Bull. Volcanol. Soc. Japan, Ser. 2
Vol. 35 (1990) No. 2, pp. 111-129

ARTICLE

The 1988-1989 Explosive Eruption of Tokachi-dake, Central Hokkaido, Its Sequence and Mode

Yoshio KATSUI, Shimpei KAWACHI*, Yuko KONDO**, Yasuo IKEDA*, Mitsuhiro NAKAGAWA*, Yoshihiko GOTOH*, Hiromitsu YAMAGISHI***, Tetsuyoshi YAMAZAKI**** and Mari SUMITA*****

(Received December 30, 1989; Accepted March 10, 1990)

On December 16, 1988, after 26 years of dormancy since the last eruption in 1962, Tokachi-dake began to erupt from the 62-II crater. The eruption started with phreatic explosions. Then, on December 19, the activity changed into phreatomagmatic explosions of Vulcanian type and continued intermittently until March 5, 1989. Although the composition of the essential ejecta, mafic andesite, is similar to those of 1926 and 1962 eruptions, the mode of the present eruption is considerably different. The present eruption consists of a series of 23 discrete cannon-like explosions, being frequently accompanied with small-scale pyroclastic surges and flows. The total volume of ejecta amounts to approximately $6\times10^5m^3$, of which about 20% is essential ejecta. A complete sequence of events was compiled and distribution maps of the ash-fall, ballistic blocks, and pyroclastic surges and flows were drawn for each of the larger eruptions.

The pyroclastic surges and flows of the present eruption were small scale, low temperature pyroclastic flows, rich in accessory clasts and unaccompanied by sector collapse. Therefore, the sudden melting of snow causing disastrous mudflows, as in the case of the 1926 eruption, fortunately did not occur.

1. Introduction

On December 16, 1988, after being dormant for 26 years since the last eruption in 1962, Tokachi-dake Volcano (43°25′ N, 142°41′ E) in central Hokkaido began to erupt near its summit from the 62-II crater. This was followed by more than 20 intermittent eruptions until March 5, 1989. The eruptions were characteristically explosive, regardless of the small amount of ejecta, and were frequently accompanied by pyroclastic surges and samll-scale pyroclastic flows.

Fortunately, no one was killed or injured by the present activity, although evacuation from potential mudflow disasters seriously disrupted the community at the foot of the mountain until the spring of 1989 (KATSUI, 1989).

This report describes a brief history of Tokachi-dake, the sequence of the present eruption, the

* Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, Kita-ku, Sapporo, 060 Japan.
** Obihiro University of Agriculture and Veterinary Medicine, Inada-cho, Obihiro, 080 Japan.
*** Geological Survey of Hokkaido, Sapporo, 060 Japan.
**** The Fourth High-school of Tokai University, Minami-no-Sawa, Minami-ku Sapporo, 064-21 Japan.
***** Department of Applied Earth Sciences, Nihon University, 3-25-40 Sakura-jousui, Setagaya-ku, Tokyo, 156 Japan.

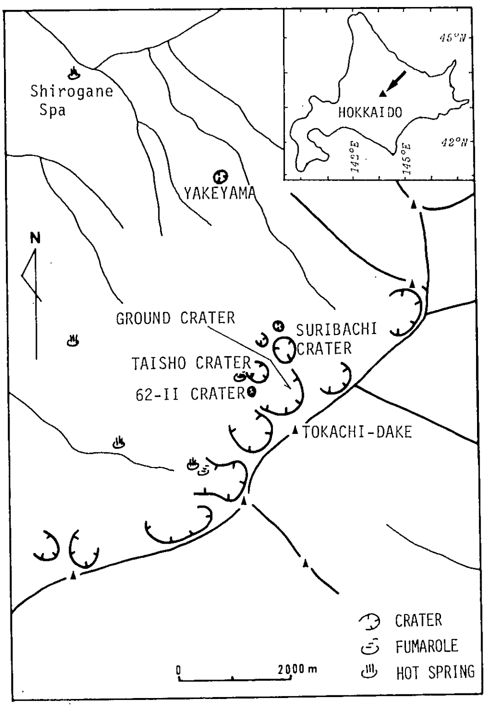

Fig. 1 Map showing craters, fumaroles and hot springs in Tokachi-dake Volcano.

distribution and nature of the ejecta, and the character of the present activity. The petrology of the ejecta and geophysical and geochemical studies of the present eruption have also been carried out by a number of staff of universities and institutes, the results of which are reported elsewhere in this journal.

2. Brief History of Tokachi-dake Volcano

Tokachi-dake Volcano is situated at the SW end of the NE–SW trending Daisetsu–Tokachi volcanic chain in the central highlands of Hokkaido. The volcano is built on a wide plateau of late Pliocene to early Pleistocene felsic pyroclastic flow deposits (IKEDA and MUKOYAMA, 1983), and consists of many volcanic cones and a few lava domes of basalt and andesite (KATSUI *et al.*, 1963a; TAKAHASHI, 1965; ISHIKAWA *et al.*, 1971).

As shown in Figs. 1 and 2, the volcanic edifices of Tokachi-dake are arranged mainly in a direction of NE–SW, and are divided into three groups; the Older, Middle and Younger Tokachi-dake Volcano Groups. The Holocene eruption centers of the Younger Tokachi-dake Volcano Group, together with fumaroles and hot springs, are located on the NW side of the main trend of volcanoes. Such structural features of Tokachi-dake Volcano may be interpreted in relation to the presence of a concealed cauldron which is similar to the major volcano-tectonic depression described by WILLIAMS (1941) (TAKAHASHI, 1965). It is evident that the volcanism of Tokachi-dake has taken place within this concealed cauldron, especially near the NE border (KATSUI *et al.*, 1963a).

The products of the Younger Tokachi-dake Volcano Group are composed mostly of mafic andesite. Accordingly, eruptions of scoria with or without lava flows are the most common manifestation throughout this period. However, occurrence of pyroclastic flows (scoria and banded-pumice flows) and sector collapse of the volcanic edifice is rarely known, as evidenced by the pre-historic eruption in ca. 240 B.C. and the 1926 eruption, respectively (ISHIKAWA *et al.*, 1971; TADA and TSUYA, 1927).

As shown in Table 1, the records of historic eruptions of Tokachi-dake only cover a short period since 1857, although it is known that an aa lava erupted from the central cone (Maruyama) in ca. 1670, as indicated by a radiocarbon date (ISHIKAWA *et al.*, 1971). All of the historic eruptions occurred from the central cone and in the vicinity of Ground Crater (Fig. 2). The regular repetition of historic eruptions of Tokachi-dake, at an interval of 30–40 years, attracts our attention in regard to the prediction of eruption in the near future (ISHIKAWA *et al.*, 1971; KATSUI *et al.*, 1987). The present eruption occurred after an interval of 26 years.

The essential products erupted during historic times are mafic andesite, however, the types of

Table 1. Volcanic eruptions of Tokachi-dake in historic times
(date from TADA and TSUYA, 1927; KATSUI *et al.*, 1963; ISHIKAWA *et al.*, 1971).

Year	Events
ca. 240 B.C.*	A pyroclastic flow occurred and reached Shirogane Spa, 6 km NW of the crater.
ca. 1670 A.D.*	A lava flow descended to Bogaku-dai, 3 km NW of the central cone (Maruyama).
1857	An eruption column issued, possibly from the central cone.
ca. 1887	Eruption columns and ash-falls.
1926	Since 3 years ago, solfataric activity notably increased and minor ash-ejection occurred accompanied with tremors and rumbling. On May 24, 1926, at 1211, the first explosion occurred and caused mudflow by snow melting. The mudflow destroyed an inn at the place of Shirogane Spa. The second explosion occurred at 1618 and the NW sector of the central cone collapsed, producing a hot volcanic avalanche (ca. 4×10^6 m^3). The avalanche produced disastrous mudflow by snow melting, which reached Kamifurano village, 25 km NW of the crater, with an average velosity of 60 km/h. The avalanche and mudflow killed 144 persons and destroyed 5080 houses. Intermittent small eruptions occurred until Dec. 1928.
1962	Solfataric activity increased from about 1952. The first eruption (phreatic explosion) occurred on June 29. Five sulfur-mine workers were killed by ballistic blocks. About 3 hours later, the second eruption (magmatic) started. The eruption column reached 12,000 m above the crater, and ash fell toward the E. The strong eruption continued for about 11 hours, then the activity declined and lasted until July 5. Weak eruptions intermittently occurred through to the end of July. A row of new craters (62-0∼III craters) formed along the SW rim of Ground Crater. The total volume of ejecta amounted to $7.1\times10^7 m^3$.

