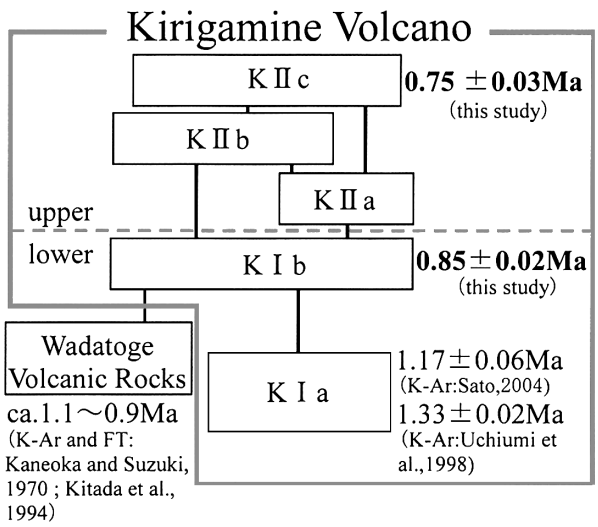

Fig. 2. Stratigraphic relationship of Quaternary volcanic products in the Kirigamine Volcano and the Wadatoge Volcanic Rocks, modified from Compilation Group of Natural History in Suwa (1975).

ment rocks of adjacent Yatsugatake Volcanoes.

Part of the Kirigamine Volcano filled in the Oiwake Volcanic Graben (Fig. 1). The Oiwake Volcanic Graben, some 3 km wide and 13 km in length, has a vertical displacement of more than 200 m (Kawachi, 1974). The Takayama Volcanic Rocks (Teshima and Kawachi, 1994) on the north of Kirigamine Volcano were deformed by activity of the Takayama Fault (Kawachi, 1974), a boundary of the Oiwake Volcanic Graben (Fig. 1). Kawachi (1997) shows an age of 0.84±0.02 Ma for the lava of the Takayama Volcanic Rocks. The arrangement of the adjacent Yatsugatake Volcanoes, especially the northwestern Yatsugatake Volcanoes, is controlled by this graben (Kawachi, 1974). However, the origin and forming age of this graben are not clear.

Volcanic rocks of the Kirigamine Volcano are composed of hornblende or pyroxene andesite or dacite (Yamazaki, 1965; Compilation Group of Natural History in Suwa, 1975; Nakai *et al.,* 2000). The first stratigraphic study of the volcanic rocks of the Kirigamine Volcano was made by Sawamura and Owa (1953). After that, Yamazaki (1965), the Compilation Group of Natural History in Suwa (1975), Yamazaki *et al.* (1976) and Nakai *et al.* (2000) reported the stratigraphy.

Based on the stratigraphy of the entire Kirigamine Volcano by the Compilation Group of Natural History in Suwa (1975), the Kirigamine Volcano is divided into lower (K I) and upper (K II) parts, both of which are further subdivided into K Ia～b and K IIa～c units in ascending order (Figs. 1 and 2). Two radiometric ages, 1.33±0.02 Ma (Uchiumi *et al.,* 1998) and 1.17±0.06 Ma (Sato, 2004) for the K Ia unit have been obtained for this volcano. The K Ib unit of this volcano covers Wadatoge Volcanic Rocks (0.9–1.1 Ma: Kaneoka and Suzuki, 1970; Kitada *et al.,* 1994).

3. Samples and Analyses

We analyzed the following samples for the K-Ar ages: the lava of K Ib unit (Loc. 1; sample No. K-1) in Takayama at the northern part of volcano, and the lava of K IIc unit (Loc. 2; sample No. K-2), from the summit area of Mt. Kurumayama at the central part of volcano. The K Ib unit at Takayama covers the Wadatoge Volcanic Rocks and partly covers the Oiwake Volcanic Graben. The K IIc unit in the summit area of Mt. Kurumayama is the youngest geological unit in the Kirigamine Volcano. Sampling localities, petrographic descriptions, and SiO_2 contents of the two samples are shown in Table 1. Localities are also shown in Fig. 1. Both phenocrysts and groundmass are fresh without any alteration products in these samples.

