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YPm-IV pumice bed in Northern Yatsugatake, Yatsugatake Volcanic Chain, central Japan

—Studies on Yatsugatake tephra Part 1—

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Abstract

The source of the YPm-IV air fall pumice bed is identified to be Yokodake Volcano, Northern Yatsugatake, central Japan. The pumice was erupted as a predecessor of either Y_3, Y_4 or Y_5 lava flow of Yokodake Volcano. The YPm-IV pumice bed is so far the only tephra, the source of which is reasonably accurately determined among many pumice beds of Yatsugatake Volcanic Chain. Based on the fission track age, 14,000 years B.P., of the YPm-IV bed, the latest activity of Yatsugatake Volcanic Chain is estimated to be Holocene, and the ages more than ten lava domes which form the western main alignment of Northern Yatsugatake to be late Late Pleistocene.

The stratigraphy (Table 1), volume (0.17 km^3), distribution (Fig. 5), and variation of thickness and grain size (Fig. 6) are described. Heavy mineral composition (wt%) of the YPm-IV pumice for 1/8–1/16 mm mineral fraction is as follows: hypersthene (46.7), augite (30.1), titanomagnetite (18.8) and hornblende (4.5). Refractive index of glass is 1.502_7. Curie temperature of the titanomagnetite is 403 °C.

Introduction

A characteristic air fall pumice bed is developed in the uppermost part of tephra on the NE foothills of Yatsugatake Volcanic Chain, central Japan. The pumice bed has been described as the pale orange-colored, large grain-sized pumice bed (IIJIMA *et al.*, 1968), YPm-IV (NAKAYA, 1971), Amaike Pumice (KAWACHI, 1974–75), or 'Dekapami' (COLLABORATIVE RESEARCH GROUP for YATSUGATAKE, 1976, 1977).

NAKAYA (1971) studied the stratigraphy, distribution, heavy mineral composition and thermomagnetic nature of iron ore mineral of the pumice bed. KAWACHI (1974–75) correlated the bed to the most recent lava dome activities around Yokodake Volcano, Northern Yatsugatake. More specifically, the bed was considered by him to immediately precede the Hatchodaira lava flow (Y_9 lava of this paper) which is the latest lava flow known in entire Yatsugatake Volcanic Chain. The COLLABORATIVE RESEARCH GROUP for YATSUGATAKE (1976, 1977) interpreted the eruptive source of the pumice to be the Lake Amaike "explosion crater", SE of Mt. Yokodake, Northern Yatsugatake, and reported a fission track age of 14,000 years B.P. from an obsidian fragment in the bed. However, one of the authors (S.K.) has found contradictory evidence at an outcrop recently exposed at the eastern flank of Mt. Yokodake where the bed is overlain by one of Yokodake lavas older than Y_9 lava. Thus the stratigraphic position of the pumice bed needs to be re-examined.

In this paper, the authors will describe the stratigraphy, distribution, volume, and petrography of the pumice bed, and will discuss the significance of its age to the development of Yatsugatake Volcanic Chain.

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(KAWACHI, 1974–75), with the aid of the Geological Survey of Japan. The authors would like to express their sincere gratitude to Profs. Kunio KOBAYASHI and Kan'ichi MOMOSE, Shinshu University, for their kindest encouragement throughout this study. Mr. Toshio FURUTA, University of Tokyo, supplied us with thermomagnetic data of the titanomagnetite, while Mr. Ryuji AOYAGI, Miyazaki Middle School, Kawasaki, analyzed the mineral. The authors are very grateful for these gentlemen. Mr. Shigeshi OTA and Miss Chiaki SATO of Hokkaido University deserve appreciation for their valuable assistance in drafting diagrams and typing.

Geological outline of Yokodake Volcano

The Geology of Yokodake Volcano was described in detail by KAWACHI (1974–75). The summary is given here.

Mt. Yokodake (2,472.5 m a.s.l.) is one of the several late stage lava domes in the northern part of the western alignment of Northern Yatsugatake, Yatsugatake Volcanic Chain (Fig. 1). It is underlain by various deposits ejected during the Younger Yatsugatake period. The dome has an oval plan, the longer diameter being 4 km from east to west, and the shorter 2 odd km from north to south at the base, while at the top the EW diameter being 1.5 km, and the NS 1 km. The flanking slope is steep and the relative height on the west is 670 m while being 470 m on the east. Eight small craters exist at the top of Mt. Yokodake (Fig. 2). A number of lava flows poured out from six "parasitic" craters which surround two "central" ones. Based on stratigraphic sequence and vegetation cover in the field and through aerial photographs, nine different lava flows, Y_1 to Y_9, can be identified, and their relative age, except the sequence of Y_3, Y_4 and Y_5, be assessed (Table 1). In the leftmost column of Table 1 are shown the development stages in the Younger Yatsugatake period (designated by II) for each group of lava activity (cf. KAWACHI, 1974–75). In the Table, stages II-1, II-3 and II-4 are not shown, because the first two are missing in the Northern Yatsugatake area and only a part of stage II-4 mater-