* No historic record but radiocarbon date.

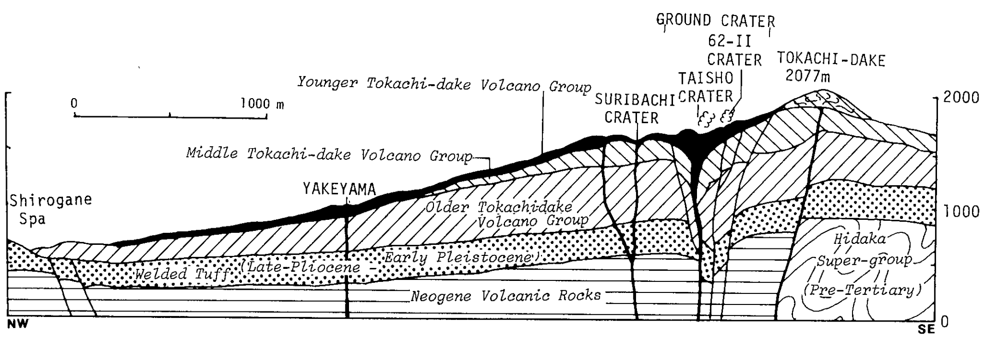

Fig. 2 NW–SE cross-section of Tokachi-dake Volcano (simplified from KATSUI *et al.*, 1963a).

eruption were not the same. Phreatic explosions occasionally occurred in an early phase of activity resulting in disasters as evidenced in the 1926 and 1962 eruptions. In the activity of May 1926, a strong phreatic explosion preceded the magmatic eruptions of mafic andesite and caused a sector collapse of the NW part of the central cone, producing a hot volcanic avalanche which destroyed a sulfur mine and triggered a disastrous mudflow by snow melting. The mudflow, traveling 25 km from the crater with an average velocity of 60 km/h, devastated primeval forest on the foot of the mountain and destroyed an inn at the present Shirogane Spa and two villages of Kamifurano and

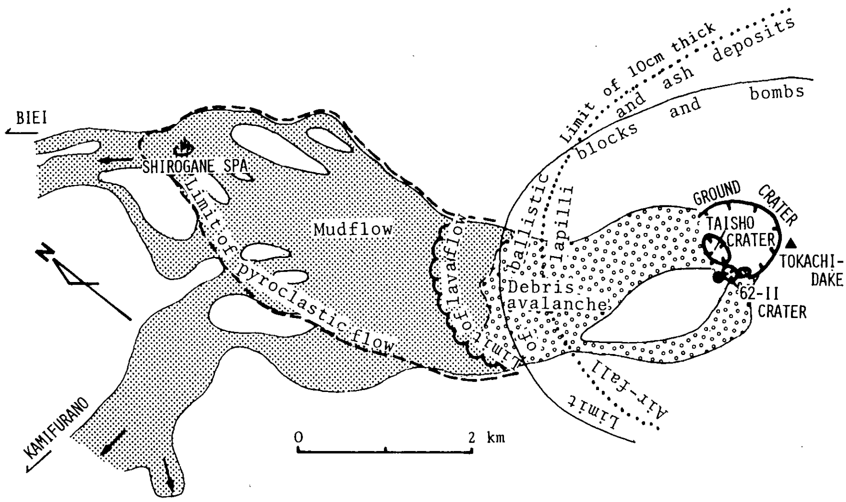

Fig. 3 Hazard map of Tokachi-dake Volcano (part of the colored map issued from Biei Town Office, 1988). Hazard zoning made by the senior author (Y.K.).

Biei. The avalanche and mudflow killed 144 persons (TADA and TSUYA, 1927; ISHIKAWA *et al.*, 1971).

The 1962 activity resulted in a large-scale scoria eruption. However, it was also preceded by a phreatic explosion, the ballistic blocks killing 5 workers of a sulfur mine near the crater (KATSUI *et al.*, 1963b).

3. Sequence of the 1988–1989 Eruption

3–1 Activity prior to the eruption

After the 1962 eruption, earthquake swarms occurred from 1968 to 1969 at Tokachi-dake. This event was possibly caused by shallow intrusion of magma, however no eruption occurred. YOKOYAMA (1985) interpreted this as a "stillborn" eruption.

Then, prior to the present eruption, the following anomalous phenomena were observed: 1) renewal of fumarolic activity at the 62-I crater in 1974, 2) increase in seismicity in 1983, and 3) mud eruptions followed by minor ash emissions and spontaneous combustion of sulfur at the 62-I crater in 1985 (KATSUI *et al.*, 1987). These phenomena are similar to those preceding both the 1926 and 1962 eruptions of Tokachi-dake (ISHIKAWA *et al.*, 1971).

In November 1985, it was reported that about 25000 people were killed by a large mudflow from Nevado del Ruiz Volcano in Colombia. This large mudflow was triggered by melting of an icecap by a pyroclastic flow (KATSUI, 1986). The news of this event made a significant impact on the community of Kamifurano and Biei on the western flank of Tokachi-dake, because both towns have been severely destroyed by the 1926 mudflow, as mentioned above. Thereafter, both towns introduced various measures for the preventation of volcanic disasters. Hazard maps for evacuation were prepared and circulated to every home before the present eruption (Fig. 3).

In the late summer of 1985, the activity of the 62-I crater slightly declined. However, in late September 1988, the seismicity at Tokachi-dake slightly increased. Then, the daily frequency of

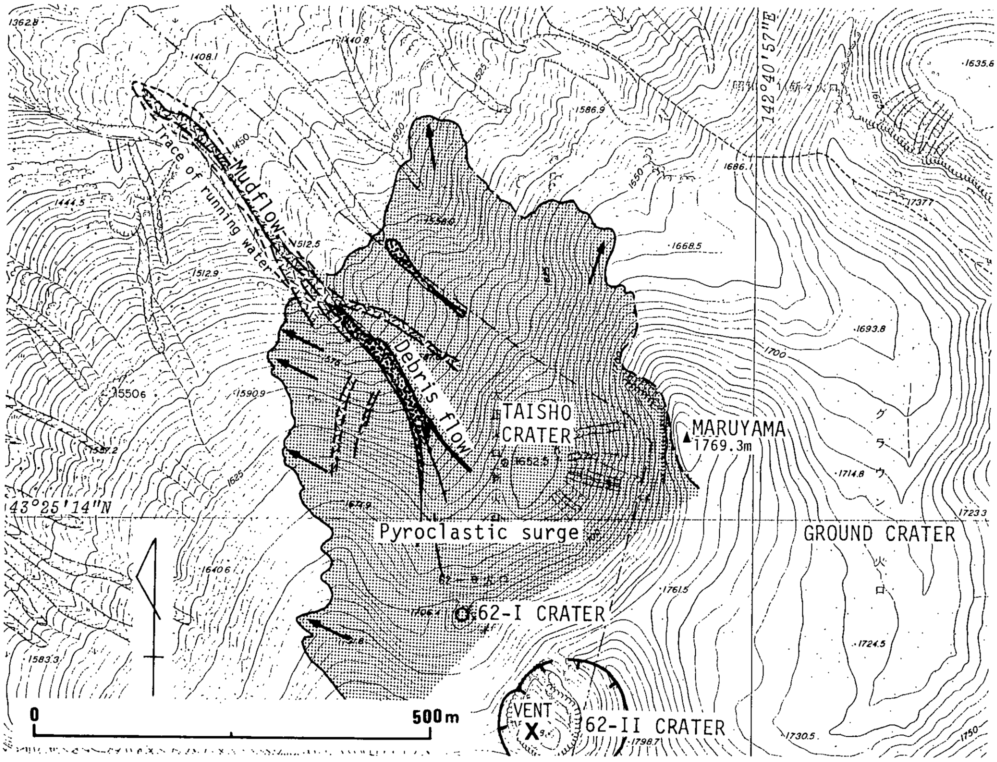

Fig. 4 Distribution of the pyroclastic surge deposit of December 19, 1988. Arrow shows flow direction of the surge. A small-scale mudflow and debris flow occurred by snow melting. The summit area was not visible. Fig. 4 to10 were drawn on the base map of the volcano (scale 1 : 5,000) issued from the Geographical Survey of Japan.

earthquakes increased toward the middle of December 1988, when the present eruption commenced (OKADA *et al.*, 1990). Prior to the first moderate explosion on December 16, snow, darkened by ash, was noticed near the 62-II crater on December 5 and 13. Personnel of the Tokachi-dake Observatory of Japan Meteorological Agency (JMA), 6 km NW of the crater, observed a gray to dark gray plume emitting from the crater in the afternoon of December 13.

