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THE 1977–1978 ERUPTION OF USU VOLCANO

by

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(with 16 text-figures, 4 tables and 6 plates)

Abstract

The 1977–1978 activity of Usu Volcano began with a series of major eruptions of dacite pumice from August 7 to 14, 1977, which was preceded by a local earthquake swarm. After the First Stage eruptions, due to rising of the residual viscous magma, notable crustal movements accompanied by earthquakes continued and fumarolic activity increased at the summit. In November, 1977, the Second Stage eruptions broke out with a minor phreatic explosion and intermittently occurred in 1978 gradually increasing in scale of activity. Thus, moderate phreatomagmatic and magmatic eruptions as well as phreatic ones occurred in August and Sptember, then the eruptive activity stopped in October.

Subsequent to our first report on the First Stage eruptions (Katsui, et al., 1978), the whole sequence of the Second Stage eruptions is described here, together with the nature of the ejecta, and character and scale of the eruption.

Introduction

Usu Volcano (42°32'N, 140°50'E) located on the southern rim of the Tōya Caldera, Hokkaido, renewed activity in 1663 with a large scale rhyolitic pumice eruption, after a long period of dormancy for several thousand years. Since 1769, characteristic eruptions of dacite magma including nuée ardente and lava dome or cryptodome building, usually accompanied by frequent local earthquakes, have been repeated every 30 to 50 years. The eruptions occurred both from the summit and the northeastern foot of Usu Volcano. During the activity in 1943–1945, Shōwa-Shinzan, a new lava dome, was produced by a viscous dacite magma on the eastern foot of the volcano (Minakami, Ishikawa and Yagi, 1951).

Recently, during August 7 to 14, 1977, a series of major eruptions of hypersthene dacite pumice occurred from the summit of Usu Volcano, after 32 years of dormancy since the birth of Shōwa-Shinzan. This first stage of eruption was preceded by a local earthquake swarm for about 30 hours, and a crustal movement at the summit area. After the major pumice eruptions, due to rising of the residual viscous magma, marked crustal movements have continued at the summit and on the northeastern flank, being accompanied by frequent local earthquakes. The above activity of Usu Volcano, has been already reported by Katsui et al. (1978).

Toward the end of 1977, fumarolic activity increased at the summit, and the Second Stage eruptions began with a minor phreatic explosion in November. Such eruptions have intermittently occurred in the following ten months from the beginning of 1978, gradually increasing in scale of activity. Thus, moderate phreatomagmatic and magmatic eruptions as

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well as phreatic ones occurred in August to September, 1978, then the eruptive activity declined and stopped in October. After the Second Stage eruptions, fumarolic activity and crustal movement accompanied by local earthquakes continued.

The whole sequence of the present eruptions has been traced by the writers. This report is intended to describe the sequence of the activity, the nature of the ejecta, and the character and scale of the eruptions which varied considerably with time.

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Sequence of the 1977–1978 Eruption

The 1977–1978 eruption of Usu Volcano documented in Appendix is divided into the following two stages and three substages, based on the sequence and nature of the eruptions.

First Stage (sub-Plinian eruptions) (Aug. 7–14, 1977)

Four big eruptions of dacite pumice, two moderate and ten small ones, forming Craters 1, 2, 3 and 4 at the summit of Usu Volcano.

Second Stage (phreatic-phreatomagmatic-magmatic eruptions)

Substage I (Nov. 16, 1977 – Mar. 13, 1978).

Typical phreatic eruptions from Craters A – H.

Substage II (Apr. 24 – Jun. 27, 1978)

Phreatic to phreatomagmatic eruptions from Crater I.

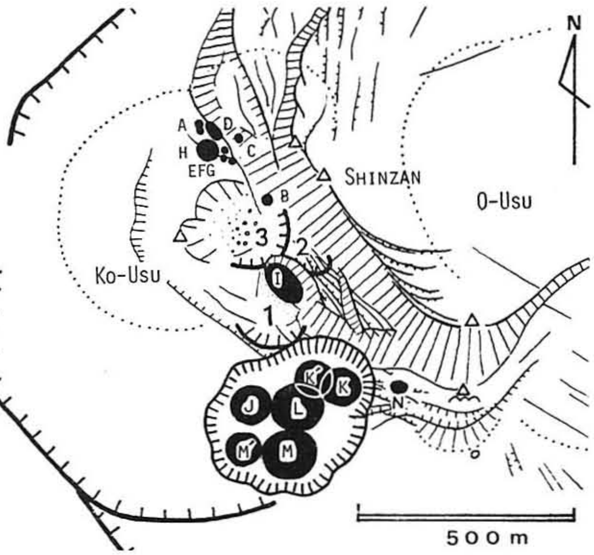
Substage III (Jul. 9 – Oct. 27, 1978)

Phreatic-phreatomagmatic-magmatic eruptions from Craters J – N.

On August 7, 1977, a major eruption of dacite pumice occurred at the summit of Usu Volcano after 32 years of dormancy since the birth of Shōwa-Shinzan lava dome during 1943–1945. Four big eruptions, two moderate and ten small ones have been recorded until the midnight of August 13–14. The sequence of the 1977 pumice eruption has been reported by Katsui et al. (1978).

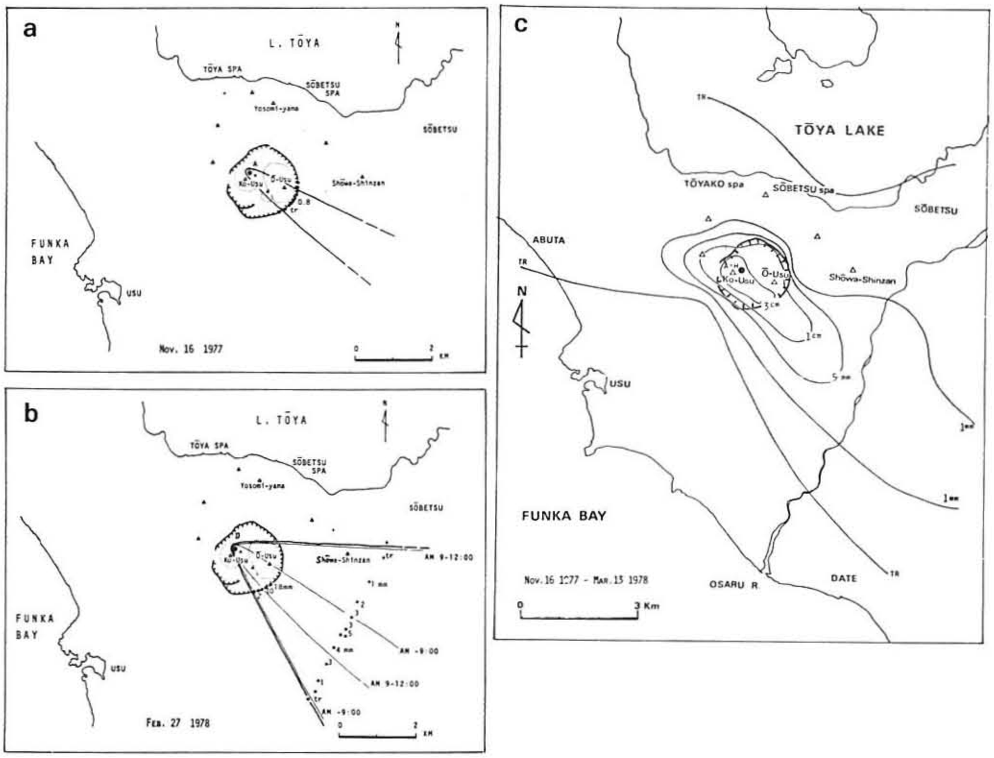
Subsequent to the pumice eruptions of the First Stage, notable crustal movements accompanied by local earthquakes occurred on the summit and the northeastern flank of the volcano. In the somma-atrio of the volcano numerous normal faults running in a NW-SE direction were produced. The pre-existing lava domes, Ko-Usu, Ogariyama and O-Usu, were successively cut by the major faults. Simultaneously, creation of a new roof-mountain with new peaks which are tentatively called "Naka-Usu Shinzan" and "Shin-Ogariyama" proceeded in the atrio. It is evident that these crustal deformations were caused by the upward movement of the viscous magma, which is a characteristic feature in recent activities of Usu (Minakami et al., 1951). Furthermore, new fumaroles appeared and the thermal areas have expanded in the atrio, especially along the major faults and the old crater wall around Ko-Usu, which was apparently due to approach of the magma to the surface.

On November 16, 1977, the first phreatic eruption of the Substage I broke out after 94 days of quiescence since the major pumice eruptions. At 5:40 (JST) on November 16, the eruption cloud was formed above the summit of Usu Volcano. The cloud continuously rose up until 9:05 and was trailed toward southeast by the wind, as recorded in Appendix. During the eruption no rumbling was heard from the foot of the volcano. A small twinned crater (Crater A, 3 m across) was formed by the eruption, as shown in Text-fig. 1 and Plate 1, fig. 1.



Text-fig. 1 Localities of the craters produced by the Second Stage eruption in 1977–1978.

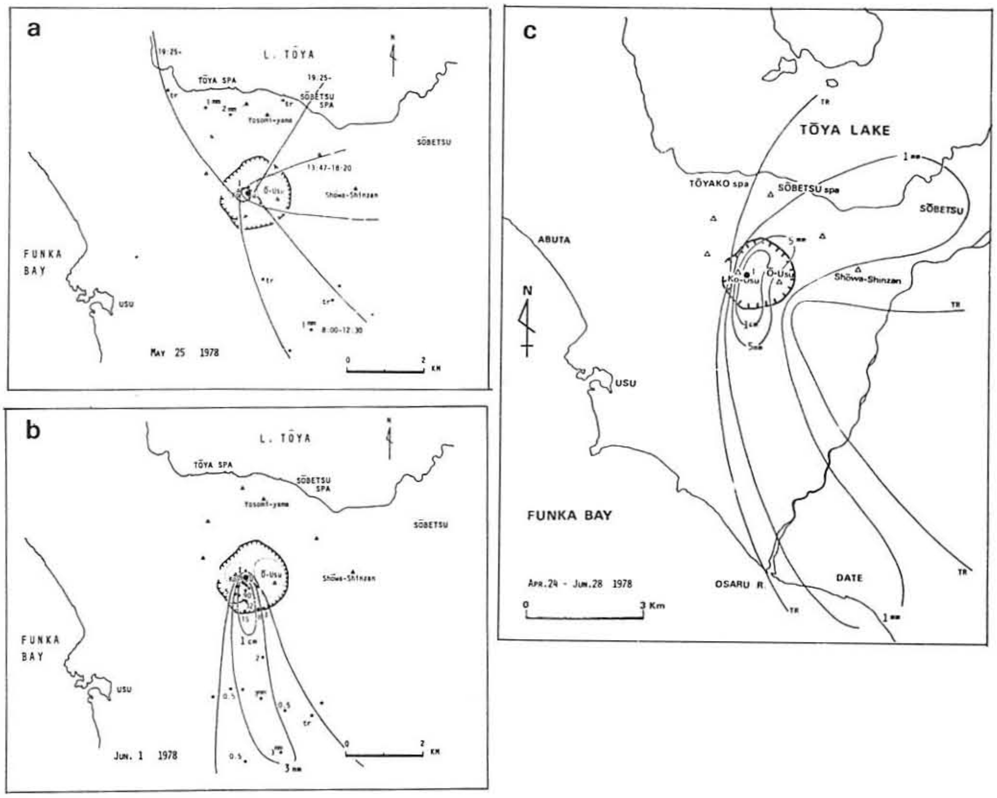
In early 1978, Usu Volcano became more active and phreatic eruptions occurred on January 13, February 25 and 27, repeated intermittently in March 1 to 4, and almost continuously from March 5 to 13. As the result of these eruptions, seven new craters, B, C, D, E, F, G, and H, opened successively on the NE side of the Ko-Usu dome, the location of which coincides with the major normal fault which borders the southeastern margin of the growing new roof-mountain. The biggest eruption of the Substage I took place in the early morning of February 27. The smoke rose up continuously from Crater D (Plate 1, fig. 2), then it was blown eastward by the wind until 12:00. As shown in Text-fig.



Text-fig. 2 Map showing the distribution and thickness of the ash-fall deposites; (a) November 16, 1977, (b) February 27, 1978, and (c) cumulative thickness contour lines of the ash-fall deposits produced during November 16, 1977, and March 13, 1978.

2b the ash ejected by this eruption dispersed over the white snow and deposited about 5 mm thick on the ESE foot of the mountain. Subsequent to small eruptions in the beginning of March, a sustaining eruption from Crater H was observed from the morning of March 5 to the sunset of 13 (Plate 1, fig. 3). In such a snowy season the ash-fall deposits were interlayered by snow, showing an alternation of black and white layers (Plate 1, fig. 4). The activity of the Substage I was followed by 42 days of quiescence until beginning of the next substage. On April 24, the activity of Substage II began with opening of Crater I which is located on the eastern flank of the Ko-Usu dome and just at the center among the Craters 1, 2 and 3 produced by the major pumice eruptions in 1977. Before opening of the Crater I, it was noticed that the ground-surface temperature notably increased and recorded the maximum at this point.