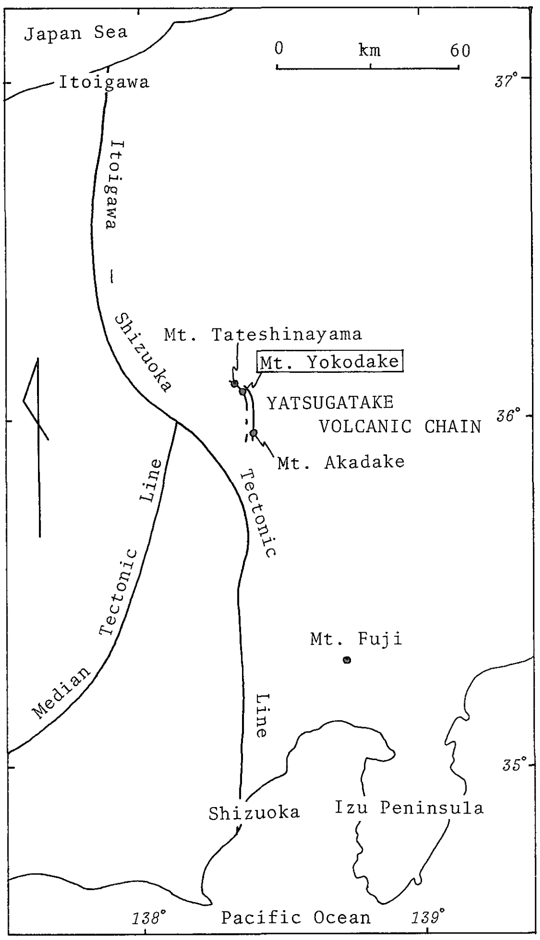


Fig. 1 Location of Yokodake Volcano, central Japan.

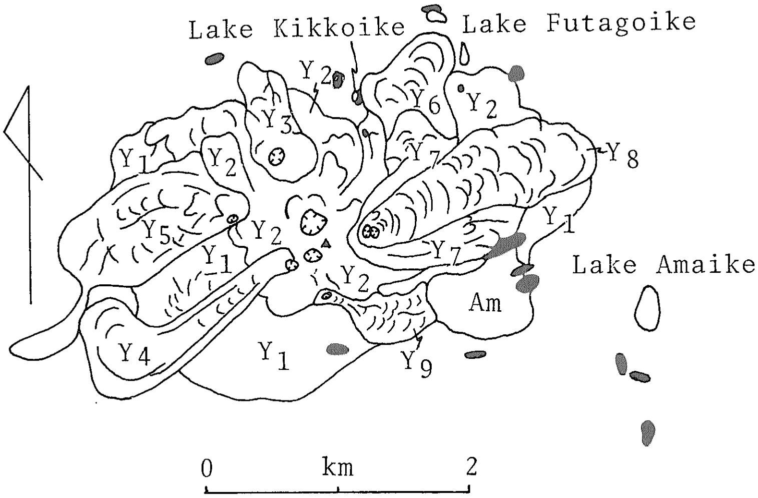


Fig. 2 Geologic map of Yokodake Volcano.

The areas with thick YPm-IV pumice bed are shown in black.
For abbreviation s see Table 1. (The small blank areas immediately above Y_9 and Am, Y_4 and Y_5 are alluvium)

Table 1 List of lavas of Yokodake Volcano and Amaikeyama Volcano.

	Lava** (symbol)	rock	crater***	area (km²)	volume (km³)	remarks
II-6*	Hatchodaira lava (Y_9)	(hor.)-hyp.-aug. andesite	+	0.2	0.00₃	Poorly vegetated
	Ōtake lava (Y_8)	(hor.)-aug.-hyp. andesite	++	0.8	0.03	Birth of Nanatsuike (seven depressions) on Y_8 lava
	Mittsudake lava (Y_7)	(hor.)-hyp.-aug. andesite	–	0.9 (0.5+0.4)****	0.04	
	Futagoike lava (Y_6)	(hor.)-aug.-hyp. andesite	–	0.8 (0.4+0.4)	0.03	Formation of Lakes Futagoike and Kikkoike
II-5	Apron lava (Y_5)	hor.-hyp.-aug. andesite	+	1.0	0.02	Secondary lava flows from the tip of primary flows
	Stocking lava (Y_4)	hor.-hyp.-aug. andesite	+	0.6	0.01	Eruption of YPm-IV Pumice predating one of them
	Point lava (Y_3)	aug.-hor.-hyp. andesite	+	0.3	0.01	(hor.)-aug.-hyp. andesite 440 km², 0.17 km³
	Central crater lava (Y_2)	hor.-hyp.-aug. andesite	++	1.7 (1.3+0.4)	0.26	Surface grooves well preserved on lavas younger than this
II-2	Basal lava (Y_1)	(hor.) dacitic obsidian-pitchstone / hor.-hyp.-aug. andesite	–	6.5 (1.5+5.0)	0.54	Basal unit of Yokodake Volcano / Birth of Lake Amaike
			total	12.8	0.94₃	
II-2	Amaikeyama lava (Am)	hor.-hyp.-aug. andesite	–	0.5	0.02	Lava dome with clear flow structure

*Stages of the Younger Yatsugatake period (KAWACHI, 1974–75).
**Relative length of the time interval is shown by broken, full and wavy lines in the order of increasing length.
***Plus sign: crater present (two pluses: two craters)/Minus sign: crater not present.
****In the parentheses is shown exposed area followed by estimated area which is not exposed.
hor.; hornblende hyp.; hypersthene aug.; augite

ials erupted from other centers is found between Y_1 and Y_2.