3–2 Sequence of the Eruption

The sequence of the 1988–1989 eruption was compiled on the basis of our observations together with those of the JMA and Usu Volcano Observatory of Hokkaido University (UVO). Information, photos and video images provided by news media, Biei and Kamifurano Town Offices, Self Defence Force of Japan, and others were also referred to. The results are presented in Table 2.

The eruption occurred in the winter from mid-December 1988 to early March 1989. Snowfalls frequently prevented close observation of the summit area. However, there was a merit in that each of the explosions , the distribution of new ejecta was well observed on the surface of new snow which concealed the ejecta of preceding explosions. Figs. 4 to 10 show the distribution of new ejecta of the relatively large eruptions.

The present eruption started with a moderate phreatic explosion from the 62-II crater on

Table. 2 Sequence of the 1988–1989 eruption of Tokachi-dake.

No.	Date	Time*[1]	Scale*[2]	Remarks
1988				
1)	Dec. 16	0524	M	Phreatic explosion occurred from 62-II Crater. Ash fell toward the SE (Ash-fall A in Fig. 13).
2)	Dec. 18	0838	M	Phreatic explosion. Ash-fall B toward the ESE.
3)	Dec. 19	2147*[3]	L	Phreatomagmatic explosion. An air-shock was felt. A red-hot eruption column was observed above the crater. A pyroclastic surge caused a small-scale mudflow and a debris flow by snow melting. The mudflow reached about 1,400 m a. s. l. (Fig. 4). Ash fell up to Abashiri city, 150 km ENE of the volcano (Ash-fall C).
4)	Dec. 24	2212	M?	Phreatomagmatic explosion accompanied by a pyroclastic surge. A red-hot eruption column was observed. (A series of photos of the eruption was taken by JMA's Tokachi-dake Volcano Observatory.)
5)	Dec. 25	0049	L	Phreatomagmatic explosion. An air-shock was felt. Red-hot blocks were ejected as high as 300 m, and an ash-laden cloud ascended high above the crater. A pyroclastic surge descended the northern slope and stoppped at 1,610 m (Point A in Fig. 5) and 1,480 m a. s. l. (Point B). A pyroclastic flow traveled 1.1 km from the crater and stopped at 1,355 m a. s. l. (Point C). Secondary ash-laden clouds originated from the descending pyroclastic flow brought about a thin ash deposit on the lee-side of the flow. (cf. Commentary on the photogravures in this issue.) Impact craters of ballistic blocks and secondary debris flow deposits were observed from the air in the morning. Ash-fall D toward SE.
6)	Dec. 30	0527	S	A small eruption. Ash fell toward the SSE (Ash-fall E).
1989				
7)	Jan. 1	0212	S	A red-hot column, several tens of meters high, and subsequently, a glow was observed. No ash-fall was reported.
8)	Jan. 8	1938	M	Phreatomagmatic explosion accompanied by a pyroclastic surge and pyroclastic flow. A red-hot column about 300 m high was observed. The pyroclastic flow was dense and rich in lithic fragments and traveled only a short distance. A large hot block (0108 block), ca. 5 m across, was found in the flow (Fig. 6). Impact craters were distributed to the E, and ash-fall to the SE (Ash-fall F). A minor debris flow occurred on the NE foot of the 62-II pyroclastic cone.
9)	Jan.13	2229	S	Air-wave and subsequent harmonic tremors were recorded by UVO. Neither eruption column nor deposit was observed except a glow above the crater.
10)	Jan.16	1855	L	A strong air-shock was felt. Three minutes later, the cable of mudflow sensors of Biei-town was cut by a pyroclastic flow (Fig. 7). Ash-fall G toward the SE. Poor visibility prevented observation near the crater.
11)	Jan. 20	0321*[4]	M	Phreatomagmatic explosion accompanied by pyroclastic surge. Strong air-shock was felt. Red-hot blocks were ejected toward the E and N (Fig. 8). Ash-fall H toward the ESE.
12)	Jan. 22	0014	S	A weak air-wave was recorded by UVO. No eruption products were confirmed.
13)	Jan. 23	1217	S	A very weak air-wave was recorded by UVO. No eruption products were confirmed.
14)	Jan. 27	0144	S	A strong air-shock was felt at the mountain foot. Poor visibility prevented observation.

Table 2. (continued)

No.	Date	Time*1	Scale*2	Remarks
15)	Jan. 28	0518	S	Air-waves were recorded by UVO. Ash-fall I fell toward the SE. Snow prevented observation of the eruption products near the crater.
16)	Jan.28	0611	S	
17)	Jan.28	0700	S	
18)	Feb. 1	1818	S	An air-wave was recorded by UVO. Subsequently a glow was observed. Ash-fall J to the ESE. Bad weather prevented close examination.
19)	Feb. 4	0038	M	An air-shock was felt at the mountain foot. Ash-fall K toward the SSE. Further events unknown.
20)	Feb. 6	0937	S	An air-shock was felt at the mountain foot. Ash-fall L toward the SE. Further events unknown.
21)	Feb. 7	2354	S	An air-wave was recorded by UVO. No ash-fall was reported. Further events unknown.
22)	Feb. 8	0402	L	Phreatomagmatic explosion. Ejection of red-hot blocks and descent of a pyroclastic flow were observed. The deposits of pyroclastic surge and secondary ash-fall from the pyroclastic flow were confirmed from the air in the morning (Fig. 9). Impact craters of ballistic blocks were scattered to the N to the E of the crater. Ash-fall M toward the SE.
23)	Mar. 5	0522	M	Phreatomagmatic explosion accmpanied with a pyroclastic surge and a pyroclastic flow, the latter of which traveled 1 km and stopped at 1,340 m a. s. l. (Fig. 10). Bad weather prevented close examination. Ash-fall N fell to the ESE.

*1 Local time (=GMT+9 h.). Beginning of eruption recorded by UVO (OKADA *et al.*, 1989).

*2 Scale of eruption is expressed by volume of products: $S < 1 \times 10^3 m^3 < M < 1 \times 10^5 m^3 < L$

*3 2148 by JMA.

*4 0322 by JMA.

December 16, 1988. A similar explosion occurred on December 18. On December 19, the activity changed into phreatomagmatic explosions and a red-hot eruption column accompanied by a dark cloud was observed above the crater. This explosion was accompanied by a pyroclastic surge which melted the surface of snow in an area of approximately 500×800 m. A small mudflow generated by snow melting moved about 600 m down the NW flank (Fig. 4). Ash-fall reached Abashiri, 150 km ENE of the volcano (Ash-fall C in Fig. 13).

On December 24 at 2212 JST (Japan Standard Time), a phreatomagmatic explosion occurred. A red-hot eruption column and lightning were seen. This activity was accompanied with a small pyroclastic surge which moved 400 m down the NW flank. Immediately after this eruption, evacuation of three inhabited areas within 15 km W of the crater and the Shirogane Spa area 6 km NW, was requested by the Mayors of Kamifurano and Biei, respectively.

About 2 hours later, on December 25 at 0049 JST, a larger phreatomagmatic explosion occurred, accompanied by a pyroclastic surge and flow (Fig. 5). No mudflow was generated. JMA's Tokachi-dake Observatory took a series of photos of this eruption (cf. Commentary on the photogravures by SAWADA, 1990).

In the early morning of December 30, an eruption occurred and a small amount of ash fell toward the SSE. On December 31, after installation of a warning system for possible mudflows, evacuation of the three resident areas of Kamifurano was cancelled. However, evacuation of the Shirogane Spa area continued until the spring of 1989.

