Letter

Bull. Volcanol. Soc. Japan
Vol. 53 (2008) No. 5, pp. 151–157

The Tephra Layers Distributed around the Eastern Foot of the Zao Volcano —Ages and Volumes of the Za-To 1 to 4 Tephras—

Kotaro MIURA*, Masao BAN** and Hiroshi YAGI***

(Received, February 29, 2008; Accepted, October 9, 2008)

Ages of four scoriaceous volcanic sand layers (Za-To 1 to 4) distributed around the eastern foot of the Zao volcano are determined to be ca. 33–32, 30.7, 27.1, and 12.9 cal kyr BP, respectively, based on four newly obtained radiocarbon dates and loess chronometry. Besides, we detect To-H (To-HP) glasses from the loess below the Za-To 4 tephra. The estimated age of the loess horizon is consistent with the previously reported one for To-H (To-HP). Volumes of Za-To 1 to 4 tephras are estimated to be ca. 3×10^{-2}, 3×10^{-1}, 1×10^{-1} and 1×10^{-1} DRE km^3, respectively, and the averaged discharge rate from Za-To 1 to 4 is calculated to be ca. 0.02–0.03 km^3/ky.

Key words: Zao volcano, tephra layers, radiocarbon dating, volcanic glass, discharge rate

1. Introduction

The Zao volcano is a stratovolcano which is located in the central part of the volcanic front of the northeast Japan arc (Fig. 1). This volcano started its activity at about 1 Ma (Takaoka, *et al.,* 1989), and has continued to the present day. Geologic and petrologic studies of the whole of the eruptive products were performed by various authors (e.g. Chiba, 1961; Oba and Konda, 1989; Sakayori, 1992), and according to these studies, the newest stage of the Zao volcano began at ca. 30 ka, and numerous small to medium sized eruptions have continued for the past 30-ky. At about 30 ka, the horse shoe-shaped Umanose caldera (1.7 km in diameter), which is located in the central part of the Zao, was formed by explosive eruptions (Sakayori, 1992). The newest cone Goshikidake is situated in the inner part of the Umanose caldera and the newest crater lake Okama is located in the western part of the Goshikidake.

Tephro-stratigraphy is very useful to establish the detailed eruptive history of volcanoes (e.g. Thorarinsson, 1981). In the case of the Zao newest stage, the tephro-stratigraphic studies were performed by various authors (e.g., Imura, 1996, 1999; Itagaki *et al.,* 1981; Saigusa and Shoji, 1984). Imura (1999) recognized ten volcanic sand layers (Za-To 1 to 10). Za-To 1 to 4 tephras are mostly distributed around the eastern foot of the Zao volcano, while Za-To 5 to 10 are mainly near the summit area. Imura (1999) also estimated that the ages of Za-To 1 to 4 tephras are older than ca. 20 ka, based on a radiocarbon age (Itagaki *et al.,* 1981), and the estimated AT (Aira-Tn tephra) horizon. AT is a wide-spread tephra ejected from the Aira caldera about 29 cal kyr BP (Okuno, 2002), widely distributed in Japan. In the Zao, AT volcanic glasses which is the bubble wall type (Machida and Arai, 2003) are found in the upper part of the loess below the Za-To 4 tephra (Imura, 1996). In this study, we determined the ages of Za-To 1 to 4 tephras layers based on newly obtained four radiocarbon dates, coupled with the loess chronometry (Hayakawa, 1995) and tephrochronology. Using this new age data and the magma discharge volume estimated from the isopach maps, we have calculated the magma discharge rates during the Za-To 1 to 4 activities.

2. Stratigraphic description of the Za-To 1 to 4 tephra layers

Za-To 1 to 4 tephra layers consist of scoriaceous volcanic sand, and are well sorted and laminated. In an outcrop at Haraobi (Loc. 7; Fig. 1), all of the Za-To 1 to 4 tehpra layers can be observed and they are intercalated in the brown colored loess (partly reddish-dark brown colored paleosol), observed at the eastern foot of Zao.

* Division of Interactive Symbiosphere Sciences, Graduate School of Science and Engineering, Yamagata University, 1–4–12, Kojirakawa-machi, Yamagata, 990–8560, Japan.

** Department of Earth and Environmental Sciences, Faculty of Science, Yamagata University, 1–4–12, Kojirakawa-machi, Yamagata, 990–8560, Japan.

*** Department of Information, Environmental and Food Sciences, Faculty of Education, Art and Science, Yamagata University, 1–4–12, Kojirakawa-machi, Yamagata, 990–8560, Japan.