Each eruptive unit is described here in the ascending order. Refer to Table 1 for rock types. All the lavas contain abundant autoliths.

Y_1: This forms the basal unit of Yokodake Volcano and consists mainly of lavas. The acid nature of some rocks belonging to Y_1 contrasts with the intermediate nature of later rocks. The highest exposed point is 2,340 m a.s.l. while the lowest is 1,860 m. Y_1 is distributed in an area of 3.5 km (EW) by 2 odd km (NS). Lithologically Y_1 is correlated with stage II-2 when rhyolites and hornblende andesites of the Younger Yatsugatake period were active. A considerable interval of time is suspected between Y_1 and Y_2 activities. Amaikeyama lava (Am), which occurs on the SE side of Yokodake Volcano, but does not belong to it, is believed to have been active during this interval.

Y_2: Yokodake Volcano, as we see it today is basically defined by this lava. The trigonometrical point on its summit is located on this lava. Two circular extinct craters, one, 100 m across with a depth of 50 m, and the other, 150 m across and 30 m deep, occur near the summit. A clear time interval exists between the activities of Y_2 and Y_3.

Y_3: This is a northward lava flow from a small crater 75 m across (2,350 m a.s.l.), 750 m NE of the trigonometrical point. Surface grooves are well preserved.

Y_4: This is a westward lava flow from a small crater 100 m across (2,400 m a.s.l.), 300 m west of the trigonometrical point. It is stocking shaped in plan. Surface grooves are well preserved.

Y_5: A lava flow from a small crater 75 m across (2,330 m a.s.l.), 750 m NE of the trigonometrical point covers a large area of the steep west slope of Yokodake Volcano like an apron. Surface grooves are well preserved.

Y_6: This is a lava flow underlying lavas Y_7 and Y_8. The source crater is not exactly identified, though supposed to be around Y_8 crater. Surface grooves are well preserved. Lake Futagoike (Futago stands for a twin) had originally been a single lake formed in a depression between two adjacent domes, which was subsequently divided into two by this lava. Lake Kikkoike (Kikko means a turtle's back) likewise formed between adjacent domes, was partially buried under this lava. Polygonal ground 1.5 m across (hence the name) is developed on the shallow floor of the lake.

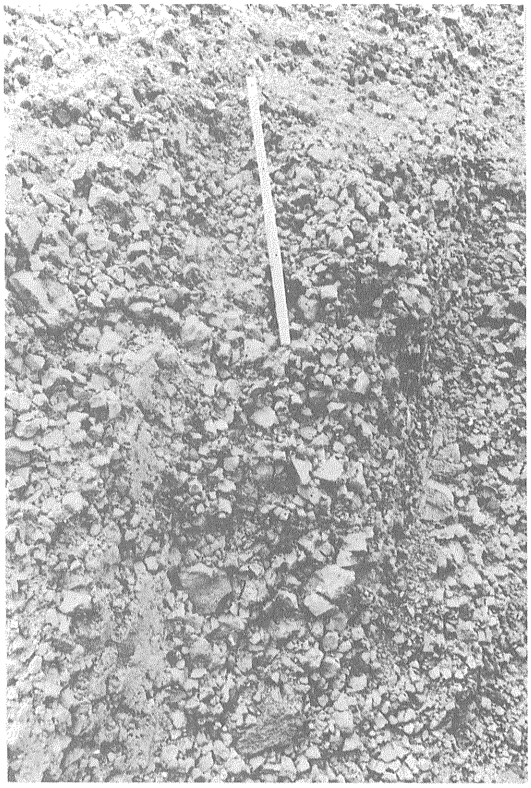
Y_7: Eruptive center, which seems identical to one of the two craters for Y_8, is located 350 m east of the trigonometrical point. Y_7 partially covers Y_6 on the north. Y_7 in turn is mostly covered by Y_8. Surface grooves are well preserved.

Y_8: Y_8 lava erupted from the two craters of the Nanatsuike (seven depressions) region, immediately east of the trigonometrical point. One crater is circular and 70 m across, while the other is elongated and 40 m by 60 m in a NS direction. The lava flowed to ENE and cascaded down a steep slope at the head of a valley dissecting the Older Yatsugatake period materials. Well-defined surface grooves are visible.