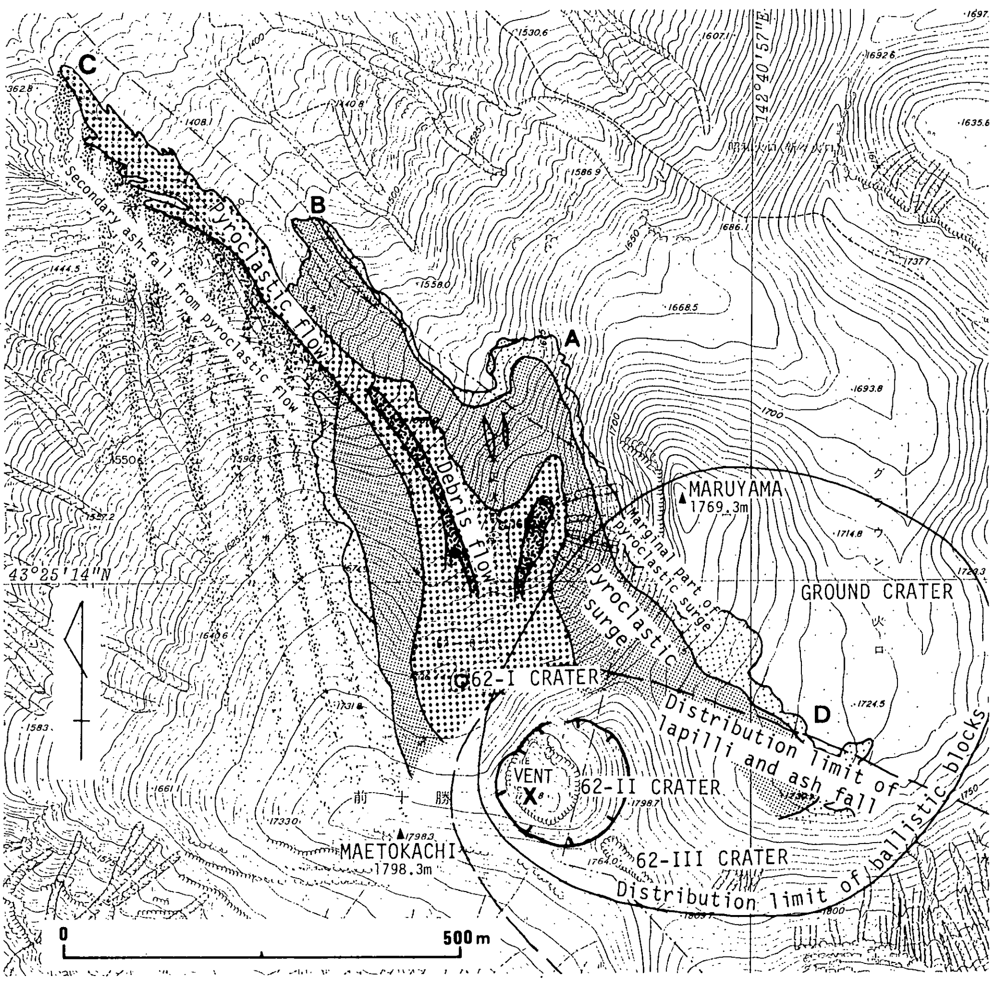

Fig. 5 Distribution of the ballistic blocks, pyroclastic surge and flow, and air-fall lapilli and ash deposits of December 25, 1988.

After a small explosion on January 1, activity resumed on January 8, and a moderate phreatomagmatic explosion occurred, accompanied with a pyroclastic surge and a short-traveled pyroclastic flow (Fig. 6).

On January 16, three minutes after an air-shock, the cable of mudflow sensors was cut by a pyroclastic flow. The pyroclastic flow moved about 1.2 km along the same route as the December 25 pyroclastic flow (Fig. 7). No mudflow was generated. Poor visibility prevented observation near the crater.

On January 20, a moderate phreatomagmatic explosion occurred, accompanied with a small pyroclastic surge (Fig. 8). Then, from January 22 to February 7, the air-waves from 10 explosions were detected, however the scale of activity was mostly small with ash-falls being reported in a few cases (Table 2).

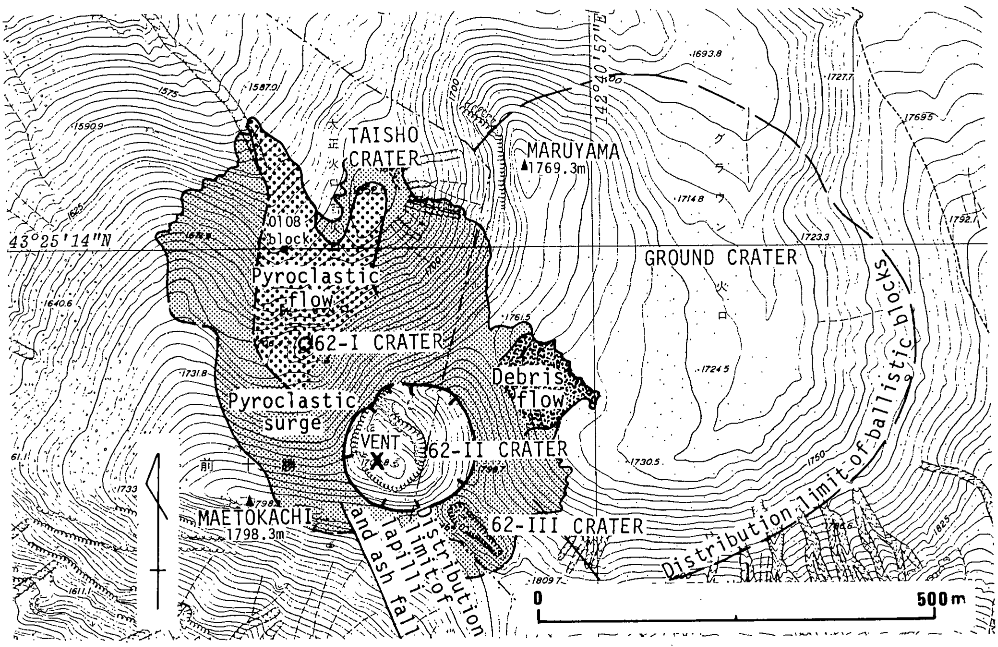

Fig. 6 Distribution of the ballistic blocks, pyroclastic surge and flow deposits of January 8, 1989.

Table 3. Velocity of the pyroclastic surge and flow of December 25, 1988.*1)

	The whole*2)				Distal part		
	av. velocity (m/sec)	inclination (degree)	length (m)	V_H/H_D*3)	velocity (m/sec)	inclination (degree)	length (m)
P. surge	20	17	725	0.31	14–23	14–23	175–225
P. flow	7	21	1060	0.38	3.5	22	425

*1) JMA's photographs of the eruption and their recorded time (SAWADA, 1990) were used for calculation.
*2) Assumed the surge and flow were generated immediately after the recorded time of the explosion earthquake (SAWADA, 1990).
*3) Ratio of vertical height dropped to horizontal distance traveled.

On February 8, a large phreatomagmatic explosion occurred, being accompanied by pyroclastic surge and flow. Red-hot ballistic blocks were ejected to the N and E of the crater (Fig. 9). After 25 days of no visible activity, on March 5, a moderate phreatomagmatic explosion occurred. This was also accompanied by a pyroclastic surge and flow (Fig. 10). Since then, no more eruptions have occurred.

As listed in Table 2, a total of 23 explosions has been recorded since December 16, 1988. Activity during the present eruption proceeded as a series of discrete cannon-like explosions with short durations of commonly several minutes, being frequently accompanied by pyroclastic surges and flows. All of the explosions occurred from the 62-II crater through a vent opened at the western part of the crater bottom. The shape of 62-II crater remained almost unchanged. The 62-I crater has been burried by the new ejecta, although fumarolic activity still continues at the same place.