Corresponding author: Masao Ban
e-mail: ban@sci.kj.yamagata-u.ac.jp

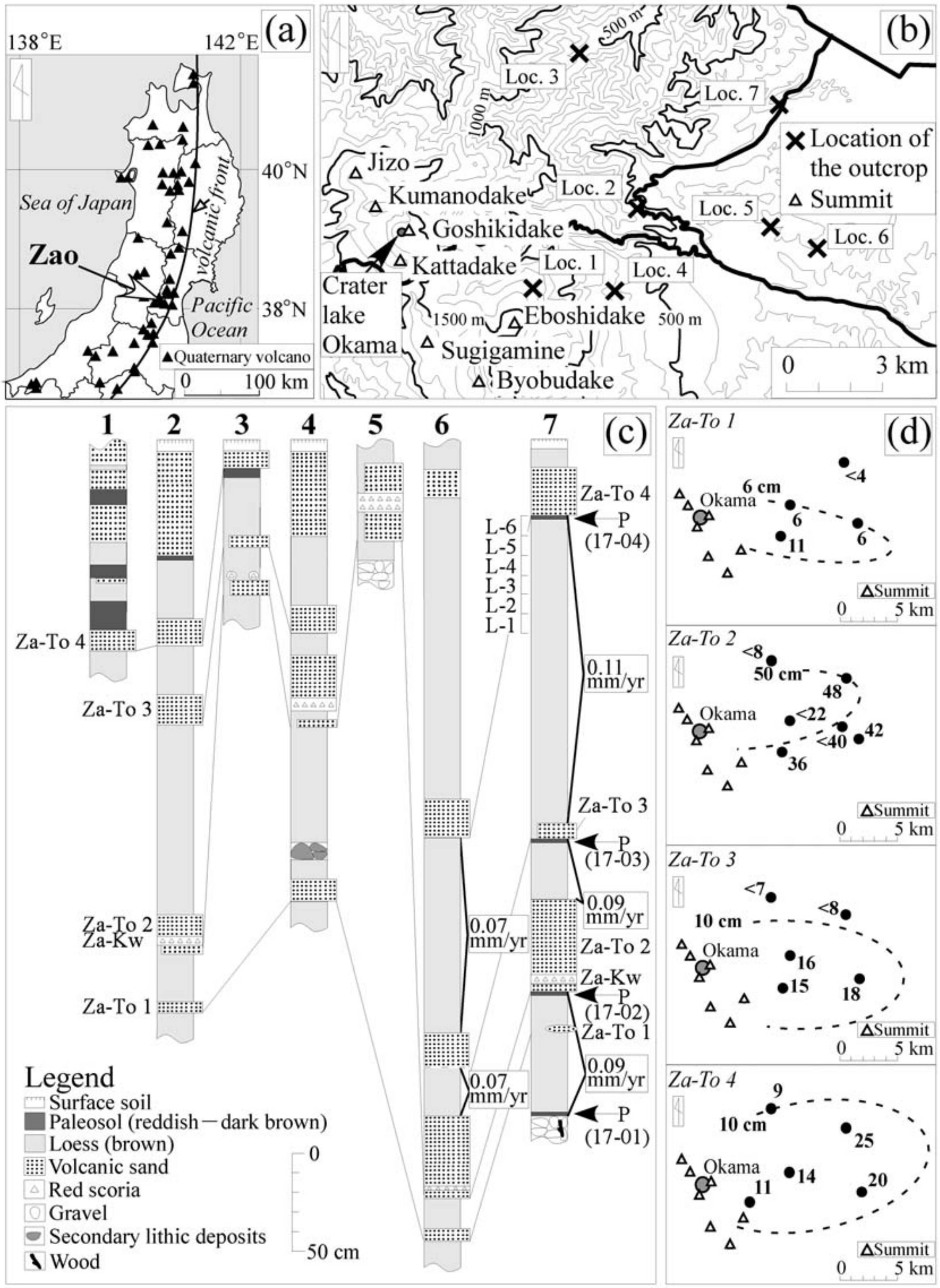

Fig. 1. Maps showing the location of the Zao volcano (a), location of the outcrop (b), correlative stratigraphic columns for representative sections (c) and isopach maps of Za-To 1 to 4 tephra layers (d). Topographic contour lines in (b) are at 100 m intervals. P and L-1 to 6 in (c) indicate the horizons of the paleosol samples and the analyzed volcanic glasses, respectively (see text for detail). The estimated sedimentation rates are also shown in the columns of Loc. 6 and 7 (see text for detail). Numbers in (d) indicate the measured thickness of the layers in cm.