Y_9: This has been erupted from a small crater 30 m across (2,315 m a.s.l.), located 350 m due south of the trigonometrical point, and has reached the west foot (2,240 m a.s.l.) of Mt. Amaike-yama. Although it is covered by creeping pines (*Pinus pumila*) the diameters of the trunks of which are up to 13 cm, the vegetation is sparsely developed compared to other lava flows of Yokodake Volcano. Surface grooves and the rock are very fresh. There is no doubt that the

3-a Eastern slope of Yokodake Volcano. The outcrop where the YPm-IV pumice was found overlying the Amaike lava and being overlain by Y_7 lava is positioned in the landslide at center right.

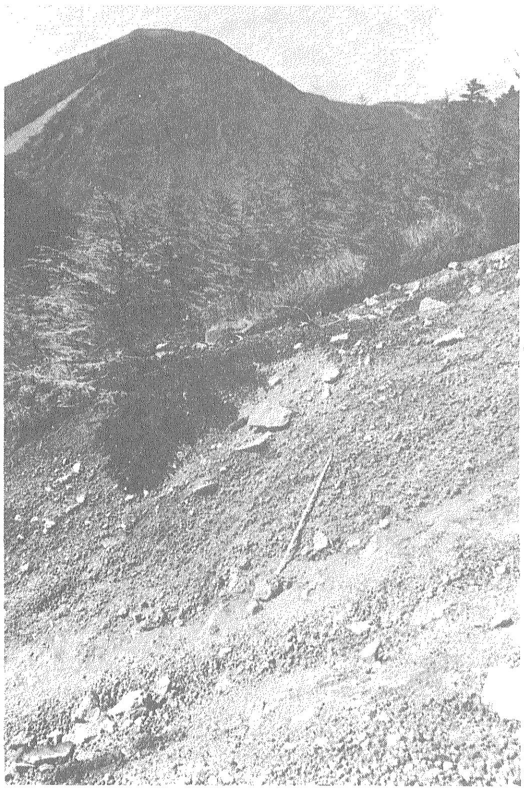
3-b A view of the outcrop shown in 3-a.



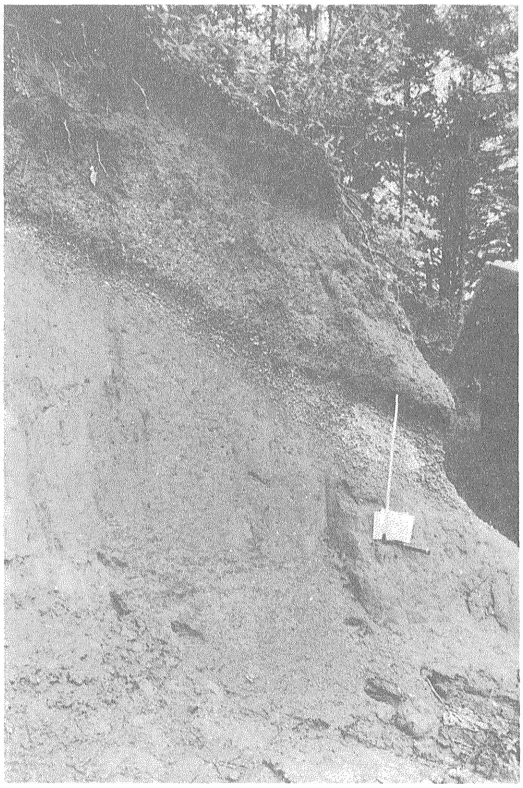
3-c A close-up view of the YPm-IV bed in the outcrop shown in 3-b.

Fig. 3 Mode of occurrence of the YPm-IV pumice bed.

3-d YPm-IV pumice bed at the type locality (YG-I).



3-e YPm-IV pumice bed in an outcrop 200 m NW of Lake Kikkoike. Fig.3 (to be continued)



3-f YPm-IV pumice bed in an outcrop near Kōmihara (5.5 km east of Lake Matsubarako).

lava represents the latest volcanic activities of entire Yatsugatake Volcanic Chain.

Stratigraphic position of the YPm-IV pumice bed

In Fig. 2 are shown the areas where the YPm-IV is well preserved. The relation between the Yokodake lava sequence and the pumice bed is directly observed in an outcrop on the eastern side of Yokodake Volcano (Fig. 3: 3-a,3-b and 3c). Here the pumice bed overlies Amaikeyama dome II-2; cf. Table 1), and is overlain by Y_7. The bed lava (Am; Stage consists of one air fall unit.

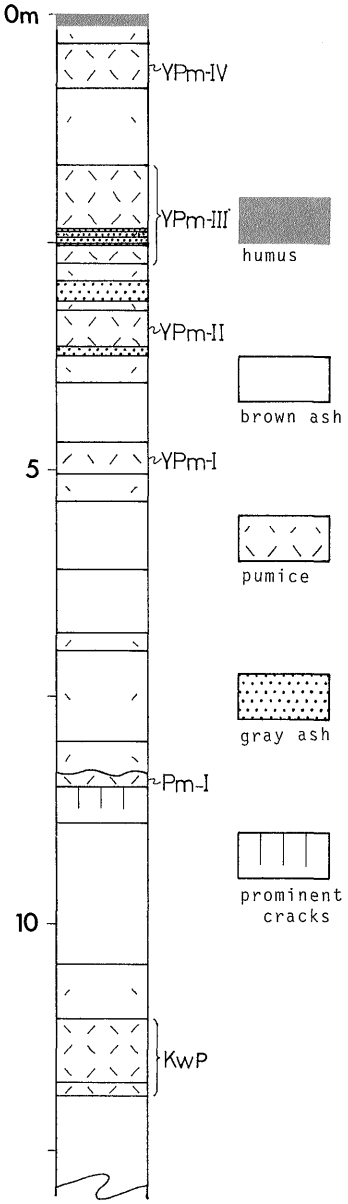


Fig. 4 Cross section of tephra at the type locality (YG-I) of the YPm-IV pumice bed.