On May 24, the Crater I renewed phreatic eruption. The eruption became severe in the evening of the next day and continued till May 30 (Plate 1, fig. 5). After a lapse of time the eruption declined gradually. Essential dacite fragments derived directly from the new magma were found in the deposits of volcanic lapilli ejected on May 26. It is the first ejection of essential materials in the 1978 activity. From May 31, the eruption became frequent, but the

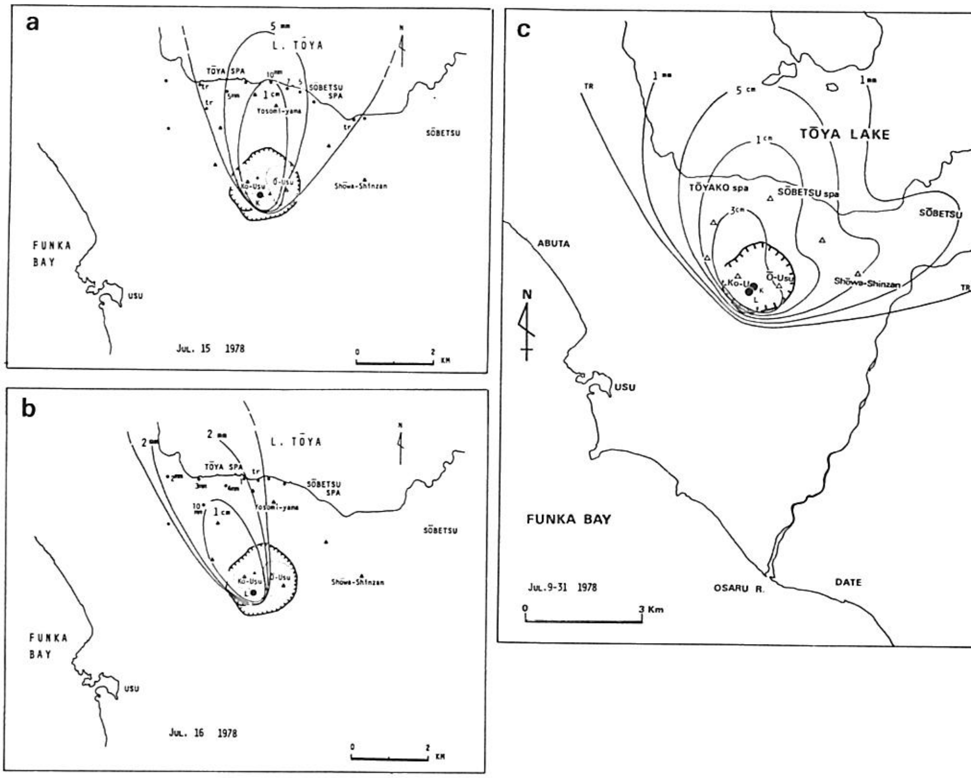


Text-fig. 3 Map showing the distribution and thickness of the ash-fall deposits; (a) May 25, (b) June 1, 1978, and (c) cumulative thickness contour lines of the ash-fall deposits produced during April 24 and June 28, 1978.

duration of each eruption became short, from several seconds to several minutes, as shown in Appendix.

From 16:15 to 16:45 on June 1 a strong eruption occurred without a severe rumbling, and the eruption cloud was trailed toward south to southeast, reaching as far as Muroran City (25 km). The distribution of the ash is shown in Text-fig. 3b. In the midnight of June 1–2, it was observed that numerous dacite blocks glowing red to reddish-yellow-color were thrown out from the Crater I in every direction, describing parabolic tracks. Frequent lightning also observed. This event indicates that the nature of the eruption was converted into a phreatomagmatic one. In fact, a number of essential blocks of new dacite were found in the ejecta. According to the result of modal analyses (Table 2), the ejecta of lapilli-size are composed of 18% new dacite and 82% accessory and accidental fragments.

On June 2, 3 and 4, small phreatic to phreatomagmatic eruptions successively occurred from the Crater I. On June 7, 27 and 28, small eruptions were also recorded. During the Substage II the Crater I was gradually enlarged by repeated eruptions and finally reached

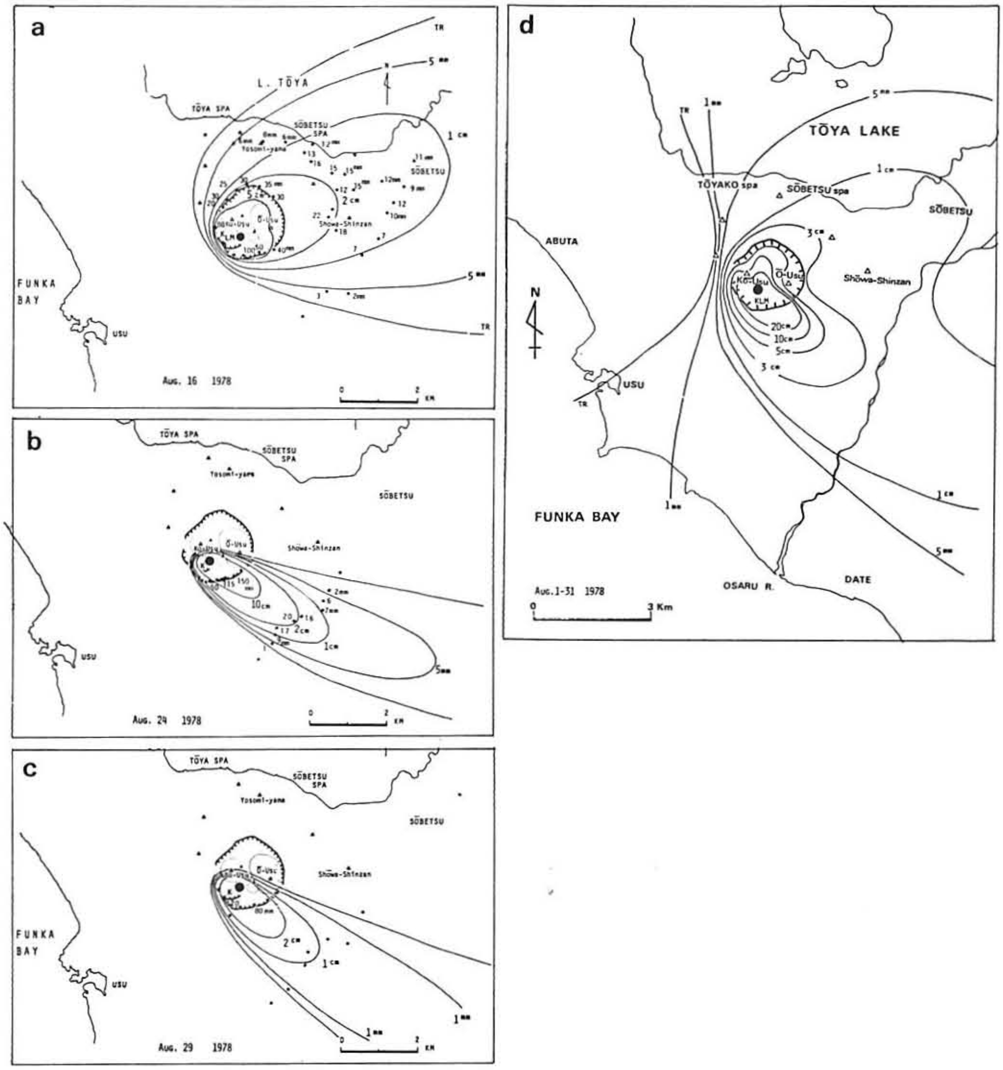


Text-fig. 4 Map showing the distribution and thickness of the ash-fall deposits: (a) July 15, (b) July 16, 1978, and (c) cumulative thickness contour lines of the ash-fall deposits produced in July, 1978.

130 × 70 m across. After that, the Crater I was buried and only strong jets of volcanic gas and white steam were observed. Since then, the center of the explosive activity migrated from the Crater I to the south, where Gin-numa, a shallow lake, stayed in the atrio.

In the Substage III, more intense eruptions broke out successively, resulting in opening of large craters more than 100 m across one after another. At 5:30 on July 9 a seismometer of the Usu Volcano Observatory (UVO) recorded a continuous tremor caused by the eruption near Gin-numa. Then, the activity proceeded intermittently until July 14. In the afternoon of July 11 a newly formed crater (Crater J) with many small pits up to several meters in diameter was observed (Plate 1, fig. 6). Most of the activities at Crater J are regarded as typical phreatic eruptions. Some of them, however, are considered to be phreatomagmatic, because a small amount of essential fragments (4 modal % essential dacite, Table 2) was found in the lapilli ejected from Crater J.

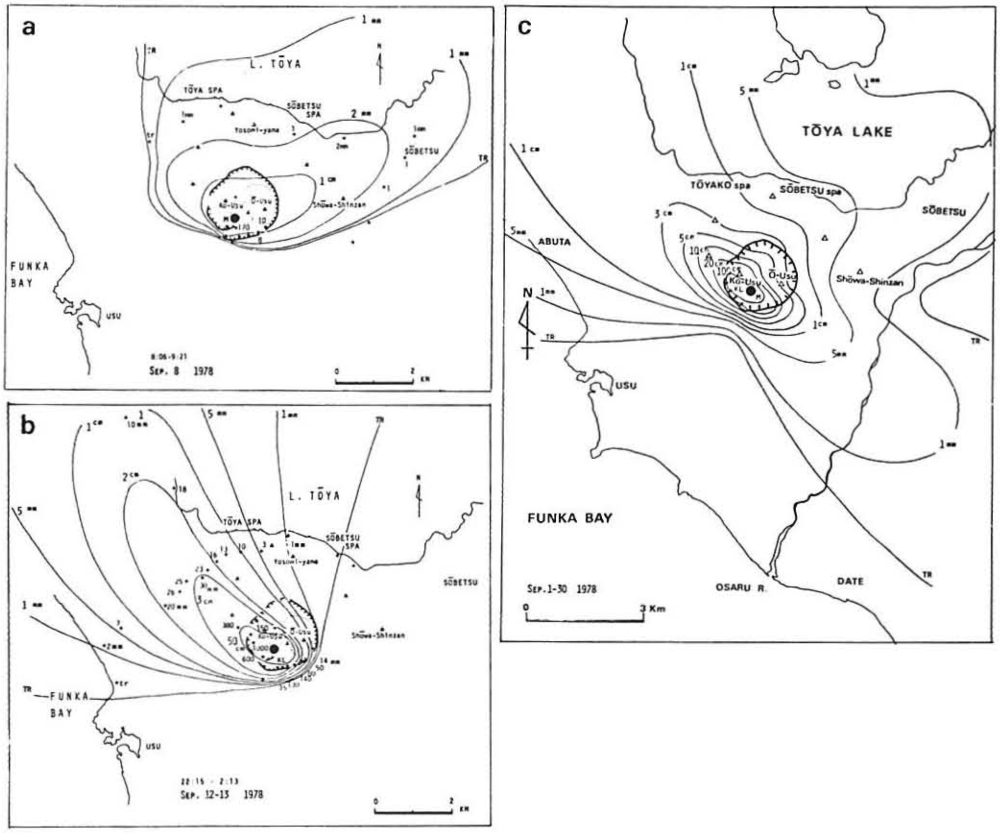
At 10:57 on July 15 a strong phreatomagmatic eruption took place abruptly near the NE border of Gin-numa, and opened a new crater (Crater K) about 120 meters in E-W diameter. The eruption is the most intense since the beginning of the Second Stage, yielding



Text-fig. 5 Map showing the distribution and thickness of the ash-fall deposits; (a) August 16, (b) August 24, (c) August 29, 1978, and (d) cumulative thickness contour lines of the ash-fall deposits produced in August, 1978.

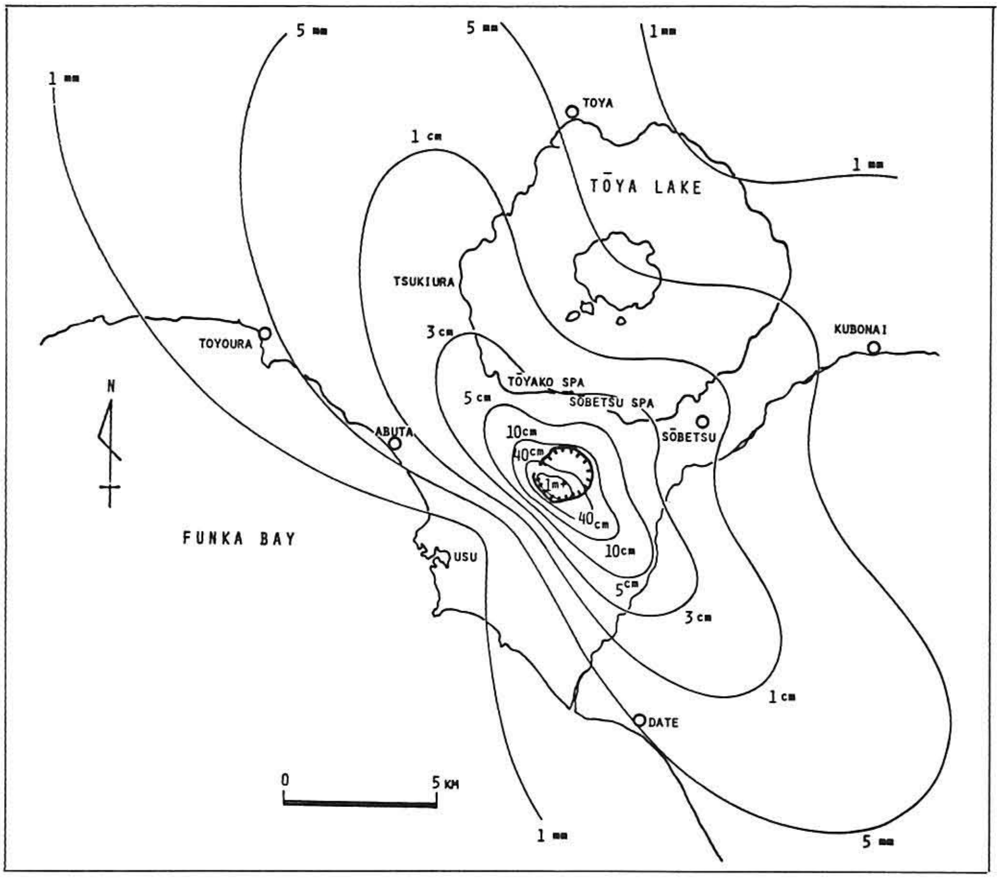
an ash-fall deposit reached approximately 10 mm in thickness on the northern flank of Usu Volcano. At about 12:35, 14:00 and 15:50 in this afternoon considerably severe eruptions occurred from Crater K.