Table 1. Radiocarbon data and calibration ages.

Sample name	Stratigraphic position	$\delta^{13}C$ (‰)	Radiocarbon age (BP)	Lab. No	Calibration range (1 σ)
17-04*	Paleosol below Za-To 4	-26.2	10,920±45	PLD-4059	a)12,902−12,853 cal BP
17-03*	Paleosol below Za-To 3	-26.4	22,560±100	PLD-4058	b)27,183−26,919 cal BP
17-02*	Paleosol below Za-To 2	-26.1	25,440±120	PLD-4057	b)30,781−30,561 cal BP
17-01**	Paleosol on top of gravel layer	-26.3	31,408±190	ID-6021	b)36,690−36,198 cal BP

*, Samples dated at the Paleo Labo Tokai branch.

**, Samples dated at the Tono Geoscience Center.

a) Calibration age based on the calibration program CALIB 5.0.2 (Stuiver and Reimer, 1993) using IntCal04 (Reimer *et al.,* 2004).

b) Calibration age based on Fairbanks calibration program (Fairbanks *et al.,* 2005).

At this outcrop, the Za-To 1 tephra layer has the smallest thickness (ca. $<$4 cm), while the Za-To 2 tephra layer is thickest (ca. 48 cm) with the Za-To 3 and 4 tephra layers having intermediate values (ca. $<$8 and 25 cm). Thicknesses of the loess between Za-To 1 and 2, 2 and 3, and 3 and 4 tephra layers are ca. 14, 31 and 160 cm, respectively. Za-To 1 tephra presents as lenses, while Za-To 2 to 4 tephras present as stratified layer. However, Za-To 3 tephra sometimes presents as discontinuous layer. The Za-To 2 tephra layer is divided into lower, middle, and upper parts. The thicknesses of these are ca. 4, 5 and 39 cm at Loc. 7, respectively. The upper and lower parts are composed of scoriaceous volcanic sands, while the middle layer is composed of red colored scoria only. Itagaki *et al.* (1981) named the red colored scoria the Zao Kawasaki scoria (Za-Kw).

In addition, a gravel layer is sometimes observed below the Za-To 1 tephra layer. The thickness of the loess lying between them is ca. 40 cm. The gravel layer is composed of subangular to subrounded gravel less than 2 m in diameter, and poorly sorted. It is considered that the gravel layer can be correlated to subangular to subrounded gravel layer which was described by Itagaki *et al.* (1981). Itagaki *et al.* (1981) reported that the radiocarbon age of wood sample from subangular to subrounded gravel layer which was obtained at the other location is 31,500 +2,610/−1,970 yr BP.

Isopach maps of Za-To 1 to 4 tephra layers are shown in Fig. 1. They are distributed mainly on the east downwind side. Isopach maps show that these tephras originated from the Zao volcano. The main axis of Za-To 1 to 4 tephras extend toward the east-southeast, east-northeast, east and east-northeast, respectively.

3. Radiocarbon age

The representative columnar sections are shown in Fig. 1. At Loc. 7, the reddish-dark brown colored paleosol ($<$2 cm thickness paleosol parts) is observed in four horizons, just above the top of the gravel layer and just below the bottom of Za-To 2, 3 and 4 tephra layers (Fig. 1). We sampled the paleosols from these horizons for radiocarbon dating. The material of samples 17–02, 17–03 and 17–04 passed through a 0.1 mm sieve was stirred by an ultrasonic cleaner, and purified by acid treatment. The pretreated material was oxidized by heating at 850℃ together with CuO. The produced CO_2 was reduced catalytically to graphite on Fe-powder with hydrogen gas at 650℃. For these three samples, we used an AMS system at the Paleo Labo Co., Ltd to make radiocarbon measurements of graphite targets with NIST OX-II as standerds. The material of sample 17–01 was purified by acid and alkali treatments. The pretreated material was oxidized by heating in a vacuum together with CuO. The produced CuO was reduced to graphite using the method of Kitagawa *et al.* (1993). For this sample, we used a Tandetron AMS system at the Tono Geoscience Center to make radiocarbon measurements of graphite targets with NIST OX-II as standards.