On a mountain track south of Lake Kikkoike, scattered pumice belonging to YPm-IV occurs on Y_2 lava. No YPm-IV pumice has been observed on Y_3, Y_4, Y_5 and Y_6 lavas.

Based on an observation of Y_3 lava on an exceptionally good exposure caused by landslide, it is certain that Y_3 is neither intercalated nor covered by the YPm-IV bed. On the other hand, at a locality (Fig. 3: 3-e) 200 m NW of Lake Kikkoike which is not far away from the Y_3 distribution, YPm-IV, 150 cmthick, with maximum grain size of pumice of 25 cm can be observed. Meanwhile at another locality 500 m S of Y_9 crater, YPm-IV overlying Y_1 is 120 odd cm thick with a maximum grain size of 15 cm.

A columnar section at the type locality of the YPm-IV 13 km ESE of Yokodake Volcano is shown in Fig. 4 (YG-I of NAKAYA, 1971; cf. Fig. 5 for the location). Here the YPm-IV is 50 cm thick and covered by 20 cm of ash with some pumice. Below YPm-IV are YPm-I, II and III, KwP (NAKAYA, 1971) and Pm-I. All the tephra but Pm-I have their origins in Yatsugatake Volcanic Chain. Pm-I is originated from Mt. Ontake far to the west of Yatsugatake Volcanic Chain (KOBAYASHI *et al.*, 1968), and has been dated to be 73,000 ± 4,000 to 95,000 ± 5,000 years B. P. (fission track age on zircon; MACHIDA and SUZUKI, 1971).

It is known that pumice fall tends to antedate lava flow in an eruptive cycle. If so, YPm-IV can be a predecessor of either Y_3, Y_4, or Y_5. Opinion of the authors is that the YPm-IV preceded Y_3. Further studies, however, are necessary.