On the next morning, July 16, another new crater (Crater L) which was produced by several big eruptions of phreatomagmatic nature was found between Craters J and K. A number of severe eruptions occurred until sunset (Plate 2). Some of the eruptions were accompanied by volcanic lightning. The eruption clouds were blown northward by the wind



Text-fig. 6 Map showing the distibution and thickness of the ash-fall deposits; (a) September 8, (b) September 12–13, 1978, and (c) cumulative thickness contour lines of the ash-fall deposits produced in September, 1978.

and produced an ash-fall deposit more than 10 mm at Tōyako Spa. It is significant that a considerable number of dacite blocks vesiculated in various degrees were ejected from Crater L. After that, a number of smaller eruptions occurred intermittently. The biggest eruptions in the Second Stage took place at 17:05 on August 16. As shown in Plate 5, the ash cloud rose up violently from all sides of the somma. Most of the cloud trailed toward northeast, resulting in a widespread deposition of ash-fall (Text-fig, 5a). The cloud partly flowed over the somma and moved down on the NE slope of the volcano similarly to nuée ardente. However, the cloud was not hot at all, according to many persons who were caught in the cloud on the northern foot of Usu Volcano. The volume of ash thrown out by this eeruption is calculated as much as $2 \times 10^6 m^3$, which is the maximum throughout the Substages I, II and III. A large number of volcanic blocks were also ejected and fell within an area 800 m from the crater, and some of them flew over the southern rim of the somma. This eruption occurred from both Craters K and L, and also from another big crater newly opened at the



Text-fig. 7 Map showing the cumulative thickness contour lines of the ejecta produced by the Second Stage eruptions in 1977–1978.

southern border of Gin-numa (Crater M, Text-fig. 1). Then, Craters J, K, L and M combined with each other, forming one big depression which was called "Gin-numa Crater".

After the severe eruption on August 16, recurrent phreatic and phreatomagmatic eruptions occurred every day with a duration of several seconds to several minutes. Typical cypressoid jets which reached a few hundred meters high were observed. The eruptions began progressively to eject light-colored dry ash, and the clouds changed lighter in color (Plate 3).

In the early morning of August 24, an unforgettable eruption occurred from Crater K. From 4:10 to 4:28, a fire-column glowing red to reddish-yellow about 300 m high above the summit of Usu Volcano, was observed in the dawn sky from the town of Usu, 4 km southeast from the summit (Plate 6, fig. 3). This eruption characteristically yielded a number of vesiculated dacite blocks. The degree of vesiculation is the highest of the essential blocks ejected during the Second Stage, as described later. Another characteristic feature of the eruption is shown in the modal analysis of the lapilli, in which the essential fragments amount to more than 48 modal % (Table 2). Accordingly, it is noticed that the eruption of August 24 shows a magmatic nature.

After the eruption, ejection of a considerable amount of dry ash of light grey color continued from Crater K. The ash consists mainly of essential dacite powder as discussed later. Such phreatomagmatic eruptions proceeded intermittently every day, accompanying with many phreatic ones. The eruptions which occurred at 17:57 on August 29, 10:55 on September 7, and 8:06 on September 8, were considerably violent. Distribution maps of each ash-fall deposit are given in Text-figs. 5 and 6. The explosive activities in early September mainly occurred from Crater M, from which a large number of essential dacite blocks, mostly in hot state, were also thrown out, but no vesiculated blocks were observed among them.

At 22:15 on September 12, just after the local earthquake swarm reached a maximum in frequency, a severe magmatic eruption broke out from Crater K. About 10 minutes after the beginning of the eruption, a red fire-column appeared, which grew up to 700 m in maximum height above the crater, being accompanied by abundant lightning. From 22:25 to 22:35, the fire-column was observed from the southern flank of the mountain (Plate 6, fig. 4). Then it gradually extinguished and the eruption stopped at 23:07. The next eruption began at midnight on September 12–13, and a fire-column rose up to about 500 m high. The column was repeatedly observed from 1:01 to 1:50. The eruption cloud was transported by the wind toward northwest, and a thick ash- and lapilli-fall deposit was formed on the northwest flank of the volcano (Text-fig. 6b). The deposit derived from the first eruption (22:15–23:07) consists of 84 modal % of essential dacite with minor accidental fragments (Table 3). This fact indicates that the eruptions of midnight on September 12–13 were caused directly by a magmatic action.

After that, eruptions occurred intermittently from the Crater M. In the beginning of October, the eruptive activity of Usu Volcano calmed down. Only a few minor eruptions were recorded on October 5, 6 and 9. Finally, on the major fault, east of the Gin-numa Crater (Text-fig. 1), Crater N was newly formed by the phreatic eruptions on October 17, 18, 21 and 27. Since then, no eruptions have been observed up to the present (August, 1979).

Craters

Development of the 14 craters (Craters A – N) which were formed by the eruptions during the Second Stage (Substages I, II and III), has been well ascertained as described earlier. These craters are distributed along the southwestern foot of the newly growing roof-mountain as shown in Text-fig. 1. The eruption points are very significant in considering of uplifting of the present magma.

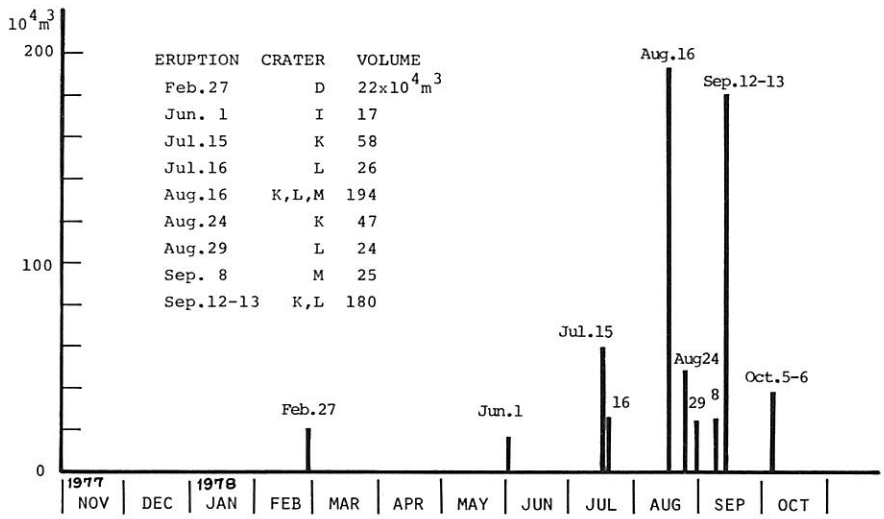
In the case of the formation of the Shōwa-Shinzan lava dome on the eastern foot of Usu Volcano in 1944–1945, the explosive eruptions occurred from several points aligned in a ring which represents the border circle of the extruding dacite dome (Ishikawa, 1950:

Mimatsu, 1962). During the 1910 activity of Meiji-Shinzan on the northern foot of Usu Volcano, 45 craters were formed in total, most of which are located along a tectonic line which coincides with the southern border of the new cryptodome (Omori, 1911; Sato, 1913).

The alignment of Craters A – N in the present case, probably indicates that the dacite magma has been intruding along the NW – SE trending major fault, which coincides with the southwestern border of the roof-mountain. The position of the magma head may be restricted within a narrow limit of the distribution area of the craters.

Distribution of the Ash-fall Deposits

Distribution and thickness of each ash-fall deposit produced by the Second Stage eruptions from November 16, 1977, to October 6, 1978, have been traced as shown in Text-figs. 2 – 6. The field survey of the distribution of ash was carried out just after each eruption, accordingly the ash deposits were not yet wet in many cases. As the eruption cloud was brought away toward the leeward of the wind, the distribution pattern of the ash-fall deposit was controlled almost entirely by the wind direction. For this reason the cumulative thickness contour maps are also controlled by the prevailing wind in this region. As shown in Text-fig. 7, the total thickness contour lines for all the ash-fall deposits of the Second Stage, are characteristically elongate in both directions of northwest and southeast. This pattern is very similar to that of the major eruptions of the First Stage, in August 7–14, 1977.



Text-fig. 8 Volume of the ejecta produced by notable eruptions in the Second Stage.

Volume of the Ash-fall Deposits

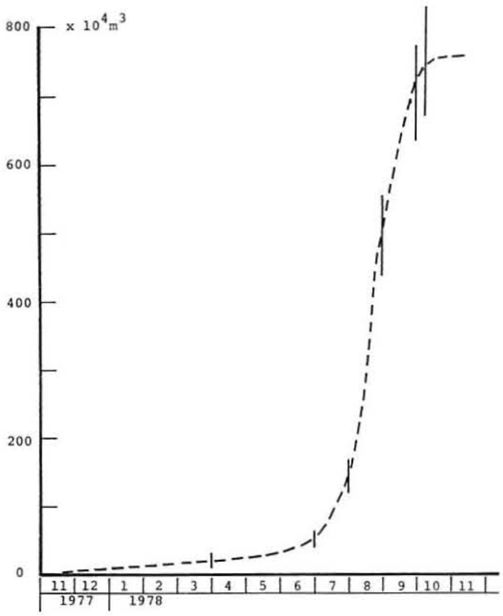
Volume of the 1977–1978 tephras ejected from Usu Volcano was calculated on the basis of the thickness contour lines. The results are summarized in Table 1.

The volume of the tephra produced by the major pumice eruptions from August 7 to 14, 1977, amount to as much as $8300 \times 10^4 m^3$ (Katsui et al., 1978). The volume of the ejecta yielded by the explosive eruptions throughout the Second Stage amount to $750 \pm 80 \times 10^4 m^3$, being approximately equivalent to one-tenth of the volume of the 1977 tephra.

Table 1 Total volume of the 1977–1978 ejecta.

FIRST STAGE	ΣAug. 7–14, 1977	8300×10^4 m³
SECOND STAGE		
SUBSTAGE I	Nov. 16, 1977–Mar. 13, 1978	24×10^4 m³
SUBSTAGE II	Apr. 24–Jun. 28, 1978	31×10^4 m³
SUBSTAGE III	Jul. 9–31, 1978	92×10^4 m³
	Aug. 1–31, 1978	350×10^4 m³
	Sep. 1–31, 1978	210×10^4 m³
	Oct. 1–27, 1978	47×10^4 m³
	Σ Nov., 1977 – Oct., 1978	$750 \pm 80 \times 10^4$ m³

During the Second Stage the eruptions became intense with time as already mentioned, and the volume of ejecta produced by each eruption also increased gradationally. In Text-fig.



Text-fig. 9 Cumulative curve for the volume of ejecta produced in the Second Stage.

8, the volume of some thick and widespread tephras is given versus time. It is evident from the figure that the volume of the tephra ejected in the Substage III increased notably. Such progressive pattern of the activity is also clearly shown in Text-fig. 9, in which the cumulative curve for the volume of ejecta shows a moderate gradient up to July, 1978, then changes steeply from August to September, and finally becomes gently again.

Nature of the Ejecta

1) Modal Variation of the Ejected Fragments

Fifteen samples of the lapilli-size fractions (4–32 mm) of the ejecta yielded by the eruptions during the Second Stage from November 16, 1977, to October 6, 1978, were modally analysed by means of counting the number of those of different nature. Besides the essential dacite fragments, they are composed of the 1977 pumice, accessory fragments such as dacite lava and pumice mostly derived from the 1769, 1822 and 1853 nuée ardente deposits, the 1663 Us-b pumice, Ko-Usu dome lava, and basaltic rocks from the Usu-somma lava, and accidental fragments from the basement rocks such as welded tuff, Tertiary volcanics, and quartz diorite plutonics. The results of the modal analyses are shown in Table 2 and Text-fig. 10. Such a modal composition is useful to consider the nature of eruption and the mechanism of rising of magma, and to estimate the internal structure of volcano.

All of the materials ejected by the phreatic eruptions in Substage I are derived from the pre-existing rocks under the Craters A – H. No essential dacite derived from the new magma was found. Modal variation throughout the Substage I shows a tendency with time to increase in the Ko-Usu dome lava and to decrease in other dacite, the somma lava, and basement volcanics. All the craters are located on the northeastern side of the Ko-Usu dome. It is inferred from the nature of these ejecta that the geologic sequence beneath the eruption points consists of the Ko-Usu dome lava at the top, natural brick baked by the dome lava, nuée ardente deposits, various air-fall deposits including the Us-b pumice, the somma lava, and the basement volcanics and plutonics, in descending order. If ejection of these materials was restricted above the explosion level, the tendency of the modal variation of ejecta may indicate that the explosion level moved upward during the Substage I.

Volcanic lapilli ejected by the Substage II eruptions characteristically contain trace or small amounts of the essential dacite. For instance, the essential dacite fragments thrown out on June 1, 1978, attain more than 18 modal %. Though the eruption was triggered by steam explosion, the essential ejecta are thought to have been derived directly from the solidifying part of the magma. Such an eruption may be classified as phreatomagmatic one. The nature of this eruption was also confirmed by the ejection of "hot" essential dacite blocks, which was observed at midnight on June 1.