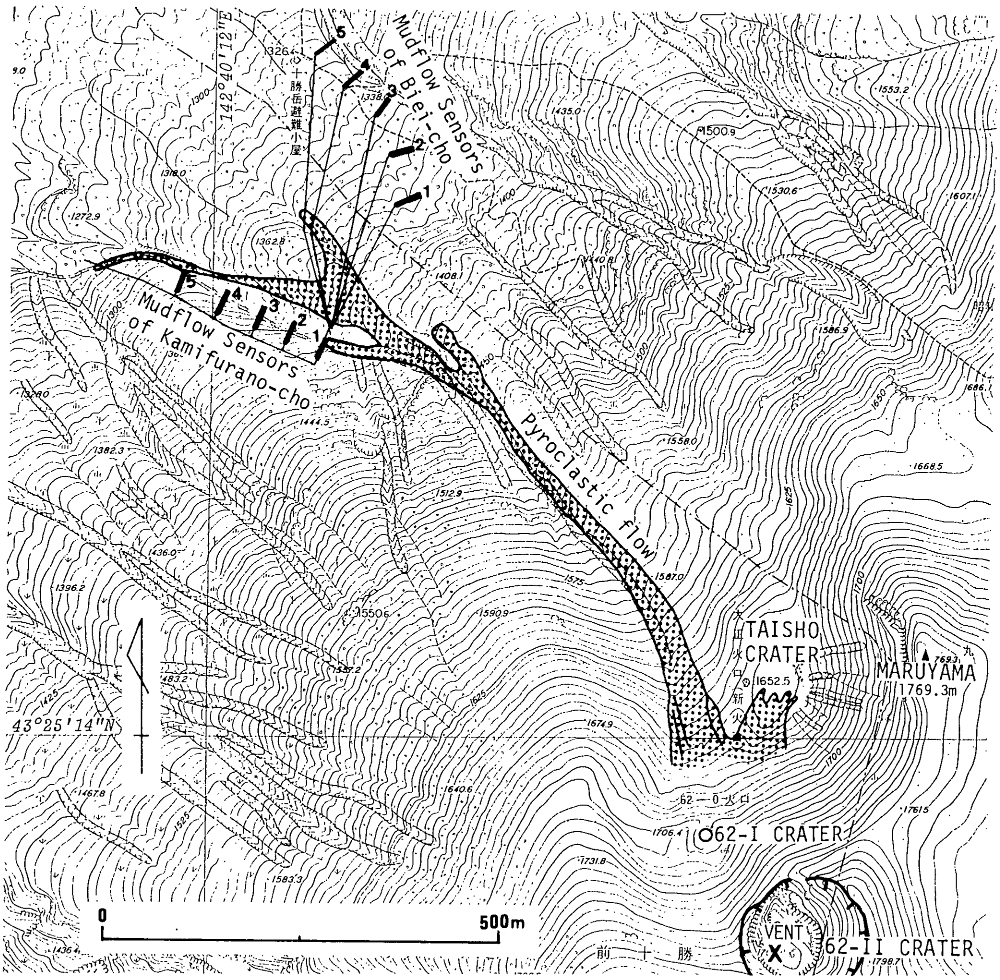

Fig. 7 Distribution of the pyroclastic flow deposit of January 16, 1989. About 3 minutes after the eruption, the cable of mudflow sensors of Biei-cho was cut by the flow. The summit area was not visible.

4. Distribution and Nature of the Ejecta

4-1 Ballistic blocks

Volcanic blocks ejected by the present eruption were distributed up to approximately 1.3 km from the source. The limit of their distribution is shown in Figs. 5, 6, 8, and 9. In the early stages of the eruption, ballistic blocks were thrown mainly toward the E of the crater, since the new vent was opened at the western part of the crater bottom (Figs. 5 and 6). However, in the middle to late stages, many large essential blocks, about 20 m in max. size, were ejected to the N as well as to the E of the crater (Figs. 8 and 9). This evidence may be interpreted as a rise in the explosion level due

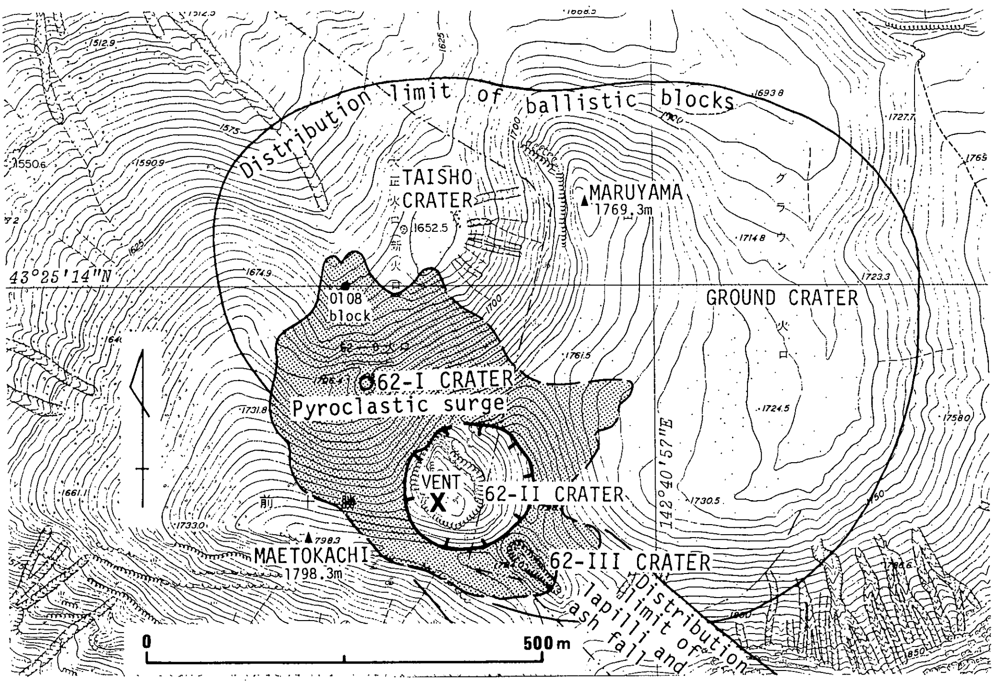

Fig. 8 Distribution of the ballistic blocks and pyroclastic surge deposit of January 20, 1989.

to ascent of magma toward the later stages of eruption.

The ballistic blocks are composed of both accessory and essential rocks. The essential blocks consist of mafic andesite having similar chemical and mineral conpositions to the 1962 scoriaceous bombs of Tokachi-dake (IKEDA *et al.*, 1990). However, their morphological features are very different from the 1962 bombs. The ballistic blocks from the present eruption are usually jointed as shown in Fig. 11. Such features indicate that the blocks were derived from the cooled, semi-congealed cap of the magma in the vent. In addition to the mafic andesite, glassy rock, which was possibly derived from melting (or softening) of an altered andesite by the mafic andesite magma in a vent, was found. A large block of vent breccia intruded by a dike of fresh mafic andesite was also ejected (0108 block in Figs. 6, 8, 9) (IKEDA *et al.*, 1990).

4–2 Pyroclastic surge deposits

Pyroclastic surges occurred 7 times during the present eruption, being accompanied with or without pyroclastic flows. They were low particle concentration, turbulent, ash-clouds with an average velocity of 20 m/sec (Table 3).

The December 19 pyroclastic surge covered an area as large as 500×800 m and triggered a mudflow by snow melt (Fig. 4). However, no notable mudflows were generated by subsequent pyroclastic surges. The December 25 pyroclastic surge included red-hot clasts which displayed explosion during the movement of surge (cf. Photos Nos. 1 and 2 in SAWADA, 1990).

The pyroclastic surge deposits mantled topography with a thickness usually less than 5 cm. However, their distribution was apparently controlled by the shape of the crater and nearby topography. As shown in Figs. 4–6 and 8–10, the main parts of the deposits most frequently extend