The results are shown in Table 1. Radiocarbon ages were corrected by $\delta^{13}C$ and calculated using a Libby half-life of 5,568 years. The well known radiocarbon age calibration curve IntCal04 (Reimer *et al.,* 2004) extends back to 26 cal kyr BP, however the calibration curve spanning 26 to 50 cal kyr BP is tentative (van der Plicht *et al.,* 2004). The age of the sample 17–04 was calibrated by the calibration program CALIB 5.0.2 (Stuiver and Reimer, 1993) using IntCal04 (Reimer *et al.,* 2004), but the other three samples were calibrated by Fairbanks calibration program (Fairbanks *et al.,* 2005) (Table 1), because these three ages are out of range of the IntCal04. The calibrated calendar ages are used in the following discussion. It is considered that the radiocarbon ages of the samples 17–02, 17–03 and 17–04 are equivalent to those of the nearby tephra layers. Because the radiocarbon dates paleosols underlying tephra layers, can represent the eruption age (Okuno, 2001). Thus, the ages of the Za-To 2 to 4 tephra layers are deduced to be ca. 30.7, 27.1, and 12.9 cal kyr BP, respectively. The radiocarbon age of the

Table 2. Representative compositions of volcanic glasses in L-1 to 6.

	L-1		L-2			L-3			
Sample no.	17a-6 70 low-K_2O	17a-6 64 high-K_2O	17a-5 88 To-H (To-HP)	17a-5 114 low-K_2O	17a-5 96 high-K_2O	17a-4 47 AT	17a-4 34 To-H (To-HP)	17a-4 35 low-K_2O	17d-4 82 high-K_2O
wt.%									
SiO_2	75.57	76.67	76.66	77.21	74.73	77.16	77.48	75.95	71.99
TiO_2	0.21	0.10	0.43	0.26	0.16	0.13	0.40	0.14	0.14
Al_2O_3	11.98	11.72	12.66	11.78	11.29	11.94	12.81	11.94	10.90
FeO*	1.36	1.66	1.91	1.14	0.85	1.11	1.86	1.03	0.96
MnO	0.02	0.06	0.07	0.06	0.05	0.10	0.10	0.12	0.05
MgO	0.22	0.00	0.43	0.28	0.10	0.14	0.47	0.21	0.12
CaO	1.56	1.18	2.07	1.41	1.06	1.06	2.13	1.53	1.05
Na_2O	3.71	4.04	4.10	4.18	2.71	3.51	4.04	3.56	1.74
K_2O	1.47	2.45	1.26	1.48	4.24	3.52	1.19	1.55	4.22
P_2O_5	0.00	0.07	0.06	0.03	0.00	0.03	0.04	0.08	0.00
Total	96.11	97.95	99.66	97.84	95.19	98.69	100.50	96.10	91.17

	L-4				L-5			L-6		
Sample no.	17a-3 18 AT	17d-3 43 To-H (To-HP)	17a-3 20 low-K_2O	17c-3 9 high-K_2O	17d-2 6 AT	17d-2 55 To-H (To-HP)	17d-2 32 high-K_2O	17b-1 5 AT	17-1 16 To-H (To-HP)	17b-1 26 high-K_2O
wt.%										
SiO_2	77.82	75.52	75.69	74.38	76.11	73.46	73.02	74.73	71.49	71.27
TiO_2	0.16	0.31	0.17	0.16	0.12	0.44	0.13	0.12	0.43	0.13
Al_2O_3	12.05	12.24	11.99	11.72	11.80	13.02	11.28	11.68	12.55	11.00
FeO*	1.23	1.69	1.41	1.29	1.23	1.97	1.01	1.04	2.05	1.06
MnO	0.02	0.15	0.23	0.10	0.01	0.03	0.11	0.15	0.12	0.04
MgO	0.11	0.42	0.20	0.09	0.12	0.51	0.10	0.12	0.49	0.06
CaO	0.80	1.98	1.18	1.07	1.07	2.15	1.01	1.12	2.51	0.92
Na_2O	3.65	4.33	3.25	3.48	3.64	4.04	2.06	3.14	3.86	1.80
K_2O	3.52	1.29	1.36	3.76	3.62	1.20	4.09	3.83	1.15	3.97
P_2O_5	0.09	0.00	0.11	0.00	0.01	0.08	0.05	0.05	0.07	0.09
Total	99.46	97.93	95.60	96.07	97.73	96.91	92.85	95.98	94.72	90.32

FeO*, total iron calculated as FeO.

sample 17–01 is in the range of the error bar of that of a wood sample from the gravel layer which was reported by Itagaki *et al.* (1981).