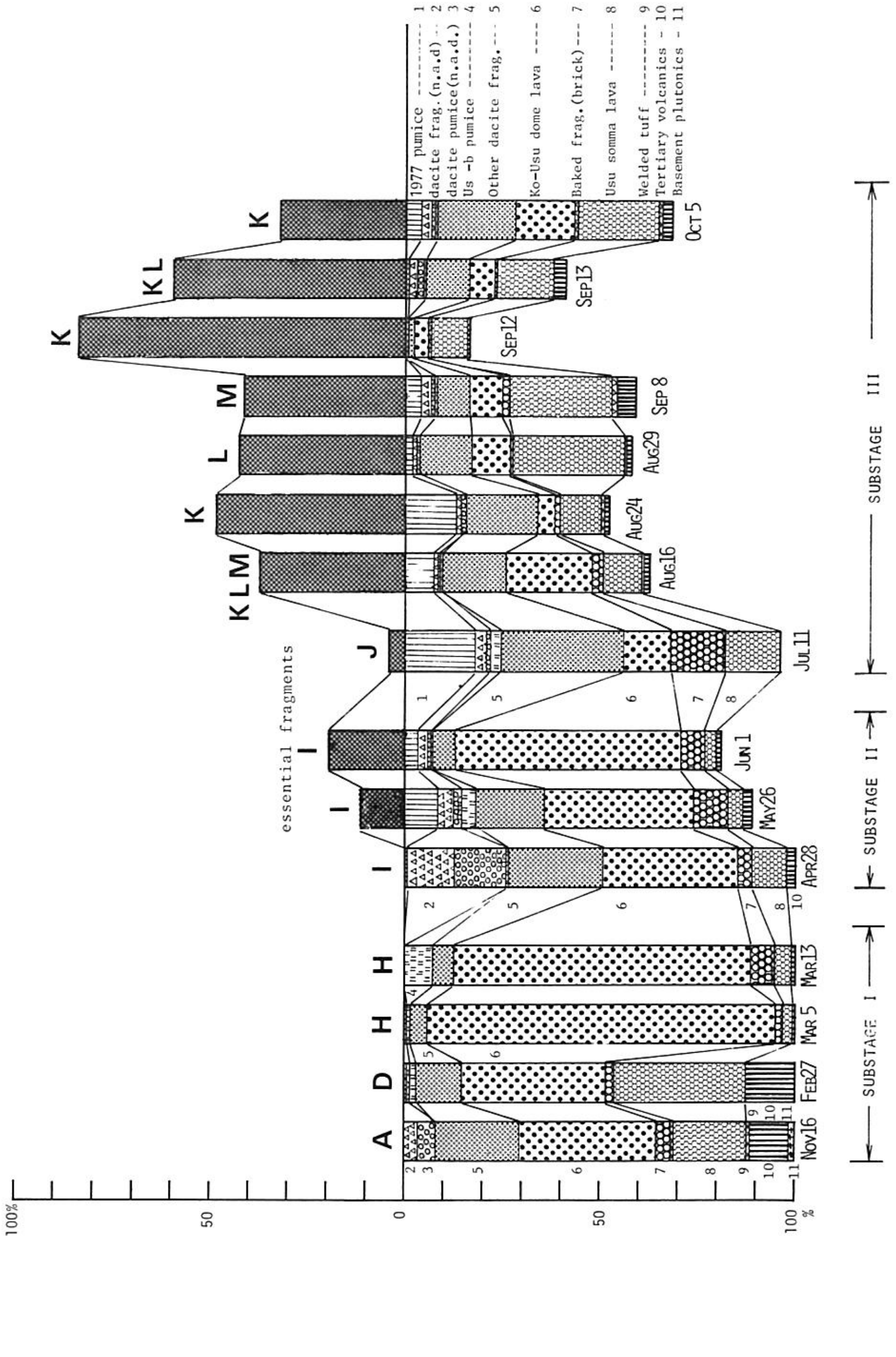
The modal composition of the accessory and accidental ejecta displays a similar tendency to that of the Substage I, i.e. increase in the fragments from the Ko-Usu dome lava and decrease in those from the somma lava and another accessory dacite are notable with progression of the eruption. This tendency can be most probably interpreted in terms of the upward movement of the magma. Because the Crater I is situated on the eastern side of the Ko-Usu dome, the modal variation of the accessory and accidental ejecta seems to have a similar tendency to that of the Substage I.

Table 2 Modal analyses of the Usu 1977-1978 volcanic lapilli ejected from Craters A–M.

Date of eruption	Nov.16	Feb.27	Mar.5	Mar.13	Apr.24	May 26	Jun. 1
Crater name	A	D	H	H	I	I	I
Sample No.	1116-1	227-5	305-3	318-2	428-10	526-1	602-6
Number of fragments	309	154	217	194	421	296	630
New essential fragments	0	0	0	0	0	11.1	18.6
1977 pumice	0	0	0	0	0.7	8.4	3.3
Dacite frag. from n.a.d.	3.6	0.7	0.5	0	12.4	4.1	2.7
Dacite pum. from n.a.d.	4.5	0.7	0	0	13.1	2.0	0.8
Us-b pumice	0	1.3	0.9	7.2	0.7	3.4	0.2
Other dacite fragments	21.4	11.7	4.2	5.2	24.5	17.2	5.7
Ko-Usu dome lava	34.9	37.0	89.9	76.3	34.0	38.6	58.3
Baked fragments (brick)	4.5	1.9	1.8	6.2	3.7	8.8	6.8
Usu somma lava	19.1	33.8	2.3	4.1	8.8	3.7	2.4
Welded tuff	0.3	0	0	0	0	0	0
Tertiary volcanics	10.4	12.9	0.5	1.0	2.1	2.7	1.2
Basement plutonics	1.3	0	0	0	0	0	0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Date of eruption	Jul.11	Aug.16	Aug.24	Aug.29	Sep.8	Sep.12	Sep.13	Oct.5
Crater name	J	K.L.M	K	L	M	K	K.L	K
Sample No.	712-2	820-1	824-3	830-2	908-2	912-5	913-2	1007-2
Number of fragments	269	289	197	340	281	830	370	375
New essential fragments	4.1	37.4	48.2	42.4	40.9	83.5	59.2	32.3
1977 pumice	18.2	7.6	13.2	1.8	3.9	0.8	1.1	4.0
Dacite frag. from n.a.d.	3.0	0.7	1.5	0.9	2.8	0	1.9	2.4
Dactic pum. from n.a.d.	1.1	0.7	1.0	0.3	0.7	0	1.6	0.8
Us-b pumice	2.5	0.3	0	0	0.4	0	0.3	0.8
Other dacite fragments	30.9	15.9	18.3	14.1	8.2	1.2	11.9	20.3
Ko-Usu dome lava	11.9	22.8	4.1	9.7	8.6	3.5	5.9	14.9
Baked fragments (brick)	13.8	2.8	1.0	0.3	1.8	0.6	0.6	1.1
Usu somma lava	13.8	9.4	10.7	28.7	25.6	10.2	14.3	20.5
Welded tuff	0.7	0.7	1.0	0.3	1.4	0	0	0.5
Tertiary volcanics	0	1.7	1.0	1.5	5.7	0.2	3.2	2.4
Basement plutonics	0	0	0	0	0	0	0	0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

n.a.d.: nuée ardente deposits



Text-fig. 10 Modal variation of the 1977–1978 ejecta in lapilli size. Upper half showing the modal composition of the essential dacite fragments. A – M are name of craters.

During the Substage III, a large amount of essential dacite fragments were ejected by big eruptions, such as those of August 16, 24, 29 and September 8 and 12–13 (Table 2). In many cases, more than 40 modal % essential fragments are included in the ejecta. Especially, those in the ejecta of the September 12 eruption exceed 80 modal %. This is the most characteristic feature during the Substage III eruptions. Such abundant essential fragments, some of which are fairly vesiculated as will be described later, were produced apparently by magmatic eruptions.

The content of the fragments of the Ko-Usu dome lava in the Substage III ejecta is clearly smaller than that in the Substages I and II ejecta. The decrease of the Ko-Usu dome lava in the ejecta may be ascribed to migration of the eruption point away from the dome. Basaltic fragmetns of the somma lava ejected in the Substage III are more abundant than those in the Substage II. This seems to indicate that the explosion might have occurred at a slightly lower level than that of the Substages I and II.

Variation diagram of the modal composition for the ejecta of the Substages I, II and III is given in Text-fig. 10. It is obvious that the essential dacite fragments appeared in the Substage II at first, and the amount increased with progression of the eruptions, reaching to the maximum on September 12 in the Substage III, and then decreased.

2) Vesiculation of the Essential Ejecta

The pumice ejected by the eruptions from August 7 to 14, 1977, shows a considerable difference in vesiculation. Apparent density of the pumice from the Us-1977-I pumice-fall deposit (Big I) ranges from 0.25 to 1.45 g/cm^3, the Us-1977-II (Big II) from 0.75 to 1.7, the Us-1977-III (Big III) from 0.6 to 1.75, the Us-1977-IV (Big IV) from 0.45 to 1.2, and the Us-1977-SB (SB) from 1.75 to 2.25. It is evident that the degree of vesiculation of the essential ejecta decreases with time, except for that of the Us-1977-IV which ejected from a new crater apart from the earlier ones. This can be interpreted in terms of water in the magma, which may have concentrated in the apex.

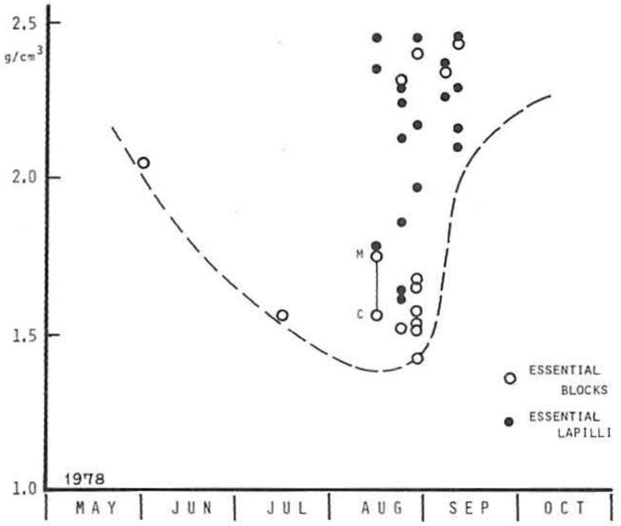
Apparent densities of some essential ejecta thrown out by the Second Stage eruptions in 1978 are given in Text-fig. 11. In this case, the vesiculation degree of the essential ejecta became greater generally with progression of the eruptions, and reached to the maximum, then rapidly became less. The most vesiculated essential ejecta, about 1.4 g/cm^3 in apparent density, were thrown out on August 29.

The 1977–1978 activity of Usu Volcano is characterized by two vesiculations of the dacite magma; the first vesiculation occurred in August 7–14, 1977, and the second one in summer of 1978. The vesicularity of the essential fragments ejected in the Second Stage increased with their volume of ejection, as mentioned earlier.

3) Nature of the Ash

A preliminary study on the ash ejected in August 7–14, 1977 has been reported by Katsui et al. (1978) and Kondō et al. (1978). During the Second Stage, dry ash samples (<2 mm) were also collected just after the eruption from the points 0 to 3.5 km from the sources. The characteristic feature of the ash samples is given in Table 3.

The ashes ejected from Craters B, H and I were strongly acidic (pH=3.4–5.9), and



Text-fig. 11 Variation of the apparent densities of the essential dacite blocks and lapilli.

rich in water-soluble Cl^- (495-17260 ppm) and SO_4^{2-} (160-4830 ppm), as shown in Table 3. By contrast, those from Craters K, L and M were neutral or weakly alkaline (pH= 6.8–8.5), and showed a slight decrease in the concentration of the water-soluble Cl^- (421-1064 ppm) and SO_4^{2-} (256-1031 ppm). Matsuo et al. (1977) reported that the 1977 ashes which erupted from the Craters 1, 2 and 3 were fairly high in Cl/S molar ratio (0.6–3.8). When the Cl/S molar ratios of the water-soluble components of the ash (1.9–19.2) ejected from Craters A, B, H and I are also taken into consideration, it is suggested that the temperatures of the coexisting gas phase with these ashes were very high.

As shown in Table 3, the ash samples contain 2.5–6.2% clay. The clay fraction ($<2\mu$) separated from the samples is characterized by the presence of abundant montmorillonite and subordinate chlorite and metahalloysite. These clay minerals are considered to have derived from the atrio-deposits on the summit of Usu Volcano (Kondō, 1969; Matsuo et al., 1977; Katsui et al., 1978; Kondō et al., 1978). The ejected ash had a high adsorptivity and viscosity, and also showed high dispersion in air and water. Such properties are probably due to the presence of the montmorillonitic clay in the ash. The presence of such clay minerals in the ash gave rise to severe devastation to the urban, forest and agricultural lands near the volcano during the eruptions on rainy days.

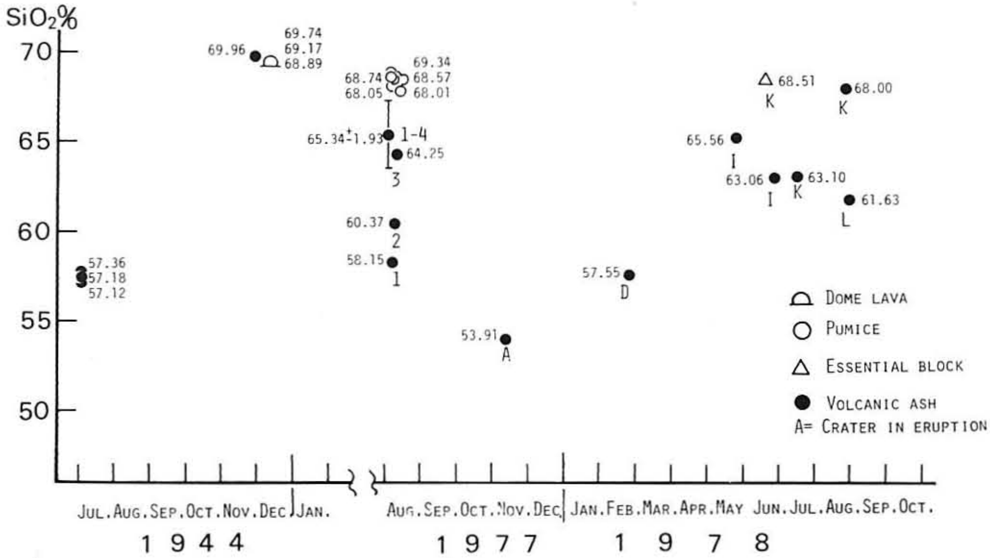
The silica contents of the 1977–1978 ashes, pumices and essential blocks are plotted in a variation diagram together with those of the 1944 tephra (Shōwa-Shinzan) (Text-fig. 12). The silica contents of the 1977–1978 ashes show a wide range from 53.91 (Crater A) to 68.00 wt % (Crater K). The difference in the color of dry ash may depend on the chemical and mineralogical compositions. In this connection an interesting relationship is found between the variation in silica contents of the ash and the sequence of the Second Stage eruption. As shown in Table 3 and Text-fig. 12, the ashes ejected in the Substage I (typical phreatic eruptions) are greyish brown or grey in color and poor in silica (SiO_2 =

Table 3 Some characteristics of the Usu 1977–1978 ash.