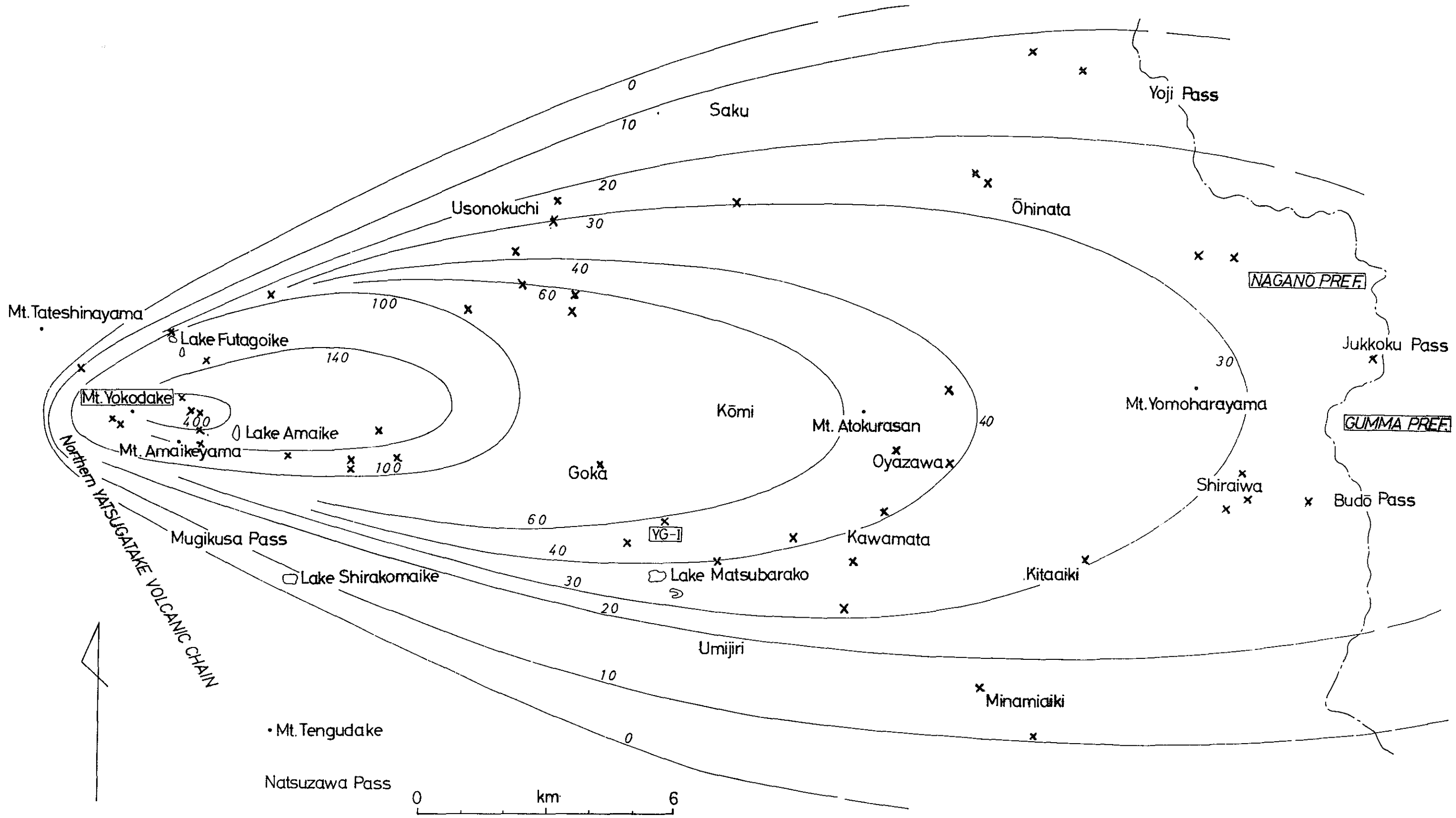


Fig. 5 Distribution of the YPm-IV pumice bed (thickness in cm). Crosses show the observed points.

Mode of occurrence and distribution of YPm-IV

In an outcrop shown in Fig. 3:3-a and 3-b, a the YPm-IV bed, 4 m thick, is found to rest on a 30 degree slope covered by Y_7 lava. Here the grain sizes of pumice and obsidian fragments are 25 cm (max.), 5 to 6 cm (average), and 13 cm (max.), 2 to 3 cm (average), respectively. The obsidian-pumice ratio is 1: 40. Grains of the upper part of the pumice bed is finer than the rest of the bed. Crude stratification is also present. Individual pumice particles tend to show rounded outline, suggesting some secondary depositional process for this part of the bed.

On the other hand, in all the other outcrops, including type locality, YG-I, where the depositional slope is gentle to flat (Fig. 3: 3-d, 3-e, and 3-f), stratification has never been recognized. Vertical sorting of grain size is nowhere to be observed. Therefore, it can be concluded that the observeds econdary deposition is exceptional, and that the YPm-IV is a single air-fall unit.

An isopach map (Fig. 5) and a diagram showing the variation in grain size of pumice and obsidian fragments with the distance from the source (Fig. 6) for the YPm-IV are given. Apart from a 100 cm isopach which shows a little bulge to the north, the distribution pattern is symmetrical with respect to the EW axis. The distribution reaches far to the east of the Jukkoku Pass located on the boundary dividing the Nagano and Gumma prefectures. The widest distribution in a NS direction is located between northern Saku and southern Minamiaiki. It is thickest at the eastern foot of Mt. Yokodake (4 m).

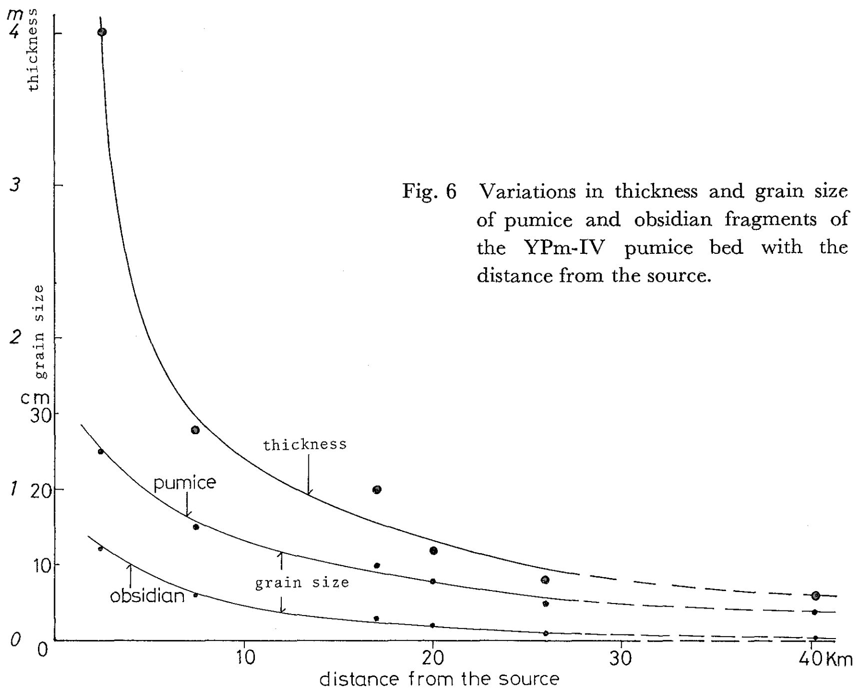


Fig. 6 Variations in thickness and grain size of pumice and obsidian fragments of the YPm-IV pumice bed with the distance from the source.