Samples were crushed and sieved to obtain 60 (250 μm) to 80 mesh (176.8 μm) fractions. Phenocrysts were removed from the fractions using a hand magnet and an isodynamic separator. The groundmass fraction was used for potassium and argon analysis. The argon isotope was analyzed by isotope dilution at Hiruzen Institute for Geology and Chronology Co. Ltd.. The concentration of potassium was also determined by flame spectrometric analysis at the same laboratory, too. The analyses and the age determination method were based on the method described by Nagao *et al.* (1984) and Itaya *et al.* (1991). For calculation of K-Ar age, $\lambda_e = 0.581 \times 10^{-10}$/yr, $\lambda_\beta = 0.4962 \times 10^{-10}$/y and $^{40}K/K = 0.0001167$ (Steiger and Jäger, 1977) were used. Average ages were calculated using formu-

Table 1. Localities and petrographic descriptions of dated lava samples.

Sample No. (Locality*)	Geological unit	Sampling Site Latitude**	Longitude**	Altitude	Phenocryst	Groundmass	Texture	SiO_2 (Wt.%)
K-1 (Loc. 1)	K I b	36° 08′ 48″ N	138° 11′ 17″ E	1440m	pl>cpx>opx>op	gl>pl>op	hyalopilitic	57.3
K-2 (Loc. 2)	K II c	36° 06′ 09″ N	138° 11′ 42″ E	1915m	pl>cpx>opx>op	gl>pl>op	hyalopilitic	57.3

pl : plagioclase, cpx : clinopyroxene, opx : orthopyroxene, op : opaque mineral, gl : glass
* see Fig. 1 ** based on the WGS84 Datum

Table 2. K-Ar ages of lava samples determined by this study. Ages are measured for separated groundmass fraction.

Sample No	potassium (wt. %)	rad. ^{40}Ar (10^{-8}cc STP/g)	K-Ar age (Ma)	Av. Age	non-rad. ^{40}Ar (%)
K-1	1.989±0.040	6.50±0.20	0.84±0.03		51.4
		6.67±0.19	0.86±0.03	**0.85±0.02**	50.8
K-2	1.830±0.037	5.21±0.23	0.73±0.04		64.2
		5.48±0.24	0.77±0.04	**0.75±0.03**	63.0

la proposed by Tsukui *et al.* (1985).

Analytical results are summarized in Table 2. These samples have low atmospheric ^{40}Ar; lower than 65%. Obtained K-Ar ages from K-1(K Ib) and K-2(K IIc) are 0.85±0.02 and 0.75±0.03, respectively (Table 2).

4. Result and Discussion

Fig. 2 compiles the stratigraphic relationship among the lavas (Compilation Group of Natural History in Suwa, 1975) and their K-Ar ages determined in this and previous studies. All of the four determined ages from fresh samples are consistent with the stratigraphy. Therefore, all these age data represent the eruption age of each lava. The duration of the activity of the Kirigamine Volcano is concluded to be from 1.3 to 0.75 Ma (Fig. 2). Notably, the duration of the activity of the upper Kirigamine Volcano, that is, above the K Ib unit, is ca. 0.1 my.; between 0.85±0.02 Ma and 0.75± 0.03 Ma. However, the duration of the activity of the lower Kirigamine Volcano (K I unit) is 0.5 Ma that is longer than the upper volcano. Taking the number of units in the lower volcano into consideration, there is the possibility that the volcanism of lower Kirigamine volcano had an interruption.

Kawachi (1997) suggested that the formative age of the Oiwake Volcanic Graben is older than 0.8 Ma based on the K-Ar age for Takayama Volcanic Rocks. Amount of the vertical displacement of Takayama Volcanic Rocks formed by activity of the Takayama Fault (a boundary of the Oiwake Volcanic Graven) is over 200 m high (Kawachi, 1974). The present fault scarp of Takayama Fault is 200 m relative high. Thus, the formation of the fault scarp topography of Takayama Fault occurred after the formation of Takayama Volcanic Rocks. According to the age determined for the K Ib unit that filled in the Oiwake Volcanic Graben and the age of the Takayama Volcanic Rocks, the Takayama Fault mainly deformed the Takayama Volcanic Rocks at ca. 0.85 Ma. The present topography of Takayama Fault is mainly formed ca. 0.85 Ma. It is considered that the deformation rate of Takayama Fault was largest at ca. 0.85 Ma. From the result that the duration of the activity of the Takayama Fault and the Takayama and the Kirigamine Volcano corresponds closely, it is considered that structural movement accompanied by volcanism caused the formation of the Takayama Fault. Based on above ages and stratigraphic data, we point out the possibility that the Oiwake Volcanic Graben formed rapidly at ca. 0.85 Ma.