Date of deposition	Crater in eruption	Ash (dried) Color*	SiO_2 (wt %)	Median (Md, mm)	PH (H_2O)	Water-soluble anions Cl^-	SO_4^{2-}	<2μ clay (wt %)	Clay mineral composition**
1977									
Aug. 7	1 (Big I)	Yellowish gray (5Y 6/1)	58.15	0.06	8.18	103ppm	282ppm	6.05	Mont
Aug. 14	3(SB)	Yellowish gray (5Y 6/1)	64.25	0.29	7.32	69	292	4.25	Mont
Nov. 16	A	Grayish brown (7.5YR 6/2)	53.91	0.05	6.79	832	638	3.75	Mont
1978									
Jan. 13	B	Dark grayish yellow (2.5Y 4/2)	n.d.	0.05	3.37	3804	750	2.45	Mont
Feb. 27	D	Yellowish gray (2.5Y 5/1)	57.55	0.04	7.61	655	569	5.91	Mont> Chl> 7Å Hallo:
May 25	I	Light gray (7.5Y 7/1)	65.56	n.d.	4.19	2066	1150	n.d.	n.d.
Jun. 28	I	Gray (N 4/0)	63.06	0.34	5.88	495	450	6.19	Mont
Jul. 15	K	Gray (7.5Y 6/1)	63.10	n.d.	7.71	520	694	n.d.	n.d.
Aug. 24	K	Grayish white (N 7/0)	68.00	0.05	7.81	520	256	4.16	Mont

*Munsell's color notation, **Mont: Montmorillonite, Chl: Chlorite, 7Å Hallo: Metahalloysite

53.91–57.55 wt%), whereas in the Substages II and III (phreatomagmatic-magmatic eruptions) the grey or greyish white and silica-rich ashes (SiO_2 = 61.63–68.00 wt%) become abundant. It is noticed that the ashes produced by the magmatic eruptions are mostly



Text-fig. 12 Relation between the sequence of eruption and the SiO_2 contents of ejecta. Source of data: Minakami et al. (1951), Yagi (1949), Oba (1966), Matsuo et al. (1977), Katsui et al. (1978), Hokkaido Natl. Agric. Exp. Stn. (1978), Kondō et al. (unpubl.)

consisted of the essential dacite, such as the greyish white ash (SiO_2 = 68.00 wt%) which was ejected from Crater K on August 24, 1978.

Character of the Eruptions in 1977–1978

1) Types of the Eruption

Pumice Eruptions: The four big eruptions occurred in August 7 – 9, 1977, produced a series of widely dispersed pumice- and ash-fall deposits (Us-1977-I, II, III, & IV,). According to Walker's (1973) classification based on the area of dispersal and degree of fragmentation of ejecta, the eruptions can be classified into a sub-Plinian type (Suzuki et al., in preparation).

Phreatic Eruptions: The Substage I eruptions occurred from Craters A – H. The duration of individual eruptions ranges from a few to several hours or a little longer. The eruption is not so violent at the beginning. The ejecta consist almost entirely of ash. Small amounts of volcanic blocks and lapilli are distributed within a limited area less than one hundred meters from the crater. All of the ejected fragments are composed of accessory and accidental rocks derived from the intravolcano formations near the surface. No essential fragment has been found. Such eruptions can be considered to have been caused by the secondary steam which was generated by heating of the groundwater surrounding the magma (Aramaki, 1975).

Phreatic-Phreatomagmatic Eruptions: The eruptions throughout the Substage II took place from Crater I. The individual eruption was slightly stronger than that of the Substage I. A small amount of essential materials was ejected in this substage. At midnight on June 1, an eruption accompanied by ejection of a large number of "red-hot" blocks was actually observed. The block falls baked the surrounding grey ash into orange-color at the contact. Such "hot" blocks are considered to have derived directly from the magma. It is not clear, however, whether the eruption was caused by a direct action of the magma or not. Because the materials ejected are partly essential, but the eruptions are considered to have been mainly caused by the secondary steam, several eruptions in the Substage II may at least be termed hydromagmatic or phreatomagmatic ones, based on the Macdonald's (1972) classification. Many phreatic eruptions also occurred during the Substage II. Therefore, the Substage II is generally regarded as a transitional stage from phreatic to phreatomagmatic eruption.

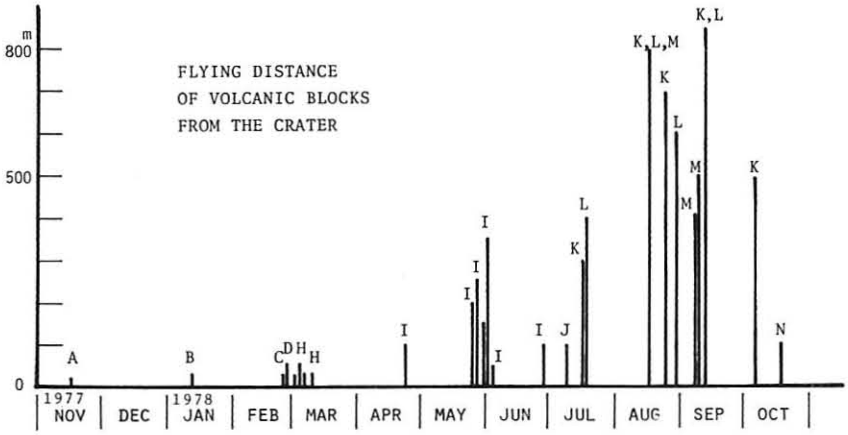
Phreatic-Phreatomagmatic-Magmatic Eruptions: A great number of eruptions took place during the Substage III as shown in Appendix, opening big Craters J, K, L, and M. A large volume of ejecta, including a considerable amount of essential materials, were also produced. Therefore, the eruptions in the Substage III generally show a phreatomagmatic nature, though many phreatic eruptions were also associated with them. The phreatic eruptions were intermittent at intervals of several seconds to a few minutes, producing ejecta without essential materials. However, several big eruptions on July 15 and 16, August 16, 24 and 29, and on September 7, 8 and 12–13 are characterized by ejections of essential materials considerably vesiculated. It is not certain whether all of the eruptions were generated directly by the action of magmatic gas or by secondary steam, but at least the eruptions on September 12–13 are considered to be magmatic ones, as the essential fragments amount more than 80 modal %. In the case of August 24 and September 12–13 eruptions, fire-columns were observed several times. It is evident that sudden release of gas from the magma played an important role in these eruptions, even though triggered by phreatic explosions at first.

2) Activities at the Crater I

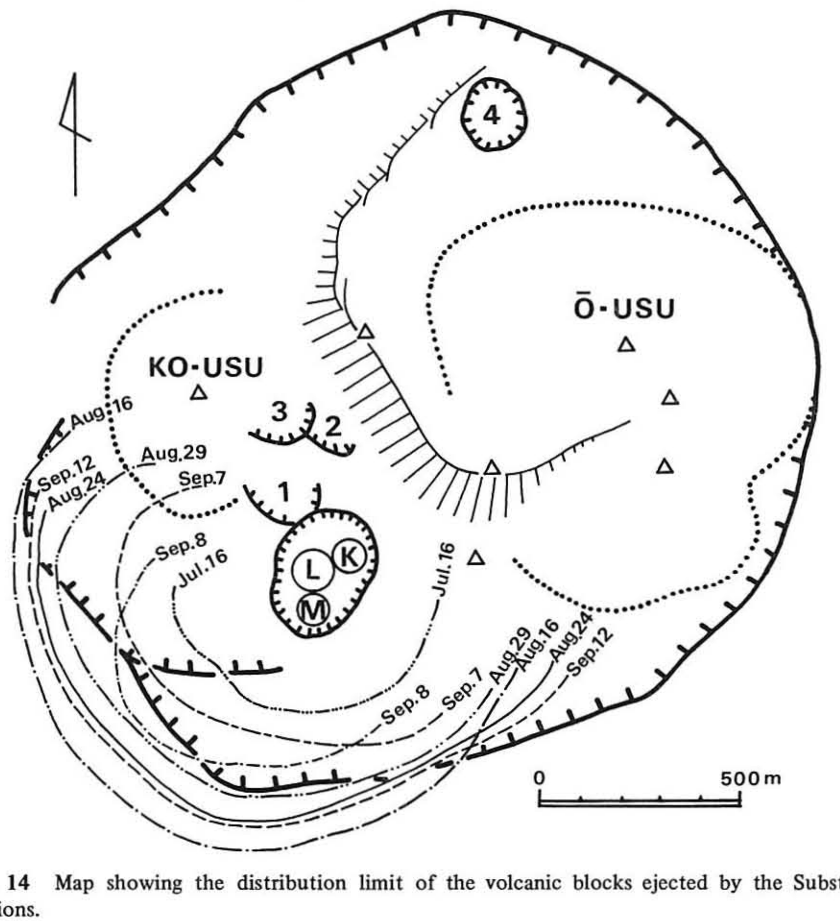
On June 1, 1978, essential "hot" blocks were ejected from Crater I. On the next day it was observed that a new dacite lava from which bluish transparent gas issued, was exposed at the northern wall of Crater I (Plate 6, fig. 1). With phreatomagmatic eruptions proceeding at the crater, a volcanic glow was observed above the crater in nights. In the night of June 16, the red-hot dacite lava appeared at the northern wall of the Crater I (Plate 6, fig. 2). According to measurement by an optical-pyrometer, the surface temperature of the dacite was more than 740°C (measured on June 28, 1978).

It is an important mode of occurrence that the dacite lava intruded into the pre-existing tephra (Us-b) and that the surface is surrounded by baked materials..

The dacite lava at the Crater I could be observed as a "red-hot" rock until September in 1978. In the case of appearance of the Shōwa-Shinzan lava dome, such "red-hot" spots were seen for about a month at each new exposure of the dacite lava (T. Ishikawa, personal communication). However, recent observations carried out from June to August, 1979,



Text-fig. 13 Flying distance of the volcanic blocks from the crater.



Text-fig. 14 Map showing the distribution limit of the volcanic blocks ejected by the Substage III eruptions.

confirmed that the red-hot rock retained high temperature, about 600°C, still glowing red at night.

3) Flying Distance of Ejecta and their Initial Velocities

The flying distance of volcanic blocks and bombs of the Second Stage eruptions in 1977–1978 is shown in Text-fig. 13. The maximum flying distance of ejecta in each substage is as follows: in the Substage I blocks about 10 cm in diameter were thrown 20 – 50 m from the crater, in the Substage II blocks 20–40 cm reached about 400 m, and in the Substage III the ejecta 50 cm in maximum diameter fell up to 800 m.

The distribution of the ejecta of big eruptions in the Substage III is shown in Text-fig. 14. The initial velocities (V_0) of ejecta of the big eruptions in the Substage III are shown in Table 4. The velocity was calculated from the following formulae using the observed horizontal and vertical distances from the crater, x and z, (Suzuki, in preparation),

$$x = \frac{1}{k} \int_{p=\tan\alpha}^{p=\tan\theta} \frac{dp}{\Phi(p) - C_2}$$

$$z = \frac{1}{k} \int_{p=\tan\alpha}^{p=\tan\theta} \frac{p\,dp}{\Phi(p) - C_2},$$

where

$$\Phi(p) = p\sqrt{1+p^2} + \log(p + \sqrt{1+p^2}),$$

$$C_2 = \Phi(\tan\alpha) + \frac{g}{kV_0^2 \cos^2\alpha},$$

$$p = \frac{dz}{dx},$$

α = angle of ejection,

θ = angle of fall,

k = coefficient of resistance = $\frac{C_D}{2} \cdot \frac{\rho_A}{\rho_R} \cdot \frac{A_R}{V_R}$,

C_D = drag coefficient (1.84 in the present calculation),

ρ_A = density of air,

A_R = sectional area of block,

ρ_R = density of block,

V_R = volume of block,

It is noticed that the flying distance increased with time from the beginning of the Second Stage and reached a maximum in August–September, 1978. Increasing of outburst power is also expressed in the maximum initial velocity of the ejecta. That of some big eruptions in the Substage III exceeded 100 m/sec, especially it attained 126 – 140 m/sec on August 24 and 120 – 129 m/sec on September 12–13, 1978.

4) Growth of the Eruption Cloud

The main eruptive activity in the Second Stage occurred from Craters J, K, L and M from July 9 to September 13, 1978. Several series of photographs of the eruptions were

Table 4 Maximum initial velocities of the ejected blocks.

DATE	CRATER	Vo (m/s)
Jul. 16	L	71–77
Aug. 16	K, L, M	107–133
Aug. 24	K	126–140
Aug. 29	L	99–119
Sep. 7	M	76–93
Sep. 8	M	92–101
Sep. 12	K, L	120–129

taken in order to analyse the growth of eruption clouds (Plates 4 and 5).

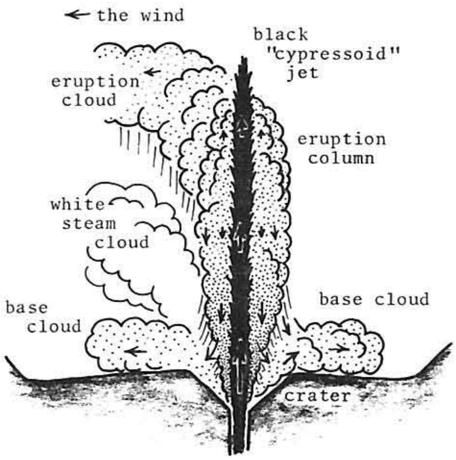
Height of the eruption cloud of phreatic and phreatomagmatic eruptions in this term was generally less than 2,000 m above the crater. In most cases of the small eruptions the height ranged between 500 to 1,000 m. Exceptionally, the eruption cloud on August 16, 1978, carrying a considerable amount of ash, exceeded about 3,000 m high. Such eruption clouds usually trailed leeward of the wind.