Petrography

The pumice of the YPm-IV pumice bed is pale orange to reddish brown in color, and well vesiculated showing fibrous appearance. Other characteristics include: apparent specific gravity, 0.43 g/ml; heavy mineral composition (wt%) for 1/8–1/16 mm fraction, hypersthene (46.7), augite (30.1), titanomagnetite (18.8) and amphibole (4.5); H/T ratio[1], 30.9; refractive index of glass of the pumice and obsidian, 1.515_4 and 1.502_7, respectively. The values correspond to the range for rhyolites with over 66% SiO_2 (KITTLEMAN, 1963).

Thermomagnetic, X-ray, and chemical analyses of titanomagnetite in 1/4–1/8 mm fractions obtained from the pumice are given in Table 2. Curie temperature (Tc) for the original sample is 403 °C and does not vary with the localities of the sample[2].

J-T curve is the Q type and the down-shift irreversible change (OZIMA and LARSON, 1967) is not recognized (Fig. 7). The lattice constant is 8.406 Å, and ilmenohematite and titanomaghemite are not detected by X-ray diffraction. TiO_2 content of 10.16 % is rather low. These data are not contradictory with the rather high Tc of 403 °C. Tc of the annealed sample decreases from the original

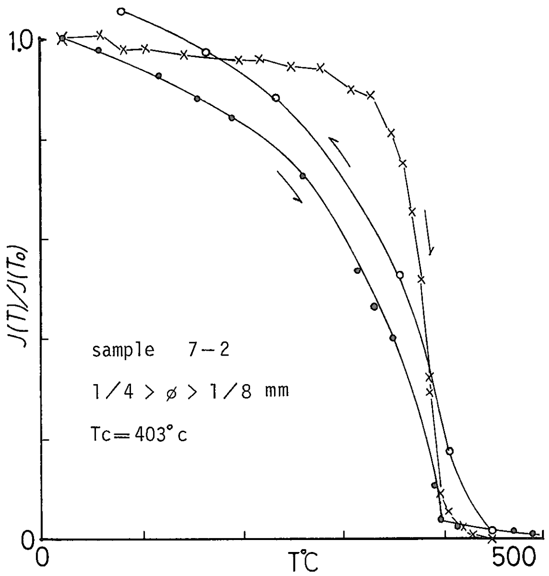


Fig. 7 J-T curves of the YPm-IV pumice from the type locality (YG-I).
One set of curves shown in the open and solid circles is obtained at Hex = 2,500 Oe, whereas the other shown in crosses (heating only) at Hex ca. 300 Oe.

Table 2 Nature of titanomagnetite.

	thermomagnetic analysis		X-ray analysis	chemical composition (mol%)[2]			atomic ratio	
	Tc(℃)	type of curve	lattice constant (±0.002 Å)	FeO	Fe_2O_3	TiO_2	$\frac{32(Fe+Ti)}{O}$	$\frac{Fe}{Fe+Ti}$
original	403	Q type, 1 phase	8.406	51.40	32.20	10.16	23.69	0.927
annealed[1]	380	Q type, 1 phase	8.409	——			——	
	385	Q type, 1 phase	——	54.21	35.08	10.71	23.90	0.921

1) Vacuum sealed in pyrex tubes (10 mmHg), and heated at 650–750 °C for 2.5–4.0 hours.
2) Analyst: Ryuji Aoyagi.

1) H/T = wt% of all heavy minerals/(wt% of all minerals and glass).
2) FUJIWARA *et al.* (1977) stated that Tc tends to increase toward upper tephra horizon within "one volcanic unit" which corresponds to the tephra at the bottom of Fig. 4 of this paper to the one just below Pm-I, or from YPm-I to YPm-IV. However, it is not clear what the "one volcanic unit" signifies with respect to the source or sources of the tephra, as the source(s) has not been known at all except for YPm-IV, and since there are many possible sources scattered over 10 km in a NS direction within Yatsugatake Volcanic Chain.

Tc by 23 °C. Various Tc values are obtained after annealing fractions of the same sample in different pyrex tubes. After annealing, the lattice constant does not vary, but FeO increases while Fe_2O_3 decreases suggesting that the decrease of Tc is due to reduction during annealing (NAKAYA, 1971), and not to the change related to the low temperature oxidation following deposition, such as the formation of titanomaghemite, which further transforms itself into α-Fe_2O_3 along grains and cracks.

It seems unlikely for the titanomagnetite to have experienced high temperature oxidation. Thus the measured Tc is understood to be original. However, the coarse-grained (1/2–1/4 mm) fraction tends to show lower Tc (395 °C) than the fine-grained (1/8–1/16 mm; 403 °C). The significance of the above observation is not fully understood.