The Kirigamine Volcano composes the uppermost unit of the upper Enrei Volcanic Rocks (Compilation Group of Natural History in Suwa, 1975). The age of 1.44±0.02 Ma for the lava of the lower unit of the lower Enrei Volcanic Rocks (Compilation Group of Natural History in Suwa, 1975; Kubota, 1999) is obtained by Uchiumi *et al.* (1998). The paleomagnetic stratigraphy of the Enrei Volcanic Rocks suggests that most of the formation belongs to the Lower Pleistocene (Momose *et al.,* 1966; Miwa and Hoshi, 2002). Sato (2004) considered that the volcanic activity after Pliocene in Suwa and Yatsugatake areas was started suddenly at Pleistocene. Judging from the above studies, such as Momose *et al.* (1966), Compilation Group of Natural History in Suwa (1975), Uchiumi *et al.* (1998), Kubota (1999), Miwa and Hoshi (2002), Sato (2004) and this study, the duration of the activity of the Enrei

Volcanic Rocks is mainly ca. 1.5 to 0.75 Ma. This duration of activity of the Enrei Volcanic Rocks almost corresponds to the active period in the Early Pleistocene of the Yatsugatake Volcanoes that adjoined Suwa area, such as 0 and 1 stages of the Older Yatsugatake Volcanoes (ca. 1.3–0.78 Ma: Kawachi, 1974, 1977, 1997; Kaneoka *et al.,* 1980; Kaneoka and Kawachi, 1983; Akimoto *et al.,* 2002). Furthermore, the active period of these volcanoes corresponds to the active period (ca. 1.4 Ma: Kaneoka *et al.,* 1993) of the Meshimoriyama Volcanic Rocks (Kawachi, 1977), too. Kawachi (1974) had shown that the Enrei Volcanic Rocks is older than the volcanic rocks of the Yatsugatake Volcanoes of the Early Pleistocene (e.g. Kasuga Volcanic Rocks: Kawachi, 1974). Kaneoka and Kawachi (1983) suggested that the start of the volcanic activity of the Yatsugatake volcanoes agreed with a part of the duration of the activity of the Enrei Volcanic Rocks. Based on this study, it has become clear that these volcanic rocks were formed in the same period (ca. 1.5–0.75 Ma). According to estimations from the geological maps by Nakano *et al.* (1998) and by Ozaki *et al.* (2002), the covered areas of these volcanic rocks are 800 km^2. Thus, in the Suwa and Yatsugatake areas in the Early Pleistocene, volcanic activity occurred with enormous volumes, covering a large area.

Acknowledgments

We would like to thank Professor Y. Miyake of Shinshu University and Dr. K. Umeda of Japan Nuclear Cycle Development Institute for their constructive comments on an early version of this manuscript. Mr. G. McCrank of ex-JNC International Fellow helped us with English. Mr. H. Hayashi of PESCO Co. Ltd. helped in the preparation of thin section. We also thank an anonymous reviewer, Mr. S. Nakano of AIST GSJ, and Associate Professor M. Tsukui of Chiba University for reviewing the manuscript.