The sedimentation rate of loess is considered to be relatively constant in a flat area (Hayakawa, 1995) such as Loc. 6 and 7. Using the obtained ages of Za-To 2 to 4 and the thickness of the loess between them, the rates during Za-To 2 to 3, and Za-To 3 to 4 tephra layers are calculated to be similar value of ca. 0.07 mm/yr at Loc. 6. At Loc. 7, those are calculated to be ca. 0.09 and 0.11 mm/yr, respectively. The rate during the sample no. 17–01 loess horizon to Za-To 2 tephra layers is also calculated to be 0.09 mm/yr. These values are in the range of the sedimentation rate of the loess in Japan (0.04–0.15 mm/yr) reported by Hayakawa and Yui (1989). Using the obtained rates, the age of Za-To 1 tephra layer at Loc. 6 and Loc. 7 are calculated to be ca. 33 and 32 ka, respectively. The age of the Za-To 1 tephra layer would be some time between ca. 33 and 32 cal kyr BP.

4. Volcanic glasses in the loess

We re-examined the volcanic glass shards in the upper part of the loess below the Za-To 4 tephra where volcanic glasses were reported by Imura (1996).

At Loc. 7, we collected six samples (L-1, 2, 3, 4, 5 and 6) from the upper part of the loess (60 cm in thickness) below the boundary with the Za-To 4 tephra layer. Samples L-1 to 6 were collected from the loess at 60–50 to 10–0 cm from the boundary (Fig. 1). The samples were washed by an ultrasonic cleaner, dried in an oven at 60℃, and sieved. Volcanic glasses obtained in the range of 0.088–0.125 mm were used for microscope observation and chemical analysis. Knowing the chemical composition of the volcanic glasses is very useful when identifying the widespread tephras. The chemical compositions of the glasses were undertaken with a JEOL 8600M electron microprobe at Yamagata University using a wavelength-dispersive technique. Operating conditions were 15 kV accelerating voltage, 0.01 μA beam current and a 10 μm defocused beam. Analyses were corrected using the oxide ZAF method.

Under the microscope, most of the volcanic glass shards shape in L-1 to 6 are the pumice type (Machida and Arai, 2003), while a small number of volcanic glass shards in L-3 to 6 are the bubble wall type (Machida and Arai, 2003). Representative compositions of volcanic glass shards in L-1 to 6 are listed in Table 2. All discussion here refers to analyses that have been normalized to 100% volatile free with total iron (FeO*) calculated as FeO. Representative major elements vs. SiO_2 diagrams are shown in Fig. 2. Data from the AT