As seen in Plates 4 and 5, an ash-laden, convoluted, cylindrical column, having a cap of "cauliflower"-shaped cloud, was observed above the crater. The ash-laden columns commonly rose several tens to a few hundred meters into the air. A black "cypressoid" jet, a term used by G. Imbó at the 1944 eruption of Vesuvius (Macdonald, 1972), rose up violently from the crater as shown in Text-fig. 15. Many volcanic blocks were ejected beyond the top of the jet. At times when the eruptions produced a large amount of dry ash, the black jet was mantled with an eruption column with a cap of "cauliflower"-like cloud. Similar explosion clouds with the black "cypressoid" jets have been reported from the 1952–1953 activity of the Myōjin reef (Morimoto, 1960), the 1973 activity of Nishinoshima (Ossaka, 1974), and other submarine eruptions.

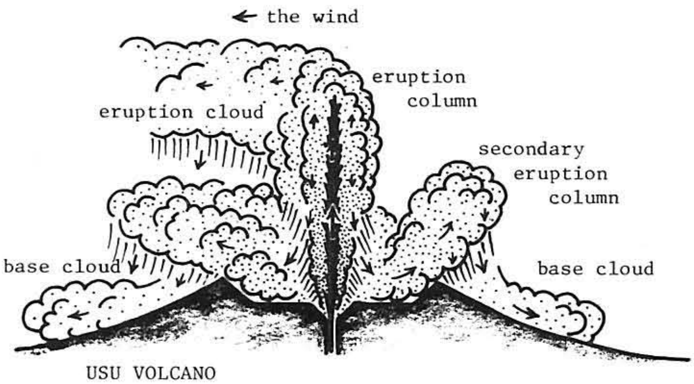
Another characteristic feature in the present phreatomagmatic eruptions is appearance of "base cloud." As shown in Plate 5, it is a ring-shaped base cloud which was produced around the vertical eruption column and horizontally moved outward. The base cloud is not so dense but carries only a small amount of ash. The deposit around the crater does not show a dune-like bedding (antidune structure). Velocity of the cloud was not so fast, being a few to several meters per second, according to analysis of the movie films. The growth mechanism of the base cloud is illustrated in Text-fig. 15. It can be explained that the base cloud is secondarily produced by fall-back of ejecta from the vertical eruption column above the crater.

At some considerably violent eruptions, as shown in Plate 6, the base cloud developed further into a secondary eruption column which rose up vertically from all sides of the Usu-somma wall. Text-fig. 16 shows the mechanism of growth of the base cloud developing into the secondary eruption column.

The base cloud is very similar to the base surge which occurred during the 1965 activity



Text-fig. 15 Schematic diagram showing the growth mechnism of base cloud formed by phreatomagmatic eruptions from July to August, 1978.



Text-fig. 16 Schematic diagram showing the growth mechanism of secondary eruption column and base cloud occurred on August 16 and September 7 and 8, 1978.

of Taal Volcano, Philippines (Moore, 1967). Moore explained that the term "base surge" is a ring-shaped basal cloud that sweeps outward as a density flow from the base of the vertical explosion column.

The base cloud appeared in the 1978 phreatomagmatic eruptions of Usu Volcano is considered to be different from the base surge defined by Moore in some aspects, i.e. mechanism of its movement (initially lack in a horizontal velocity), density of the cloud, and structure of the resultant deposits.

Concluding Remarks

Subsequent to the First Stage eruptions of sub-Plinian type in August, 1977, the Second Stage eruptions occurred intermittently from November, 1977, to October, 1978, opening

14 new craters in the somma-atrio of Usu Volcano. The volume of the ejecta produced by the Second Stage eruptions amounts to $750 \pm 80 \times 10^4 m^3$, being approximately equivalent to one-tenth of that of the First Stage tephra.

During the Second Stage, the character of activity varied from phreatic to phreatomagmatic and magmatic eruptions. The nature, volume, flying distance and maximum initial velocity of the ejecta varied also with time. Thus, in August–September, 1978, the eruption reached a maximum throwing a considerable amount of essential blocks at an initial velocity 120 – 140 m/sec. Then, the eruptive activity declined.

The 1977–1978 activity of Usu Volcano is characterized by two vesiculations of the dacite magma, the first vesiculation occurred in August, 1977, and the second one in August–September, 1978.

The Second Stage eruptions are considered to have been caused by the residual, viscous magma of dacite which intruded near the surface forming a new cryptodome. The location of the new craters opened in the Second Stage coincides with the southern border of the cryptodome. A small red-hot dacite mass on the northern wall of the Crater I, may represent a top of the magma.

The base clouds observed in the present activity may be one of the characteristic features of the phreatomagmatic eruptions in the Second Stage. Some diagnostic characters of the base cloud which distinguished it from Moore's base surge are pointed out in the earlier pages. Probably, appearance of the base cloud is not rare but supposed to be more common especially in phreatomagmatic eruptions of other volcanoes.

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Appendix

Records of the eruptions of Usu Volcano in 1977-1978

	DATE OF ERUPTION	AXIS	NAME	THICKNESS (mm)	CRATER
1977					
Aug. 7	9:10–11:13, 11:15–30.	S60°E	I	150 (Sonkai)	1
	13:31–.				
	16:20–.				
	18:22–.				
8	13:35–14:10.				
	15:20–18:00.	N40°W	II	300 (Konomi)	2
	19:00–.				
	23:40–	N45°W	III	230 (Konomi)	3
9	–1:55, 2:10–15.				
	4:45–7:30.	N10°E	DT	35 (Sōbetsu Spa)	3
	8:15–25, 8:55–9:05, 08–25.				
	10:20–11:05.	N75°E	NK	6 (Sōbetsu)	?
	11:20–13:55, 13:57–14:20.	S65°E	IV	110 (Sonkai)	4
	16:02–.				
12	8:12–9:00.	N35°W	MH	5 (Konomi)	3
13	22:37–				
14	–1:30, 35–55, 2:00–.	N70°E	SB	30 (Matsumoto-yama)	3

	DATE OF FRUPTION	AXIS	THICKNESS (mm)	CRATER (m)
1977				
Nov. 16	–5:40–9:05.	SE	tr (Kaminagawa)	A (3x3)
1978				
Jan. 13	–7:40–11:25–.	E-SE	tr (Shōwa-Shinzan)	B (5x5)
Feb. 25	15:57–16:56.	NE	tr (Sankei)	C (3x3)
27	–7:50–12:00.	ESE	5 (Sonkai)	D (15x20)
Mar. 1	–9:00–12:00–.	SE	tr (Ōdaira)	E (5x5)
2	–11:30–18:00–.	SE	tr (Ōdaira)	F (5x5)
3	15:13–16:00,	NW	tr (Tōyako Spa)	G (5x5)
	16:15–17:50–.	NE	tr (Sankei)	G

	4	–9:00.	W	tr (Izumi)	H (?)
	5	–6:30–9:00,	S	tr (Wakkaoi)	H (20×20)
		10:05–15:53–,	SE	tr (Ōdaira)	H
	6	–1:00–.	ESE	tr (Sekinai)	H
		–7:40–16:00–,	SSE	tr (Kami-Nagawa)	H
	7	–7:50–13:25–,	ENE-E	tr (Shōwa-Shinzan)	H
	8	–11:40–15:30–,	?	?	H
	9	–7:15–17:40–,	SSE-S	tr (Wakkaoi)	H
	10	–, ?, –,			
	11	–15:50–16:30–,	NE-ENE	tr (Sankei)	H
	12	–12:00–16:30–,	ESE	tr (Sonkai)	H
	13	–7:15–14:30–.	NNE	tr (Sōbetsu Spa)	H (30×30)
Apr.	24	–19:00–22:50–,	N-NW	tr (Tōyako Spa)	I (10×5)
	25	–0:30–.	NNW	tr (Tōyako Spa)	I (10×5)
May	24	–15:00–,	SSE	tr (Kami-Nagawa)	I (10×5)
	25	–8:00–9:00–, 12:18–,	NE-SE	1 (Kami-Nagawa)	I (50×30)
		13:47–, 15:35–18:20–,	E	tr (Sōbetsu)	I
		–19:25–20:40–,	NNE-N	2 (Tōyako Spa)	I
	26	–5:00–11:56–,	NNE	tr (Tōyako Spa)	I
	27	–13:15–21:00–,	ESE	tr (Ōdaira)	I
	28	–6:00–10:30–,	ESE	? (Ōdaira)	I
	29	–6:20–,	SE	tr (Kami-Nagawa)	I
		23:30–,	WSW	tr (Abuta)	I
	30	–6:40–8:15–,	WSW	?	I (80×40)
		–14:30–, –17:42–, –,	NW-S	?	I
	31	–, 11:36 (45"), 37–(10"), 51–(30"), 12:16–(1'), 34–(30"), 36–(15"), 37–(27"), 38–(7"), 39–(10"), 40–(20"), 41–(20"), (15"), 43–(20"), 43–(1'7"), 45–(1'), 47–(18"), 48–(35"), 51–(20"), (30"), 52–(10"), 53–(13"), (18"), 55–(20"), 56–(30"), 57–(20"), 58–(15"), (20"), 59–(5"), 13:00–(5"), 03–(15"), 05–(20"), 06–(33"), (5"), 07–(20"), 09–(25"), 10–(20"), 12–(17"), 15–(18"), 17–(13"), 18–(16"), 20–(30"), 22–(16"), 23–(20"), 27–(20"), 28–(23"), 29–(12"), (22"), 30–(25"), 40–(20"), 41–(6"), 46–(14"), 47–(12"), 52–(30"), 14:03–(35"), 04–(55"), 05–(55"), 06–(25"), 08–(7'50"), 17–(1'50"), 20–(2'15"), 24–(6'7"), 30–(8'10"), 42–(2'25"), 45–(1'10"), 50–(45"), 54–(4'), 15:01–(40"), 03–(1'20"), 19–(1'10"), 47–(10"), –,	E-SE	?	I
Jun	1	–12:00, –15:00,	S-SE	3 (Nagawa)	I (100×50)
		16:15–45, –19:30–, –,	SE	tr (Ōdaira)	I
	2	–, 8:20–30, –,	E-ESE	tr (Ōdaira)	I
		–, 11:00–25, –,	ESE	tr (Sonkai)	I
		–, 11:44–(40"), 46–(20"), 49–(1'), 54–(40"), 12:08–(10"), 15–(10"), 23–(1'), 53–(2'), 57–(10'30"), 13:33–(2'), 37–, 15:20,	ESE	tr (Sonkai)	I
	3	–11:35–16:30–,	NE	2 (Sankei)	I
	4	–10:30–11:00–.	?	?	I
	7	1:00–2:30–.	NE-ENE	tr (Sōbetsu)	I (130×70)

	27	–1:40–,	NW	tr (Tōyako Spa)	I
	28	–, 11:58–12:17, 12:23–, 58–, 14:16–, 32–42, 44–, 55–, 15:33–, –.	SE-S	tr (Wakkaoi)	I
Jul.	9	5:30–, –7:30–8:00, 14:00–,	?	?	J (?)
	10	–, ?, –,			
	11	–, 13:05–10, 21–25, 27–(30"), 16:30–17:00, 18:10–,			J (100x80)
	12	–, 11:00–, –, 16:00–,	?	?	J
	13	–, 13:30–, –, 18:00–,	?	?	J
	14	–, ?, –.			
	15	10:57–11:25*.	N	10 (Daito)	K (120x100)
		–12:35–, –14:00–, 16:48–58, 17:04–(1'), 22:35–(1'), 38–(3'), 41–(15"), 46–(1'30"), 50–(2'30"), 59–(6'), 23:05–(4'), 19–(3'), 48–(1'), 52–(15"), (10"), –,	N	3 (Tōyako Spa)	K
	16	0:07–(15"), –.	N	tr (Tōyako Spa)	
		4:42–, –6:20–,	N-NNW	10 (Konomi)	L (100x100)
		8:25–29(4'), 9:27–32*, 10:37–40, 11:10–14, 27–30, 45–(30"), 12:00–02, 04–05,	N	tr (Tōyako Spa)	L
		12:25–,	N	tr (Tōyako Spa)	K
		12:30–42, 13:46–51, 15:32–(5'), 52–(2'), 55–(5'), –16:15–, 17:30–, 17:30–, 22:35–39*, 53–(30"), 55–(30"), –,	N	tr (Tōyako Spa)	L (100x100)
	17	–, ?, –,			
	18	–, ?, –,			
	19	–, 16:30–, –, 21:54–(2'), 22:05–(1'), 35–(1'), –,	?	?	L
	20	–, –14:50–, –, 17:23–(2'), 18:45–(2'), 20:01–(3'), 50–(1'), –,	?	?	L
	21	–, 10:04–08, –,	?	?	L
	22	–, 22:37–40, 41–45, –,	SW	tr (Usu)	L
	23	–, 10:55–57, 58–59, 11:34–36, 41–(20"), 44–(15"), 45–(20"), 12:16–19, 27–(10"), 29–32, 33–34, 35–(5"), 13:24–(20"), 14:08–09, –,	?	?	?
	24	–, 11:08–09 (1'30"), 12:33–35 (2'), 16:02–04 (2'), 37–44, –,	NE-E	tr (Shōwa-Shinzan)	L
	25	–, 13:00–05, 13:27–30 (3'), 30–31 (1'), 35–37 (2'), 40–41 (1'), 14:12–(30"), 14:49–15:00, –,	ENE	tr (Sōbetsu)	L
	26	–, ?, –,			
	27	–, ?, –,			
	28	–, –11:00–, 13:29–30 (1'), 47–49 (2'), 14:44–45 (1'), –,	?	?	L
	29	–, 18:50–, –,	ENE	1 (Sōbetsu)	L
	30	–, ?, –,			
	31	–, 14:57–(15"), 16:44–46 (2'), 50–(10'), 17:55–57 (2'), –18:00–, 18:11–12 (1'), 17–(30"), 20–(15"), –,	NW	1 (Miharashi)	L
		–21:50–, –22:00' –,	NW	tr(Miharashi)	L
Aug.	1	–, 10:08–13, 47–(8'30"), 11:24–32–(8'), 40–46 (6'), 47–(30"), 13:37–(20"), 46–(15"), 14:11–23 (12'), 24–26 (2'), 29–(10"), 38–51 (13'), 15:14–15 (1'), 18–28 (10'), 55–(10"), 16:46–48			