References

Akimoto, T., Furuta, T. and Kawachi, S. (2002) Paleomagnetic properties of the Yatsugatake Volcanic Chain, central Japan. *Bull. Volcanol. Soc. Japan,* **47**, 435–448.*

Compilation Group of Natural History in Suwa (1975) Natural history in the Suwa, Volume Geology. Compilation Group of Natural History in Suwa Ed., Suwa Education Group, 531 p.**

Fujimori, T. (1991) Active faults in the Suwa Basin, and its evolution as a pull-apart basin on the Itoigawa-Shizuoka Tectonic Line, central Japan. *Geograph. Rev. Japan, Ser. A,* **64**, 665–696.*

Itaya, T., Nagao, K., Inoue, K., Honjo, Y., Okada, T. and Ogata, A. (1991) Argon isotope analysis by a newly developed mass spectrometric system for K-Ar dating. *Mineral. Jour.,* **15**, 203–221.

Kaneoka, I. and Suzuki, M. (1970) K-Ar and fission track ages of some obsidians from Japan. *Jour. Geol. Soc. Japan,* **76**, 309–313.

Kaneoka, I. and Kawachi, S. (1983) K-Ar ages volcanic rocks from the northern area of the Yatsugatake volcanic chain. *Jour. Geol. Soc. Japan,* **89**, 359–361.

Kaneoka, I., Mehnert, H., Zashu, S. and Kawachi, S. (1980) Pliocene volcanic activities in the Fossa Magna region, central Japan, —K-Ar age studies of the Yatsugatake volcanic chain. *Geochem. Jour.,* **14**, 249–257.

Kaneoka, I., Kawachi, S. and Nagao, K. (1993) Period of volcanic activities of Pleistocene and Pliocene volcanoes in the eastern area of Mt. Yatsugatake based on K-Ar ages. *Abst. Volcano. Soc. Japan,* no. 2, 76.**

Kawachi, S. (1974) Geology of the Tateshinayama District. Quadrangle Series, Scale 1: 50,000, Geol. Surv. Japan, 119 p.*

Kawachi, S. (1977) Geology of the Yatsugatake District. Quadrangle Series, Scale 1: 50,000, Geol. Surv. Japan, 92 p.*

Kawachi, S. (1997) K-Ar ages of volcanic rocks from the Yatsugatake volcanic chain and adjacent areas in Nagano Pref., central Japan. *Jour. Fac. Edu. Shinshu Univ.,* **93**, 149–160.*

Kitada, N., Wadatsumi, K., Masuda, H., Nagao, K., Bigazzi, G., Kowallis, Naeser, C. W. and Deino, A. (1994) Cross check of the age dating for the glass age standard "JAS-G1". *Fission Track News Lett.* **7**, 10–11.**

Kubota, Y. (1999) Volcanostratigraphy and geologic structure of the Enrei Formation on the southwest side of Lake Suwa, Nagano Prefecture, Central Japan —A Late Pliocene to Early Pleistocene volcanic history in a junction of island arcs—. *Jour. Geol. Soc. Japan,* **105**, 25–44.*

Makimoto, H., Takagi, H., Miyachi, Y., Nakano, S., Kato, H. and Yoshioka, T. (1996) Geology of the Takato District. Quadrangle Series, Scale 1: 50,000, Geol. Surv. Japan, 114 p.*

Miwa, T. and Hoshi, H. (2002) Paleomagnetism of late Cenozoic volcanic rocks (Enrei Formation) in Nagano Prefecture, central Japan. *Jour. Geol. Soc. Japan,* **108**, 28–36.**

Momose, K., Kobayashi, K. and Yamada, T. (1959) Paleomagnetic and geologic researches for the volcanic rocks around Lake Suwa. -Paleomagnetic researches for the Pliocene volcanic rocks in central Japan (2). *Bull. Earthq. Res. Inst. Univ. Tokyo,* **37**, 433–481.

Momose, K., Kobayashi, K. and Yamada, T. (1966) Radiometric age of lava flows of the Enrei formations in central Japan (1). *Jour. Fac. Sci. Shinshu Univ.,* **1**, 93–96.