Discussion

The YPm-IV pumice bed is the only air fall deposit with its source reasonably accurately deter mined in Yatsugatake Volcanic Chain. However, no carbon specimen suitable for radiocarbon dating has been obtained from the YPm-IV bed. According to the observation by one of the authors (S.N.) in Gumma Prefecture, the YPm-IV bed occurs in a horizon slightly lower than that of the pumice fall deposit (YP of ARAI, 1962) which accompanies the dated Second Pumice Flow of Asama Volcano (ARAMAKI, 1963; Two ^{14}C ages, 10,650 $\pm$ 250 and 11,300 $\pm$ 400 years B.P., are given in KOBAYASHI, 1964). The fission track age of 14,000 years B.P. for YPm-IV does not contradict these data.

Based on these known ages mentioned above, the volcanic activities of the Younger Yatsugatake period are discussed below.

Stage II-2 of the Younger Yatsugatake period is characterized by the activities of acid rocks such as rhyolites accompanied with dacitic obsidian and hornblende andesite. Fission track ages are determined to be 98,000 to 130,000 years B.P. (KAWACHI, 1974–75). Grooves have not been observed on the surface of lava flows of this stage even in the best aerial photos.

Generally speaking, preservation of the surface grooves of a lava depends very much on latitude, height, and above all, climatic conditions. However, in a group of volcanoes such as Yatsugatake Volcanic Chain, the degree of preservation of surface grooves can as a reliable guide to estimate the relative age of each lava flow. Surface grooves are preserved on lava flows of stage II-3 (Mineno-matsume, Minotonakayama, and Amigasayama lava flows, all located in Southern Yatsugatake), stage II-4 (Shimagareyama, Chausuyama, Maruyama, Nakayama, and a part of Tengudake lava flows, all located in Northern Yatsugatake), and stage II-5 (Tateshinayama, Yokodake Y_3, Y_4 and Y_5 lava flows) (for stages see KAWACHI, 1972, 1974–75, 1977). The distinction of stages II-3 and 4 is more on the basis of their restricted geographic distribution rather than their actual stratigraphic positions. Currently, stage II-3 and 4 are thought to be contemporaneous. A pyroclastic flow deposit related to stage II-4 activities overlies the Pm-I pumice bed on the NW foothills of Yatsugatake Volcanic Chain (KAWACHI *et al.*, 1967). Therefore, well-preserved surface grooves represent flows later than the late Late Pleistocene (Würm glaciation and after). Lava Y_9 is tentatively estimated to be Holocene in age, and Y_6, Y_7, and Y_8 lavas, to be uppermost Pleistocene to early Holocene.

Magnetic orientations of the Yokodake lavas, Y_2 to Y_9, are being investigated, and a reversed magnetic orientation which may correspond to the Laschamp excursion of Brunhes normal epoch

(BONHOMMET and BABKINE, 1967) is found.

Compared with the 1783 eruption of nearby Asama Volcano which is also an andesitic volcano (ARAMAKI, 1963), the total volume of air fall pumice is the same order of magnitude while that of the related lava flows, Y_3, Y_4, and Y_5 in Yokodake Volcano is much smaller than that of Asama Volcano. Also in Yokodake Volcano, the YPm-IV bed consists of only one single fall unit, and is not accompanied with a pyroclastic flow.

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Amaike	雨　池	Minenomatsume	峯の松目
Amigasayama	編笠山	Minotonakayama	美濃戸中山
Chausuyama	茶臼山	Nakayama	中　山
Futagoike	双子池	Saku	佐　久
Kikkkoike	亀甲池	Shimagareyama	縞枯山
Koumi	小　海	Shirakomaike	白駒池
Koumihara	小海原	Tateshinayama	蓼科山
Maruyama	丸　山	Tengudake	天狗岳
Matsubarako	松原湖	Yokodake	横　岳
Minamiaiki	南相木		

北八ガ岳火山群 YPm-IV 軽石層

——八ガ岳テフラの研究　1——

河内晋平・中谷　進・村木紘二

八ガ岳山麓に発達するテフラの最上部を占める顕著な軽石層 —YPm-IV 軽石層— について，供給源が北八ガ岳火山群横岳であること，層位が Y_3–Y_5 溶岩のいずれかの直前であること，および容積 (0.17 km^3) と分布 (Fig. 5) を明らかにした．この軽石層は今日までのところ，八ガ岳において供給源をかなりの精度で特定できた唯一のものである．

この軽石層の 1.4 万年前というフィッション・トラック年代から推して，八ガ岳最新期の活動は完新世，八ガ岳西列の主稜を構成する10コ以上の溶岩丘群は更新世後期後半に形成されたと考えられる．

YPm-IV 軽石の 1/8–1/16 mm 粒度での重鉱物組成 (wt%) は紫蘇輝石 (46.7)・普通輝石 (30.1)・チタノマグネタイト (18.8)・角閃石 (4.5) で，H/T 比〔重鉱物全重量/(全鉱物重量＋ガラス重量)〕は 30.9である．また軽石および黒曜岩片のガラスの屈折率は，それぞれ1.515_4・1.502_7 である．その他チタノマグネタイトの TiO_2 量 (10.16 mol%)・格子定数 (8.406 Å) およびその熱磁気曲線が "Q型" 1相であることなどをのべた．

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