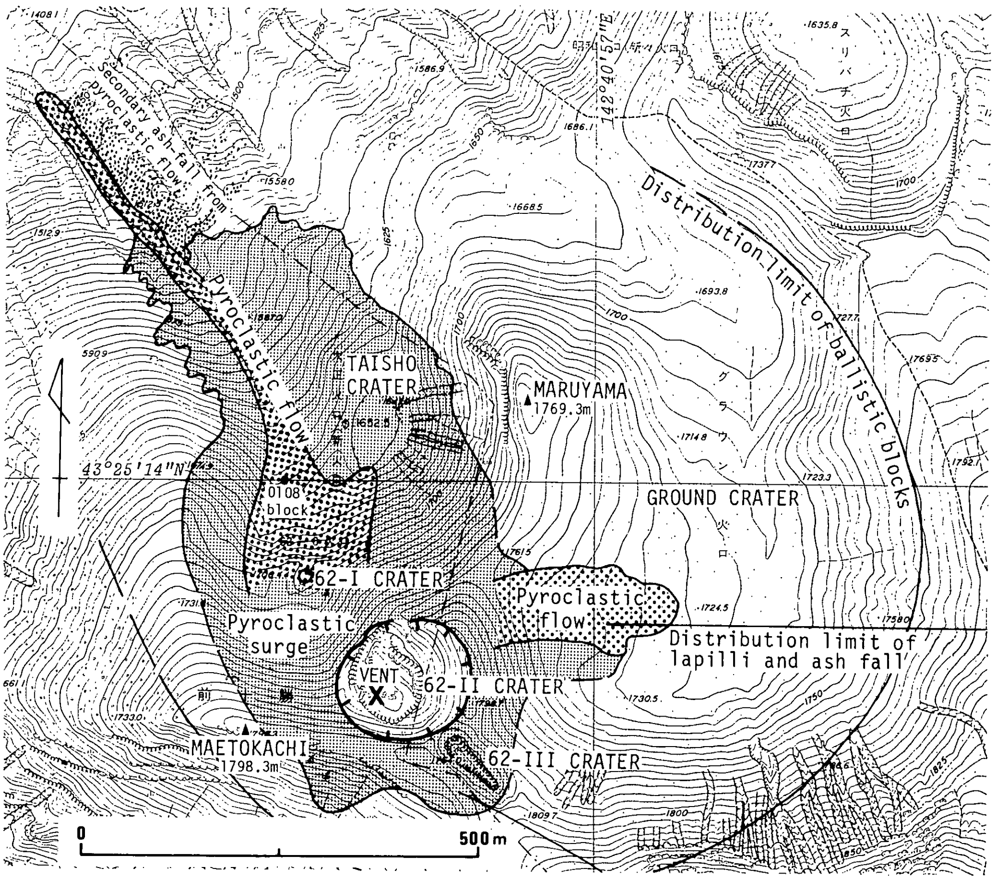

Fig. 9 Distribution of the ballistic blocks, and pyroclastic surge and flow deposits of February 8, 1989.

toward the norh, although some are distributed around the 62-II crater. The pyroclastic surge deposits are fairly well-sorted and are rich in a fine clast fraction compared with the pyroclastic flow deposits (Fig. 12).

4–3 Pyroclastic flow deposits

Five small-scale pyroclastic flows occurred during the present eruption. It was confirmed that they were accompanied by pyroclastic surges, with the exception on January 16, when poor visibility prevented observation of the deposits near the crater. These flows were high particle-concentrated block and ash-flows which traveled for a short distance, less than 1.2 km, with a much lower velocity than the pyroclastic surges (Table 3).

The December 25 pyroclastic flow, with ascending ash-clouds, was photographed (SAWADA, 1990). A morning overflight, afer 8 hours of the eruption, revealed that the pyroclastic flow had moved down along a NW valley with "levees" on both sides of the flows, and the deposit had still hot although the associated surge deposit was already cooled. About 60 hours after the eruption, the maximum temperature of the deposit was 92°C at 50 cm depth in distal parts.

The pyroclastic flow deposits are 0.4 to 2 m thick, consist of dry, poorly-sorted block and ash

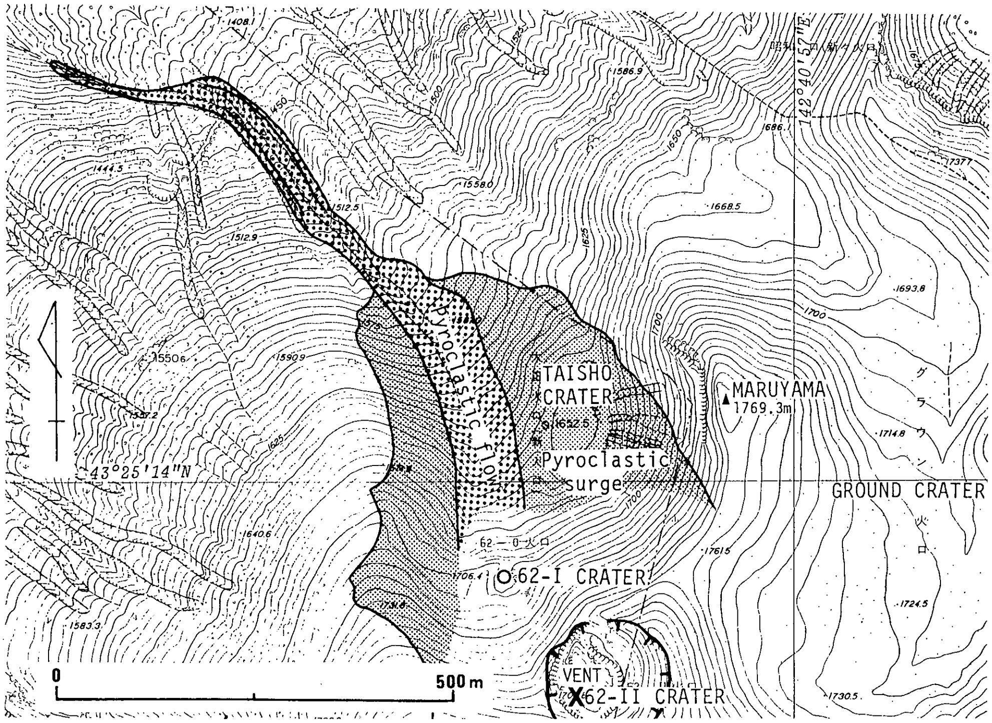

Fig. 10 Distribution of the pyroclastic surge and flow deposits of March 5, 1989. The summit area was not visible.

(Fig. 12). and occasionally contain large blocks of 1–2 m or more in size. The distribution of the pyroclastic flow deposits was controlled by the shape of the crater and nearby topography, as in the same way of the pyroclastic surge deposits, with most of them being emplaced along the valley of the NW slope (Figs. 5–7, 9, and 10).

The rock fragments included in the pyroclastic flow deposits are composed of both accessory and essential rocks, similar to the ballistic blocks described earlier. As shown in Table 4, the accessory rocks (rock types A–D) are usually predominant. The fresh rock fragments consist of essential mafic andesite (F) and glassy rock (E). Both rocks have similar petrography to those of the ballistic blocks.

4–4 Ash-fall deposits

Ash-fall information was reported for each eruption from junior high schools and high schools in east Hokkaido on request from Katsui's Laboratory of Hokkaido University. JMA's Local Meteorological Observatories in related areas and the Fire Station of Kitami supplied ash-fall samples and information for this study. Fig. 13 was prepared from the above information together with the author's observations.

Most of the ash-fall propagated toward the SE of the volcano, except for ash-fall C which reached Abashiri, 150 km ENE of the volcano (Fig. 13). The ash-fall C deposit is substantial, having the largest dimensions for the deposits of the present eruption. Although the height of the eruption column was not observed, it must have reached considerably higher than the others,

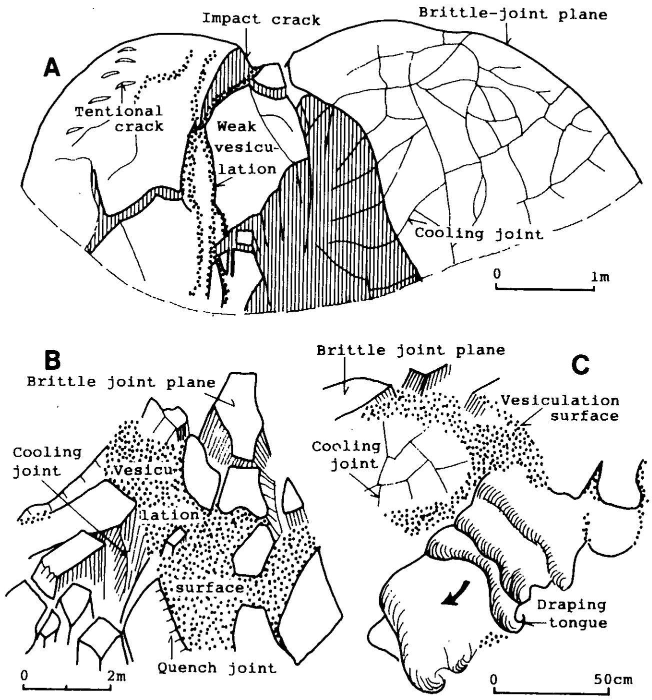

Fig. 11 Ballistic blocks from the 1988–1989 eruption. A: jointed block. B: jointed block with internal vesiculation. C: jointed block with surface vesiculation and draping tongue. All of them are essential mafic andesite.