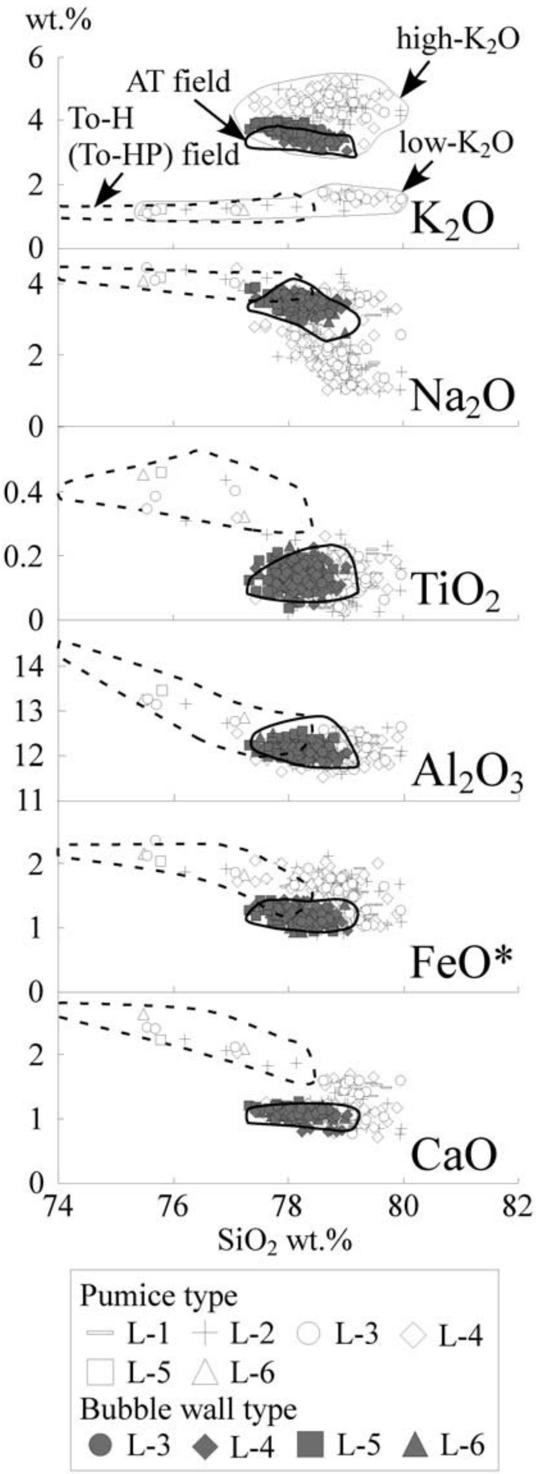

Fig. 2. SiO_2 variation diagrams for volcanic glasses. FeO* = total iron calculated as FeO. Solid and broken envelopes show fields of the AT and To-H volcanic glasses, respectively (Machida and Arai, 2003).

and To-H (To-HP) (Towada-Hachinohe tephra) by Machida and Arai (2003) are also shown in Fig. 2 for comparative purposes, because these two are the potential candidates among widespread tephras to have deposited in Zao and the surrounding area during ca. 32–12 ka. To-H (To-HP) was discharged from the Towada caldera, with an estimated age of ca. 14.5–17 ka. It is widely distributed mainly around the northern part of NE Japan. The shape of volcanic glasses is the pumice type (Machida and Arai, 2003).

The silica contents of the volcanic glass shards (L-1 to 6) ranged from 75 to 80 wt.%. In the K_2O vs. SiO_2 diagram, the volcanic glass composition is split into two groups. One group has low K_2O (1.1–1.8 wt.%) content with a range of 75–80 wt.% SiO_2, and the other has a high K_2O (2.3–5.3 wt.%) content of 77–80 wt.% SiO_2. All of the bubble wall type glasses, which were found in L-3 to 6, belong to the latter group, and the plotted area of this type of glass is similar to that of AT glasses in the K_2O vs. SiO_2 diagram as well as in the other SiO_2 variation diagrams (Fig. 2). The low-K_2O glasses can be divided further into lower (75–78 wt.%) and higher (78.5–80 wt.%) SiO_2 groups. The glasses of former group were from L-2 to 6, and the compositional range of this group is in the To-H (To-HP) field in the K_2O vs. SiO_2 diagram as well as in the other SiO_2 variation diagrams. Volcanic glasses of the high-K_2O pumice type and low-K_2O·higher SiO_2 group have different compositions from either of the AT and To-H (To-HP) glasses. It is probable that they were derived from the volcanoes in and around the Zao area.

Consequently, AT and To-H (To-HP) volcanic glasses were found in L-3 to 6 and L-2 to 6, respectively. The age of L-2 is calculated to be ca. 17.8–16.8 ka, using the sedimentation rate of the loess which was obtained in the previous section. The value is comparable to the age of To-H (To-HP) by Machida and Arai (2003). Therefore, it is considered that the AT and To-H (To-HP) volcanic glasses found in the L-3 to 6 horizons have a reworked origin and the To-H (To-HP) volcanic glasses were deposited as near primary tephra in the L-2 horizon and show the age of the loess.

5. Discharge rate

Discharge volumes of Za-To 1 to 4 tephra layers were estimated using an empirical formula proposed by Hayakawa (1985). The formula is $V = 12.2TS$ where V is the discharge volume, T is a certain thickness, and S is the area enclosed within the isopach of thickness T. Volumes of Za-To 1 to 4 tephra layers are ca. 3×10^{-2}, 3×10^{-1}, 1×10^{-1} and 1×10^{-1} DRE km^3, respectively (Table 3).

A magma-discharge stepdiagram during the Za-To 1 to 4 activities, using the volumes and the ages of the tephras obtained in this study, is shown in Fig. 3. The

Table 3. Discharge volumes of Za-To 1 to 4 tephras. Densities were determined using weight of a 100 ml beaker filled with the tephra which was dried in an oven at 105℃.

Tephra	Volume	Density (g/cm^3)	Volume (DRE; 2.5 g/cm^3)
Za-To 4	2×10^{-1} km^3	1.3	1×10^{-1} km^3
Za-To 3	2×10^{-1} km^3	1.4	1×10^{-1} km^3
Za-To 2	5×10^{-1} km^3	1.3	3×10^{-1} km^3
Za-To 1	5×10^{-2} km^3	1.4	3×10^{-2} km^3