	(2'), 48–(30"), 50–56 (6'), 16:59–(1'), 17:02–04 (2'), 04–(30"), 05–(15'), (6'), 18:10–13, –, 20:47–(30"), 21:04–06 (2'), 19–20 (1'), 22–(1'30"), 32–(1'30"), 39–(1'), 40–(10"), 56–(4'30")*, 22:14–17 (3')*,	NW-W	tr (Miharashi)	L
2	–, –8:35–, –, 11:29–32 (3'), 47–48 (1'), 12:05–20 (15'), 15:16–18 (2'), 15:21–(1'20"), –,	N	tr (Tōyako Spa)	L
3	–, 6:25–30, –, –16:45–, –17:17–,	W	tr (Irie)	L
4	–, 16:07–(5'), –,	?	?	?
5	–, 9:18–23, –,	E-ESE	tr (Sonkai)	L
	–, 13:46–14:04, 15:50–(15"), 16:04–(45"), 18–(15"), 33–(5'30"), 41–48 (7'), –, 18:18–20, –,	ESE	tr (Sonkai)	L
6	–, 9:05–14 (9'), 17–18 (1'), 38–(10"), 42–(10"), 44–(10"), 45–(30"), 47–(30"), 50–(1'10"), 51–(45"), 53–(2'30"), 56–(10"), 59–(1'30"), 10:03–04, 09–13, 13–(1'40"), 16–(1'30"), 18–19, 21–22, 24–25, 28–(5'30"), 34–(3'30"), 37' (2'30"), 41–42, 47–48, 49–55, 55–57, 58–59, 11:00–02, 41–45, 12:43–49, –,	ESE	tr (Sonkai)	L
7	–, 11:58–12:16 (18'), –, 18:16–22 –,	NE-E	tr (Shōwa-Shinzan)	L
8	–, 8:40–, 11:41–, 13:20–, 16:38–, 16:50–, –,	ENE	tr (Shōwa-Shinzan)	?
9	–, 8:40–, 10:10– (8'30"),	WSW-W	tr (Irie)	L
	11:40–, 12:30–(6'), 13:20–, 16:40–, –,	SE	tr (Muroran)	L
10	–, ?, –,			
11	–, 11:50–, 13:00–, 27–33, 38–, 50–, 14:00–, –,	W	tr (Irie)	L
	17:55–(20')*, –,	SE-SSE	2 (Kami-Nagawa)	L
12	–, 6:40–, 7:00–, –,	E-ESE	tr (Sonkai)	L
13	–, 6:30–, 7:30–, –,	?	?	L
14	–, ?, –,			
15	–, ?, –,			
16	–, 17:05–57*, –,	N-ENE	18 (Shōwa-Shinzan)	K,L,M
17	–, –6:30–,	SW	1 (Usu)	L
	–, 19:00–, –,	SSE	5 (Nagawa)	L
18	–, –6:30–, –,	W	1 (Irie)	L
	–14:00–, 16:10–20, –,	N	2 (Tōyako Spa)	L
19	–, ?, –,			
20	–, 10:35–, 53–, 11:07–, 14–, –,	N-NW	tr (Konomi)	L
21	–, ?, –,			
22	–, 10:15–24 (10'), 26–32, 35–38, 39–(30"), 41–44 (3'), 45–(30"), 48–49, –,	?	?	?
23	–, ?, –,			
24	3:24–, 4:10–28**,	ESE	20 (Sonkai)	K
	–, 22:10–11, 23:06–07*, 20–24*, –,	S	tr (Wakkaoi)	K
25	–, 6:00–, 55–, 10:35–, 11:27–29 (2'), 12:22–27, 13:19–25, 25–33, 14:15–17 (2'), 45–(10"), 52–57, 15:02–07, 16–25, 16:54–56 (2'), –,	S-SSE	tr (Wakkaoi)	K'
	17:17–20, 57–59,	E	(Sonkai)	K'
	18:10–(1'), 19:52–57 (5'), 21:30–32 (2'),			

	23:15–20, –,	NNW	tr (Tōyako Spa)	K'
26	0:33–35, –,	NNW	tr (Tōyako Spa)	K'
	11:04–09, 44–56,	E	tr (Shōwa Shinzan)	K'
	12:39–(10"), 13:18–22 (4'), –,	E	tr (Shōwa Shinzan)	K'
27	–, ?, –,			
28	–, 5:07–44, –,	N-NNW	tr (Tōyako Spa)	K'
29	–, 16:00–, 17:57–18:12*,	SE-ESE	10 (Kami-Nagawa)	L
	18:17–(1'), 19–(1'30"), 26–(20"), –,	SE	tr (Kami-Nagawa)	L
30	–, –8:00–, –,	?	?	?
31	–, 3:45–(10')*,	SSE	? (Date)	?
	4:47–(7'), –,	S	3 (Wakkaoi)	M
	11:38–44, 45–46, 51–52, –,	S	tr (Wakkaoi)	M
Sep. 1	–, 11:55–12:15,	SSE	? (Nagawa)	?
	12:49–54 (5')*, 14:49–(30"), –,	SSE	? (Nagawa)	?
2	–, 13:20–, 25–35, 35–(30"), 13:57–(13' 30"), 14:12–(30"), 14:12–15, –,	NW-NNE	3 (Tōyako Spa)	M
3	–, 5:00–, 10:30–11:20,	NW	? (Miharashi)	M
	11:50–53, 12:00–25, –,	NW-NNW	tr (Tōyako Spa)	M
4	–, ?, –,			
5	–, 15:57–(30"), 16:00–14, 17–(30"), 18–(30"), 19–(30"), –,	NE	2 (Sankei)	?
6	–, –14:15–, –,	ESE	tr (Sonkai)	?
7	–, 10:55–11:18*,	ESE	2 (Sonkai)	M
	11:19–22 (3'), 24–27, 28–29, 30–35, 35–43 (8'), 44–53, 51–52, 53–54, 55–(2'30"), 11:59–(15"), –,	ESE	tr (Sonkai)	M
	23:10–52, –,	SE	2 (Kami-Nagawa)	M
8	–, 8:06–9:06*, 12–18, 19–21, –,	NNE-ESE	2 (Sōbetsu Spa)	M
	13:35–56, –,	NE	1 (Sōbetsu Spa)	M
9	–, ?, –,			
10	–, ?, –,			
11	–, 10:05–(30"), 08–(30"), 09–(30"), 26–(1'),	SE	tr (Nagawa)	M
	12:42–(1'), 44–(1'), 49–(1'), 50–(1'), 13:00–06 (6'), 30-32 (2'), 40–(30"), 53–(30"), 14:19–(30"), 30–(1'), 37–(30"), –, –16:00–, –,	ESE	tr (Kami-Nagawa)	M
12	–, 12:28–48 (20'),	N-NNW	1 (Tōyako Spa)	M
	22:15–23:07**.	NW	8 (Miharashi)	K
13	–23:57–1:00**.	W-N	30 (Miharashi)	K
	1:01–15**, 1:25–50*, 55–2:06, 2:12–13 (1'),	N	? (Tōyako Spa)	L
14	9:50–,	WNW	?	?
	17:05–25, –,	W	tr (Izumi)	M
15	8:08–(1'30"), 10:06–(30"), –,	NW	? (Miharashi)	M
16	–, ?, –,			
17	–, ?, –,			
18	–, ?, –,			
19	–, ?, –,			
20	–, 22:10–18*, 20–32*	NE	1 (Sōbetsu)	?
21	0:30–35, 36–40, –, 9:04–(5'), –10:10–, 13:25–, 13:42–48, –,	NE	2 (Shōwa Shinzan)	?
	17:16–18, 19–20,–,	ESE	tr (Sonkai)	M
22	–, 15:52–54 (2'), –,	?	?	?
23	–, 15:38–, 16:05–07, 16:30–, –,	E	?	M
	21:00–,	E	?	M

	24	–, 15:48–56, 17:02–22, –,	?	?	M
	25	–, ?, –,			
	26	–, ?, –,			
	27	–, –11:55–, 12:25–, 12:40–, 17:35–(5'), –,	SSE	tr (Nagawa)	?
	28	–, 13:00–, 17:15–, 33–(5'), 51–(1'), –,	SE	1 (Kami-Nagawa)	?
	29	–, ?, –,			
	30	–, 7:30–, –, 14:20–(1'30"), 31–33, 33–(30"), 41–42, 44–(5'), 56–(5'), 15:39–40, 55–58, 58–(30"), 16:03–06, –,	?	?	M
Oct.	1	–, ?, –,			
	2	–, ?, –,			
	3	–, ?, –,			
	4	–, ?, –,			
	5	16:44–17:07.	SE	2 (Kami-Nagawa)	K
	6	–6:00–.	ESE	2 (Sonkai)	K
	9	–12:25–,	W	tr (Izumi)	?
	17	–4:00–, –,	SSE	tr (Date)	N
	18	10:00–, 16:10–18:30.	N-NE	2 (Sōbetsu Spa)	N
	21	4:00–, 8:08–(2').	SSE	tr (Date)	N (25×30)
	27	10:36–(5'), 44–51, 11:21–(30").	N	tr (Tōyako Spa)	N

Explanation of Plate 1

Fig. 1 Crater A, about 3 m across, formed by a phreatic eruption on November 16, 1977, at the point between Ko-Usu dome and new roof-mountain. Photo by K. Niida.

Fig. 2 Crater D, about 20 m across, formed by a phreatic eruption on February 27, 1978. Photo by K. Niida.

Fig. 3 Crater H formed by a phreatic eruption on the northeastern side of Ko-Usu dome. Photo by K. Niida on March 5, 1978

Fig. 4 New ash layers intercalated with snow at Kami-Nagawa on the southeastern foot of Usu Volcano. The ash ejected by phreatic eruptions on March 5, March 2, and February 27, from the surface to lower.

Fig. 5 Phreatic eruption at 17:15 on May 25, 1978, from the Crater I. Photo by K. Niida.

Fig. 6 Crater J with many active pits, July 12, 1978. Photo by K. Niida.

Explanation of Plate 2

Crater L in phreatic eruption, 11:13 on July 16, 1978. The black cypressoid jet about 100 m high consists mainly of accessory and accidental ejecta of sand, lapilli and block size. Photo by K. Niida.

Explanation of Plate 3

Phreatomagmatic eruption from Crater L, 13:25–33 on August 25, 1978. The eruption column with a cap of cauliflower-shaped cloud, about 250 m high, consists of a large amount of dry ash and essential dacite blocks. Crater M is observed at the right bottom. Photo by K. Niida.

Explanation of Plate 4

Figs. 1–6 Sequence of phreatomagmatic eruption, 13:30–31 on August 25, 1978, showing the growth mechanism of base cloud. The main eruption column as seen in Fig. 1 is falling down in the later pictures, then the base cloud appears in Figs. 3 and 4, and finally the base cloud collapses in Fig. 6. Photo by K. Niida.

Explanation of Plate 5

Figs. 1–6 The biggest eruption in the Second Stage, on August 16, 1978, showing the development of eruption column. Secondary eruption column as seen in Figs. 1 and 2 produces a base cloud in Figs. 3 and 4. Then the base cloud is rushing down the northern slope of the volcano and spreading further on the Tōya lake in Figs. 5 and 6. Photo by Mr. S. Iwamura.