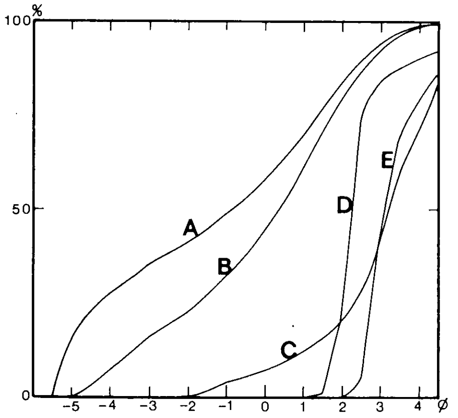

Fig. 12 Size compositions of the 1988–1989 pyroclastic deposits. A and B. Dec. 25 pyroclastic flow deposit, distal part, C. Feb. 8 pyroclastic surge deposit, distal part, D. Dec. 25 ash-fall deposit at Tomuraushi, 17 km SE of Tokachi-dake, E. Dec. 19 ash-fall deposit at Kitami, 105 km ENE of Tokachi-dake.

Table 4. Types and frequency of the rock fragments included in the 1988–1989 pyroclastic flows desposits.

	Rock Type	(1)	(2)	(3)	(4)
A)	Altered lithic fragments and scoria coated with sublimates	16.3	18.2	6.1	8.0
B)	Scoria of mafic andesite partly coated with sublimates (mostly 1962 scoria?)	42.9	15.2	5.6	10.2
C)	Lithic fragments of mafic andesite partly coated with sublimates (mostly Central Cone lava?)	10.2	17.2	13.6	29.6
D)	Gray and compact lithic fragments of andesite with or without sublimates (Maetokachi lava?)	14.3	40.8	43.9	47.7
E)	Fresh and compact glassy rock fragments with gray patches	14.3	8.1	19.6	1.1
F)	Fresh scoria and fragments of mafic andesite	2.0	0.5	11.2	3.4
	Total	100.0	100.0	100.0	100.0

Date of eruption:	Grain size (mm):	Number of fragments:
(1) Dec. 25, 1988	30 –100	49
(2) Jan. 16, 1989	7.9–200	198
(3) Feb. 8, 1989	15 –60	214
(4) Mar. 5, 1989	10 –60	88

inferred from the wind direction during this season.

The ash-fall A and B deposits consist mostly of accessory rock fragments. However, the ash-fall C and subsequent ash-fall deposits contain 20–25% fresh glass which is considered to have been derived from the new mafic andesite magma and the melted (or softened) altered andesite.

5. Volume of the Ejecta

Table 5 lists the estimated volume of the 1988–1989 ejecta of Tokachi-dake. The volume was calculated for the first order estimation from the distribution area and average thickness of each deposit, except for ballistic blocks. The total volume of the deposits amounts to about 6×10^5 m^3.

The ash-fall and pyroclastic flow deposits are nearly comparable in total volume, while the total volume of the pyroclastic surge deposit is less than one tenth of the fall and flow combined. The volume of the ballistic blocks is roughly estimated to be 1×10^4 m^3.

Table 6 summarizes the estimated volume of the historic products. The 1962 scoria eruption is the largest in scale. The volume of the present eruptive products corresponds to only 1% of the 1962 ejecta. A small abundance of essential fragments, being about 20% of the total products, is another feature of the present eruption. The 1926 ejecta are also small in volume and poor in essential fragments.

6. Characteristic Feature of the 1988–1989 Eruption

The essential rock fragments ejected during the present eruption are mafic andesite, similar to

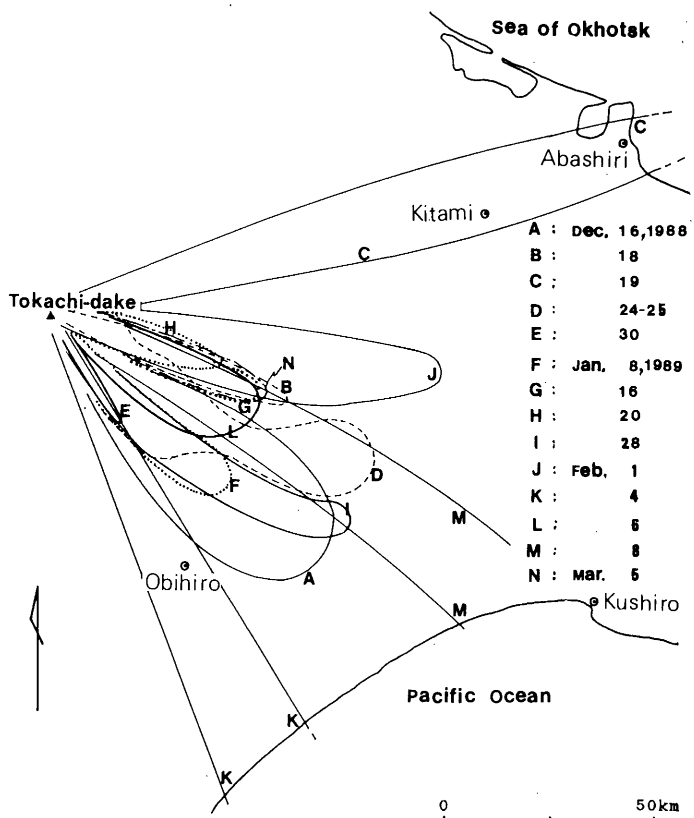

Fig. 13 Map showing ash-fall areas A–N during the 1988–1989 eruption.

the 1926 bomb and 1962 scoria (IKEDA *et al.*, 1990). However, the present eruption was markedly different in type and scale from the 1926 activity of phreatic explosions with sector collapse, followed by bomb ejection, and the 1962 activity of large scoria eruptions.

The present eruption started with phreatic explosions, and was followed by phreatomagmatic explosions. The activity is characterized by a series of discrete cannon-like explosions with short durations of commonly several minutes. These explosions were not large in scale, but were frequently accompanied by pyroclastic surges and flows.

The jointed features of essential ballistic blocks and the short duration of each explosion suggest that the phreatomagmatic explosions resulted from the sudden release of gas due to failure of the cooled, semi-congealed cap of magma, as discussed by SELF *et al.* (1979)

Such transient explosions, typical of Vulcanian eruptions, are frequently accompanied by generation of a small-volume of pyroclastic flows (CAS and WRIGHT, 1988). During the 1973 explosive eruption of Asama Volcano, ARAMAKI (1973) observed two varieties of small-scale pyroclastic flows, *i. e.* one variety, with probably finer clasts, spread over the slope with a high velocity (35 m/sec), and the other, similar to the block and ash flow of PERRET (1937), descended forming dark striae on the snow-covered slope. The two varienties are similar in clast composition and behavior to the pyroclastic surges and flows of Tokachi-dake.

Table 5. Estimated volume (m^3) of the 1988–1989 ash-fall, pyroclastic surge and pyroclastic flow desposits.

Date	Ash-fall	Pyroclastic surge	Pyroclastic flow
Dec. 16, 1988	3.7×10^4	—	—
Dec. 18	1.8×10^4	—	—
Dec. 19	1.2×10^5	1.1×10^4	—
Dec. 25	2.5×10^4	1.0×10^4	1.3×10^5
Dec. 30	4.5×10^3	—	—
Jan. 8, 1989	4.4×10^3	4.9×10^3	3.1×10^4
Jan. 16	7.0×10^3	—	1.9×10^4
Jan. 20	2.3×10^3	3.2×10^3	—
Jan. 28	2.3×10^3	—	—
Feb. 1	5.2×10^3	—	—
Feb. 4	1.7×10^3	—	—
Feb. 6	2.1×10^3	—	—
Feb. 8	1.1×10^4	1.1×10^4	1.1×10^5
Mar. 5	1.0×10^4	6.5×10^3	3.6×10^4
Total	2.5×10^5	4.7×10^4	3.3×10^5

Table 6. Estimated volume (km^3) of the historic products.

Year	Essential ejecta	Accessory ejecta	Edifice collapsed	Source of data
1926	3×10^3 + (ash-fall)	1×10^4 + (ash-fall)	2×10^6	TADA and TSUYA, 1927
1962	6.5×10^7	7.1×10^6	—	KATSUI *et al.*, 1963
1988–89	1.4×10^5	6.1×10^5	—	this study

Table 3 shows the calculated velocity of the pyroclastic surge and flow of December 25, 1988 of Tokachi-dake. The velocity of the pyroclastic flow is as low as one third of that of the surge, regardless of inclination of the slope. The velocity of both the pyroclastic surge and flow notably decreased in the distal part, suggesting that their velocity near the source region was considerably higher.