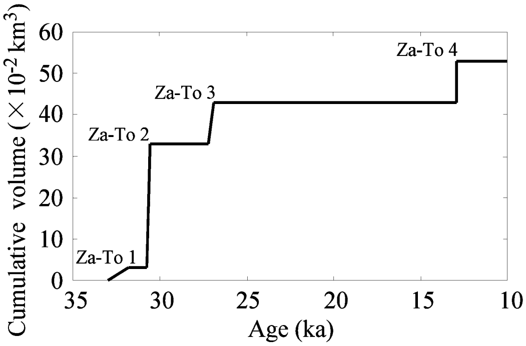

Fig. 3. A magma-discharge stepdiagram during Za-To 1 to 4 tephras.

intervals of Za-To 1 to 2 (ca. 2.3–1.3 ky) and Za-To 2 to 3 (ca. 3.6 ky) are much shorter than the interval of Za-To 3 to 4 (ca. 14.2 ky), thus Za-To 1 to 3 are regarded as a series of activities. While the average discharge rate during Za-To 1 to 4 is calculated to be ca. 0.02–0.03 km^3/ky, that of the series of activities is calculated to be larger, ca. 0.07–0.09 km^3/ky. These discharge rates are comparable to those of the newest stages of Adatara and Azuma volcanoes, which are the two nearest active volcanoes to Zao, in the volcanic front. Tephro-stratigraphic studies have been performed on the newest stages of these two volcanoes (Yamamoto and Sakaguchi, 2000; Yamamoto, 2005), and the discharge rates are estimated to be ca. 0.008 and 0.07 km^3/ky, respectively.

6. Conclusions

(1) The ages of the Za-To 1 to 4 tephra layers in the newest stage were determined to be ca. 33–32, 30.7, 27.1 and 12.9 ka, respectively.

(2) The AT and To-H (To-HP) volcanic glasses were found in the upper part of the loess below the Za-To 4 tephra. While the AT glasses have a reworked origin, the To-H (To-HP) glasses were deposited as near primary tephra.

(3) The estimated volumes of the Za-To 1 to 4 are ca. 3×10^{-2}, 3×10^{-1}, 1×10^{-1} and 1×10^{-1} DRE km^3, respectively and the averaged discharge rate during Za-To 1 to 4 is calculated to be 0.02–0.03 km^3/ky.

Acknowledgements

Many constructive comments and suggestions from Dr. M. Okuno of Fukuoka University, Dr. T. Oikawa of Geological survey of Japan, and the editor Dr. D. Miura of Central Research Institute of Electric Power Industry greatly helped to revise the manuscript. We are grateful to Dr. R. W. Jordan for correcting the English in this paper. This work was financially supported in part by Grant-i-Aid for Scientifice Research (no. 17540451) from the Japan Society for the Promotion of Science to M. Ban.

References

Chiba, T. (1961) Petrology of Zao volcano. *J. Japan. Assoc. Mineral. Petrol. Econ. Geol,* **46**, 74–81 (in Japanese with English abstract).

Fairbanks, R.G., Mortlock, R.A., Chiu, T.-C., Cao, L., Kaplan, A., Guilderson, T.P., Fairbanks, T.W., Bloom, A.L., Grootes, P.M. and Nadeau, M.-J. (2005) Radiocarbon calibration curve spanning 0 to 50,000 years BP based on paired ^{230}Th/^{234}U/^{238}U and ^{14}C dates on pristine corals. *Quarter. Sci. Rev.,* **24**, 1781–1796.

Hayakawa, Y. (1985) Pyroclastic geology of Towada volcano. *Bull. Earthq. Res. Inst.,* **60**, 507–592.

Hayakawa, Y. (1995) Characteristics of Japanese loess, and its eolian origin. *Bull. Volcanol. Soc. Japan.,* **40**, 177–190 (in Japanese with English abstract).

Hayakawa, Y. and Yui, M. (1989) Eruptive history of the Kusatsu Shirane volcano. *Quarter. Res.,* **28**, 1–17 (in Japanese with English abstract).

Imura, R. (1996) Products of Zao-Goshikidake. In *Inventory of Quaternary Outcrops-Tephras in Japan-* (Japan Association for Quaternary Research ed), 160, Japan Association for Quaternary Research, Tokyo, 352p (in Japanese).

Imura, R. (1999) Zao volcano. In *Field Guide of Volcanoes in Japan, 4, Volcanoes in Tohoku districts* (Takahashi, M. and Kobayashi, T. eds), 70–88, Tsukiji Press, Tokyo, 169 p (in Japanese).

Itagaki, N., Toyoshima, M. and Terado. T. (1981) The scoria bed of late Pleistocene in Sendai and its environs. *Tohoku Geography,* **31**, 48–53 (in Japanese).