Nagao, K., Nishido, H., Itaya, T. and Ogata, K. (1984) An age determination by K-Ar Method. *Bull. Hiruzen Res. Inst., Okayama College of Sci.,* no. 9, 19–38

Nakai, K., Uchiyama, K., Yamada, D. and Kawachi, S. (2000) Geology, petrography and active fault of Ike-no-kurumi, Kuruma-yama, and Mushikura areas in Kiri-gamine volcano, central Japan. *Bull. Inst. Nature Educ. Shiga Heights Shinshu Univ.,* **37**, 23–35.*

Nakano, S., Takeuchi, K., Kato, H., Sakai, A., Hamasaki, S., Hiroshima, T. and Komazawa, M. (1998) Geological Map of Japan, Nagano. Geological Map of Japan, 1: 200,000, Geol. Surv. Japan.*

Ozaki, M., Makimoto, H., Sugiyama, Y., Mimura, K., Sakai, A., Kubo, K., Kato, H., Komazawa, M., Hiroshima, T. and Sudo, S. (2002) Geological Map of Japan, Kofu. Geological Map of Japan, 1: 200,000, Geol. Surv. Japan.*

Sato, K. (2004) K-Ar ages of volcanic rocks in the Myogi-Arafune-Saku area and their relevance to the retreat of volcanic front. *Bull Gunma Mus. Natu. Hist.,* no. 8, 109–118.*

Sawamura, K. and Owa, E. (1953) Geology of the Suwa District. Quadrangle Series, Scale 1: 50,000, Geol. Surv. Japan, 45 p.*

Steiger, R. H. and Jäger, E. (1977) Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett.,* **36**, 359–362.

Teshima, S. and Kawachi, S. (1994) Geology and petrochemistry of the volcanic rocks in the eastern Wadatoge Pass, central Japan. *Bull. Inst. Nature Educ. Shiga Heights, Shinshu Univ.,* **31**, 1–8.**

Tsukui, M., Nishido, H. and Nagao, K. (1985) K-Ar ages of the Hiruzen volcano group and Daisen volcano. *Jour. Geol. Soc. Japan.* **91**, 279–288.*

Uchiumi, S., Nakano, S. and Uto, K. (1998) K-Ar dating on age-unknown rocks in the "Geological Map of Japan 1: 200,000, Nagano". *Bull. Geol. Surv. Japan,* **49**, 189–193.*

Yamada, N., Nozawa, T., Harayama, S., Takizawa, F., Kato, H., Hiroshima, T. and Komazawa, M. (1989) Geological Map of Japan, Takayama. Geological Map of Japan, 1: 200,000, Geol. Surv. Japan.**

Yamazaki, T. (1965) Petrography and petrochemistry of Kirigamine Volcano, central Japan. *Jour. Mineral. Petrol. Economic Geol.,* **54**, 39–103.

Yamazaki, T., Kobayashi, T. and Kawachi, S. (1976) Geology and petrography of the Wada-pass and adjacent area, Nagano Pref., central Japan. *Jour. Geol. Soc. Japan,* **82**, 127–137.*

* in Japanese with English abstract
** in Japanese

(editorial handling Masashi Tsukui)

霧ヶ峰火山の K-Ar 年代

及川輝樹・西来邦章

中部日本，諏訪地方に分布する後期鮮新世から前期更新世にかけての膨大な火山岩類は塩嶺火山岩類と呼ばれている．筆者らは塩嶺火山岩類最上部を構成する霧ヶ峰火山の火山岩から 2 つの K-Ar 年代を測定した．既知の層序・年代値と新たに得られた年代値をまとめると霧ヶ峰火山の活動期間はおよそ 1.3〜0.75 Ma である．さらに，霧ヶ峰火山に覆われる追分火山性地溝帯が主に約 0.85 Ma に形成された可能性が明らかになった．既知の塩嶺火山岩類の研究と今回得られた年代値をあわせると塩嶺火山岩類の主な形成時期は約 1.5〜0.75 Ma であり，これは諏訪地方に近接した前期更新世における八ヶ岳火山の活動時期と同じである．つまり，前期更新世の諏訪・八ヶ岳地域において，広い地域 (800 km^2) に膨大な体積の噴出物を形成した火山活動がおきたと考えられる．

Utsukushigahara: 美ヶ原，Tateshinayama: 蓼科山，Kirigamine: 霧ヶ峰，Kurumayama: 車山，Wadatoge: 和田峠，Takayama: 鷹山，Yashigamine: 八子ヶ峰，Kasuga: 春日，Meshimoriyama: 飯盛山