The content of red-hot clasts (essential and glassy rocks) in the pyroclastic surges and flows of the present eruption, is generally low. Hence, their temperature as a whole would not be as high as that of normal pyroclastic flows consisting mainly of essential clasts (ARAMAKI, 1957; ARAMAKI and YAMASAKI, 1963). The ratios of vertical height dropped (V_H) to horizontal distance traveled (H_D) for the December 25 pyroclastic surge and flow are 0.31 and 0.38, respectively (Table 3). Both values are similar to those for cold rock avalanches but higher than those for hot rock avalanches (SPARKS, 1976).

7. Concluding Remarks

After a brief review of the geology and historic activity of Tokachi-dake, the sequence of the 1988–1989 eruption was compiled, and several distribution maps of the ejecta were drawn for each of the larger eruptions.

The composition of the essential ejecta (mafic andesite)is similar to those of the 1926 and 1962 eruptions, but the mode of the present eruption is considerably different.

The present eruption started with phreatic explosions, and was followed by phreatomagmatic explosions of Vulcanian type. It consists of a series of 23 discrete cannon-like explosions, being frequently accompanied with pyroclastic surges and flows. The total volume of the ejecta amounts to about $6\times10^5m^3$, of which about 20% are essential ejecta.

The pyroclastic surges and flows of the present eruption were small scale, low temperature pyroclastic flows, rich in accessory clasts and unaccompanied by sector collapse. Therefore, the sudden melting of snow causing disastrous mudflows, as in the case of the 1926 eruption, fortunately did not occur.

Acknowledgements

We are grateful to Drs. Hm. Okada, D. Shimozuru, S. Aramaki, J. Ossaka, J. Hirabayashi, and J. Maeda for their helpful discussion, and to Mr. C. Feebrey for critical reading of the manuscript. We are indebted to Usu Volcano Observatory of Hokkaido University, Japan Meteorological Agency, Geographical Survey of Japan, Geological Survey of Hokkaido, Hokkaido National Agricultural Experiment Station, Hokkaido Government, Biei and Kamifurano Town Offices, Hokkaido Police Headquater, Self Defence Force of Japan for their help in this study. Thanks are also due to the school teachers for their ash-fall information and to the news media for their photos and video images.

A part of the expense for this study was defrayed by the Grant for Scientific Research from the Ministry of Education, Science and Culture of Japan.

References

ARAMAKI, S. (1957) Classification of pyroclastic flows. *Bull. Volcanol. Soc. Japan*, **1**, 47–57 (in Japanese with English abstract).

ARAMAKI, S. (1973) Small-scale pyroclastic flows generated during the February–March, 1973, eruption of Asama volcano. *Bull. Volcanol. Soc. Japan*, **18**, 74–94 (in Japanese with English abstract).

ARAMAKI, S. and YAMASAKI, M.(1963) Pyroclastic flows in Japan. *Bull. Volcanol.*, **26**, 89–99.

CAS, R. A. F. and WRIGHT, J. V.(1988) *Volcanic successions, modern and ancient.* Unwin Hyman, London, 528 p.

IKEDA, Y., KATSUI, Y., NAKAGAWA, M., KAWACHI, S., WATANABE, T., FUJIBAYASHI, N., SHIBATA, T. and KAGAMI, H.(1990) Petrology of the 1988–89 essential ejecta and associated glassy rocks of Tokachi-dake Volcano in central Hokkaido, Japan. *Bull. Volcanol. Soc. Japan*, **35**, 147–162.

IKEDA, Y. and MUKOYAMA, S.(1983) Stratigraphy and correlation of the pyroclastic flow deposits in the Furano–Asahikawa area, central Hokkaido, Japan. *J. Geol. Soc. Japan*, **89**, 163–172 (in Japanese with English abstract).

ISHIKAWA, T., YOKOYAMA, I., KATSUI, Y. and KASAHARA, M.(1971) *Tokachi-dake, its volcanic geology, history of eruption, present state of activity and prevention of disaster.* Committee for Prevention of Disasters of Hokkaido, Sapporo, 136 p. (in Japanese).

KATSUI, Y. (1986) The 1985 eruption of Nevado del Ruiz Volcano, Colombia, and associated mudflow disaster. *Rept. of Natural Disaster Sci. Res. Japan*, No. B-60-7, 1–102 (in Japanese with English abstract).

KATSUI, Y. (1989) The 1988 eruption of Tokachi-dake, its sequence, mechanism, and influence on community. *Rept. of Natural Disaster Sci. Res. Japan*, No. B-63-5, 1–108 (in Japanese with English abstract).

KATSUI, Y., TAKAHASHI, T. and DOI, S.(1963a) *Explanatory text of the geological map of Japan, scale 1 : 50000, Tokachidake.* Hokkaido Development Agency, 47 p. (in Japanese with English Abstract).
KATSUI, Y., TAKAHASHI, T., OBA, Y., HIRAI, Y., IWANAGA, M., NISHIMURA, T., SOYA, T. and ITO, H.(1963b) 1962 eruption of Tokachi-dake, Hokkaido. *J. Japan. Assoc. Min. Petr. Econ. Geol.*, **49**, 213–226.
KATSUI, Y., YOKOYAMA, I., OKADA, Hm. and OSHIMA, H. (1987) *Tokachi-dake, its volcanic geology, history of eruption, present state of activity and prevention of disaster—a supplement.* Committee for Prevention of Disasters of Hokkaido, Sapporo, 87 p. (in Japanese).
OKADA, Hm., NISHIMURA, Y., MIYAMACHI, H., MORI, H. and ISHIHARA, K. (1990) Geophysical significance of the 1988–89 explosive eruptions of Mt. Tokachi, Hokkaido, Japan. *Bull. Volcanol. Soc. Japan*, **35**, 175–203.
PERRET, F. (1937) The eruption of Mt. Pelée 1929–1932. *Carnegie Inst. Washington Publ. 458*, 125 p.
SAWADA, Y. (1990) "Commentary on the photogravures". *Bull. Volcanol. Soc. Japan*, **35**, 279–282.
SELF, S., WILSON, L. and NAIRN, I. A. (1979) Vulcanian eruption mechanism. *Nature*, **277**, 440–443.
SPARKS, R. S. J. (1976) Grain size variations in ignimbrites and implications for the transport of pyroclastic flows. *Sedimentology*, **23**, 147–188.
TADA, F. and TSUYA, H. (1927) The eruption of the Tokachidake Volcano, Hokkaido, on May 24th, 1926. *Bull. Earthq. Res. Inst., Univ. Tokyo*, **2**, 49–84 (in Japanese with English abstract).
TAKAHASHI, T. (1965) Geological and petrological study of the southwestern part of the Daisetsu–Tokachi volcanic chain. *Kumamoto J. Sci., Ser. B, Sect. 1 Geol.*, **6**, 1–42.
WILLIAMS, H. (1941) Calderas and their origin. *Univ. Calif. Publ., Bull. Dept. Geol. Sci.*, no. 25, 234–346.
YOKOYAMA, I. (1985) Still-born eruption of Tokachi Volcano in 1968–1969. *Bull. Volcanol. Soc. Japan*, **30**, 98 (in Japanese).

十勝岳 1988〜1989 年の爆発的噴火，その推移と様式

勝井義雄・河内晋平・近堂祐弘
池田保夫・中川光弘・後藤芳彦
山岸宏光・山崎哲良・隅田まり

1988 年 12 月 16 日，十勝岳は 62-II 火口から 26 年ぶりに噴火を始めた．この活動は水蒸気爆発で始まり，12 月 19 日にヴルカノ式のマグマ水蒸気爆発に移行し，以後 1989 年 3 月 5 日まで間欠的につづいた．この一連の噴火は，1926 年，1962 年噴火と同質の苦鉄質安山岩マグマによって起こされたものであるが，噴火様式がこれらとは異なり，23 回の独立した短い爆発的噴火からなり，しばしば小型火砕流および火砕サージを伴った．噴出物の総量は，約 6×10^5 m^3 で，本質噴出物はその約 20% にすぎなかった．この一連の噴火経緯をまとめ，さらに降下火山灰・放出岩塊・火砕サージおよび火砕流の分布図を噴火ごとに作成して示した．

今回噴出した火砕サージと火砕流は小規模で，類質岩片に富み，本質岩片を主体とする火砕流ほど高温ではなかった．また，山体崩壊も起こらなかった．このため幸い 1926 年の大正泥流のような，破壊的融雪泥流の発生には至らなかった．