Kitagawa, H., Masuzawa, T. and Matsumoto, E. (1993) A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon,* **35**, 295–300.

Machida, H. and Arai, F. (2003) **Atlas of Tephra in and Around Japan.** Univ. Tokyo Press, 336p (in Japanese).

Oba, Y. and Konda, T. (1989) Geology and petrology of central Zao volcano, Yamagata Prefecture. *Bull. Yamagata Univ.,* **12**, 199–210 (in Japanese with English abstract).

Okuno, M. (2001) Tephrochronology and radiocarbon chronology in Japan. *Quarter. Res.,* **40**, 461–470 (in Japanese with English abstract).

Okuno, M. (2002) Chronology of tephra layers in southern Kyushu, SW Japan, for the last 30,000 years. *Quarter. Res.,* **41**, 225–236 (in Japanese with English abstract).

Reimer, P.J., Billie, M.G.L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C.J.H, Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J. and Weyhenmeyer, C.E. (2004) IntCal 04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon,* **46**, 1029–1058.

Saigusa, M. and Shoji, S. (1984) Distribution and properties of Zao tephras, *Pedologist* 28, 14–25 (in Japanese with English abstract).

Sakayori, A. (1992) Geology and petrology of Zao volcano. *J. Mineral. Petrol. Econ. Geol,* **87**, 433–444 (in Japanese with English abstract).

Stuiver, M. and Reimer, P.J. (1993) Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon*, **35**, 215–230.

Takaoka, N., Konno, K., Oba, Y. and Konda, T. (1989) K-Ar dating of lavas from Zao volcano, north-eastern Japan. *J. Geol. Soc. Japan,* **95**, 157–170 (in Japanese with English abstract).

Thorarinsson, S. (1981) Tephra studies and tephrochronology: a historical review with special reference to Iceland. In *Tephra studies* (Self, S. and Sparks, R.S.J. eds), 1–12. D. Reidel Publ. Co., Dordrecht, Holland, 481p.

Van der Plicht, J., Beck, J.W., Bard, E., Billie, M.G.L., Blackwell, P.G., Buck, C.E., Friedrich, M., Guilderson, T.P., Hughen, K.A., Kromer, B., McCormac, F.G., Ramsey, C. Bronk, Reimer, P.J., Reimer, R.W., Remmele, S., Richards, D.A., Southon, J.R., Stuiver, M., and Weyhenmeyer, C.E. (2004) NotCal04 — comparison/calibration ^{14}C records 26–50 cal kyr BP. *Radiocarbon,* **46**, 1225–1238.

Yamamoto, T. (2005) Eruptive history of Azuma volcano, NE Japan, during last 7,000 years: stratigraphy and magma pluming system of the Azuma Jododaira products. *J. Geol. Soc. Japan,* **111**, 94–110 (in Japanese with English abstract).

Yamamoto, T. and Sakaguchi, K. (2000) Eruptive history of Adatara volcano, NE Japan, during last 250,000 years based on tephrostratigraphy. *J. Geol. Soc. Japan,* **106**, 865–882 (in Japanese with English abstract).

(Editiorial hundling Daisuke Miura)

蔵王火山，東麓に分布するテフラについて
—Za-To 1–4 の年代及び噴出量—

三浦光太郎・伴　雅雄・八木浩司

東北日本，蔵王火山東麓に分布する黒色スコリア質火山砂層（Za-To 1–4）について年代及び噴出量を推定した．Za-To 2–4 の年代はテフラ直下に見られる古土壌の放射性炭素年代から，暦年代で約 30.7 ka，27.1 ka，12.9 ka と推定され，Za-To 1 は上記年代値とロームの堆積速度を基に約 33–32 ka と見積もられた．Za-To 3–4 の年代はそれらの間のローム内に見られる十和田八戸テフラ（To-H, To-HP）の年代と調和的である．Za-To 1–4 の噴出量は約 3×10^{-2}，3×10^{-1}，1×10^{-1}，1×10^{-1} DRE km^3 と見積もられ，噴出率は Za-To 1–4 で約 0.02–0.03 km^3/ky, Za-To 1–3 で約 0.07–0.09 km^3/ky である．これらの噴出率は，近隣の活火山である安達太良火山や吾妻火山の最新期活動の噴出率と各々似た値を示す．

Jizo: 地蔵，Kumanodake: 熊野岳，Goshikidake: 五色岳，Kattadake: 刈田岳，Eboshidake: 烏帽子岳，Sugigamine: 杉ヶ峰，Byobudake: 屏風岳，Haraobi: 腹帯