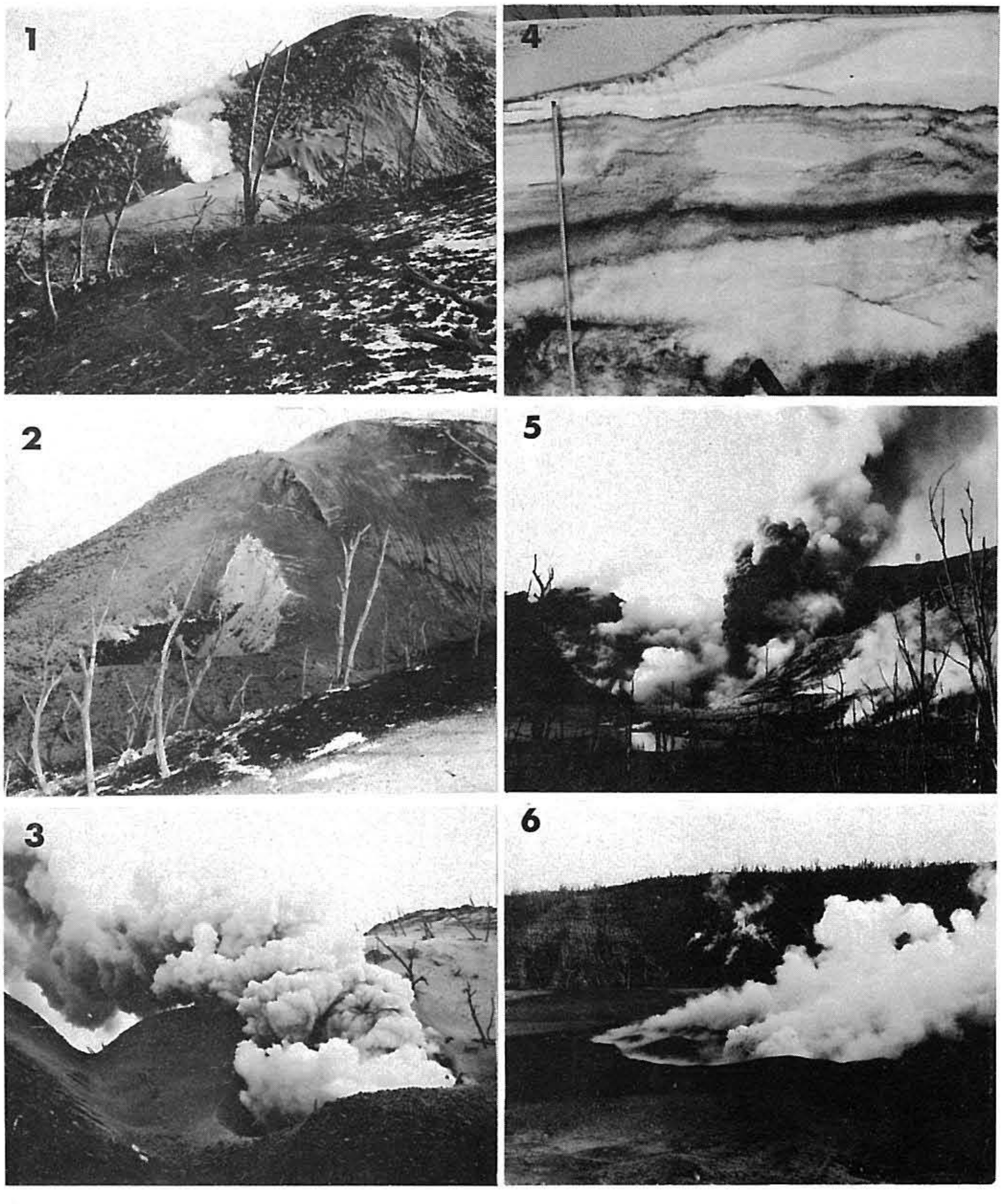
Explanation of Plate 6

Fig. 1 New decite lava appeared on the northern wall of Crater I after the phreatomagmatic eruption on June 1, 1978. Photo by K. Niida, July 12, 1978.

Fig. 2 "Red-hot" glowing of the new dacite lava on the night of July 12, 1978. The site is same as Fig. 1. Photo by K. Niida.

Fig. 3 Fire-column, about 300 m high above the summit of Usu Volcano, appeared in the eruption on August 24, 1978. Photograph taken from the southern foot of the volcano, by Mr. M. Kotake.

Fig. 4 Magmatic eruption accompanied with many sparks of volcanic discharge, 22:30 on September 12, 1978. The fire-column stood up more than 700 m high above the Crater K. Photograph taken from Nagawa on the southeastern foot of the volcano, by Mr. Y. Kawahara.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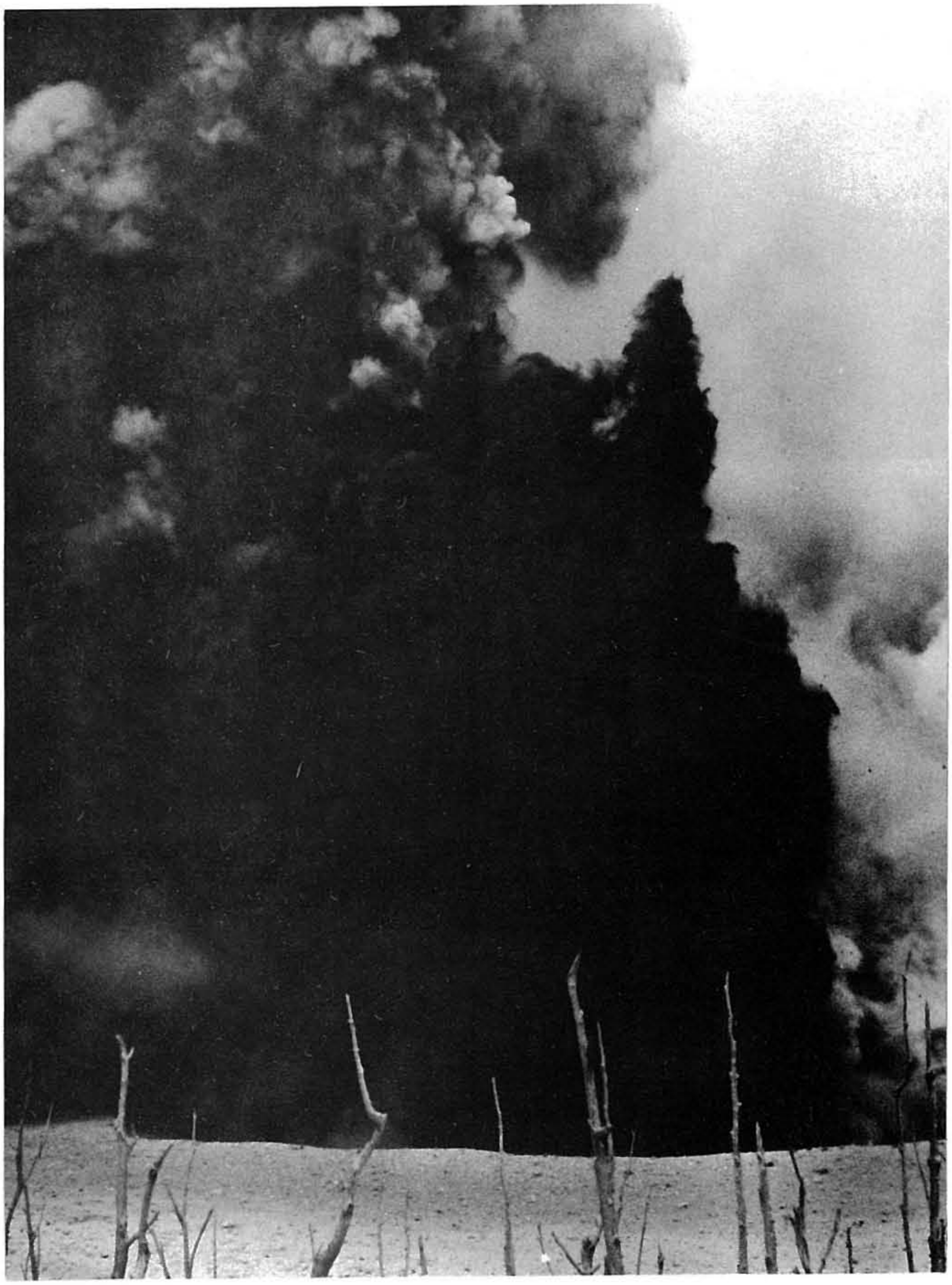

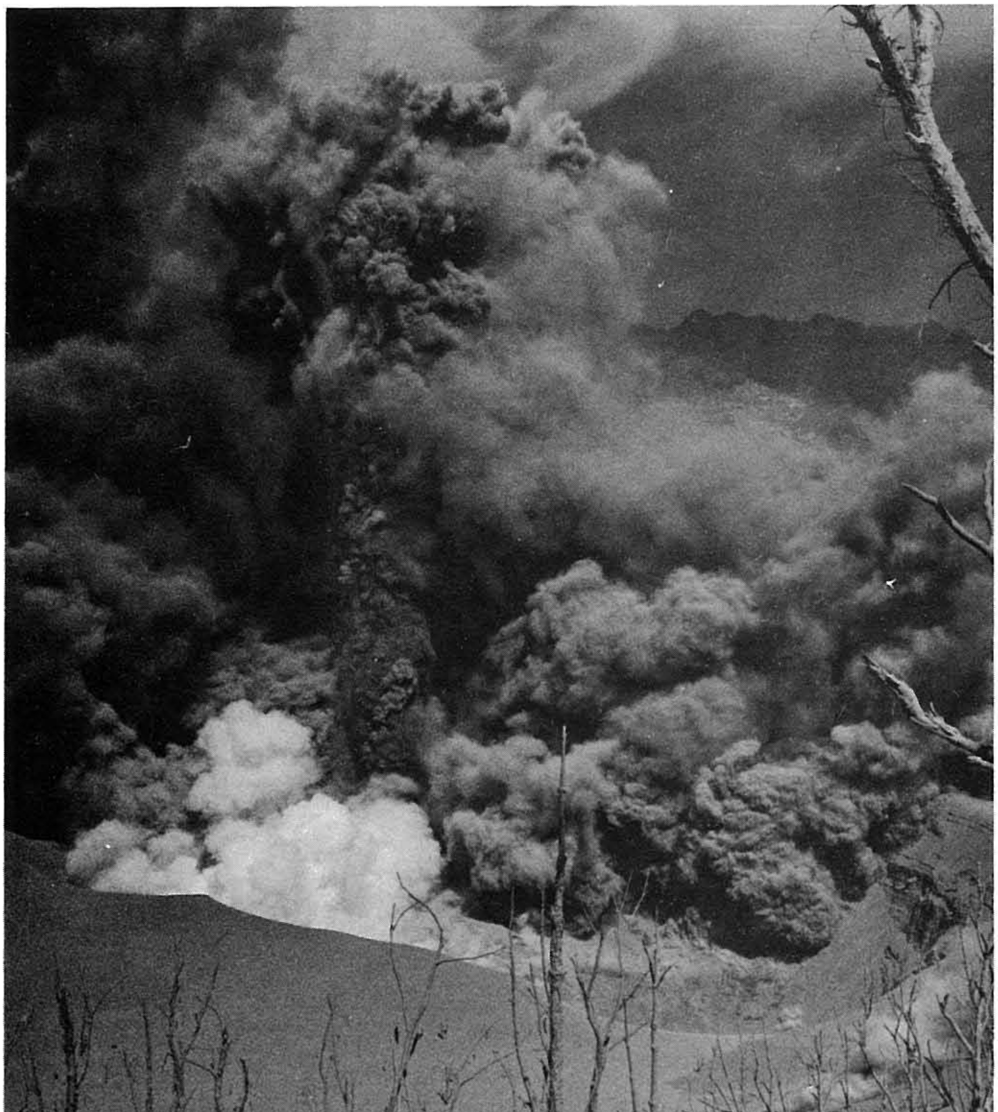

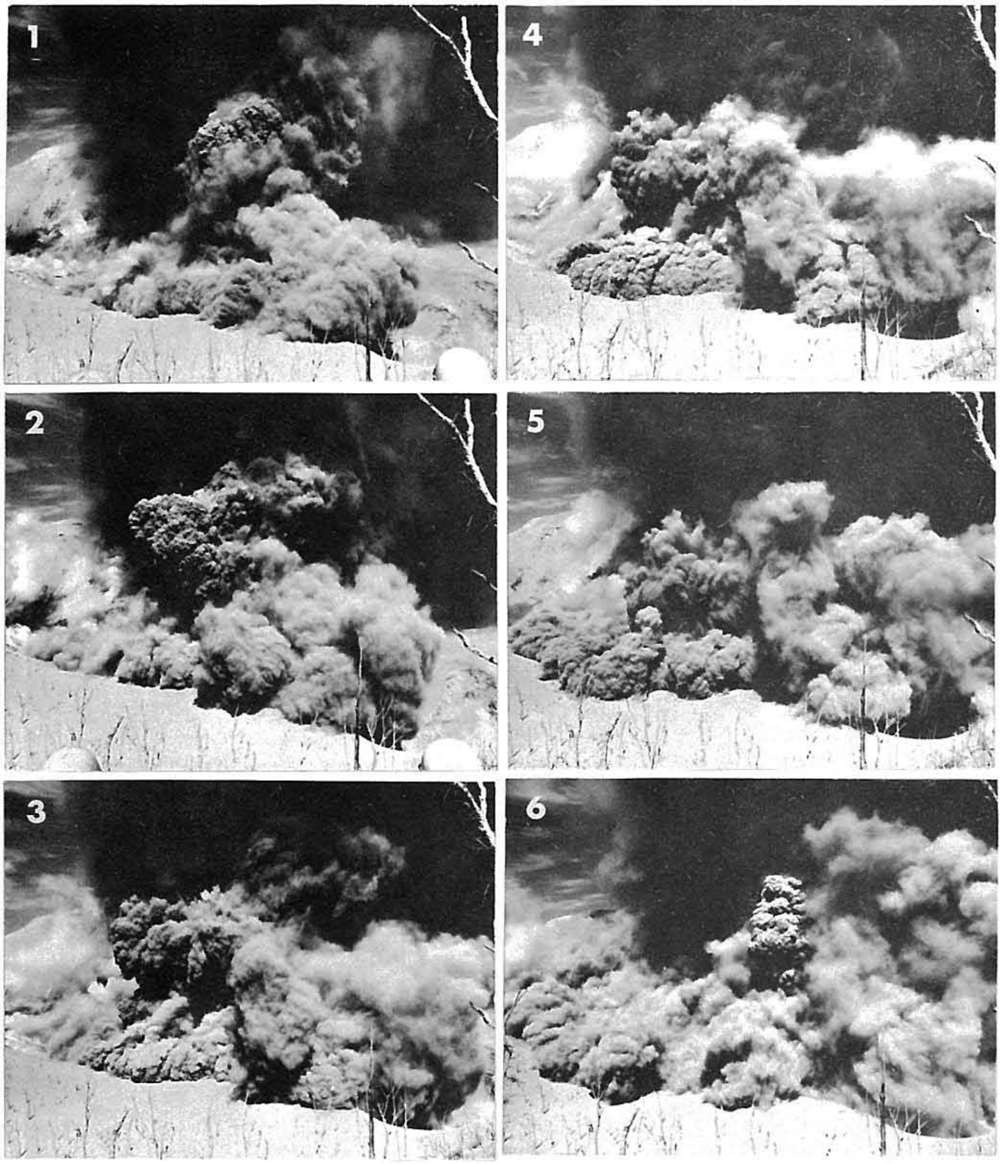
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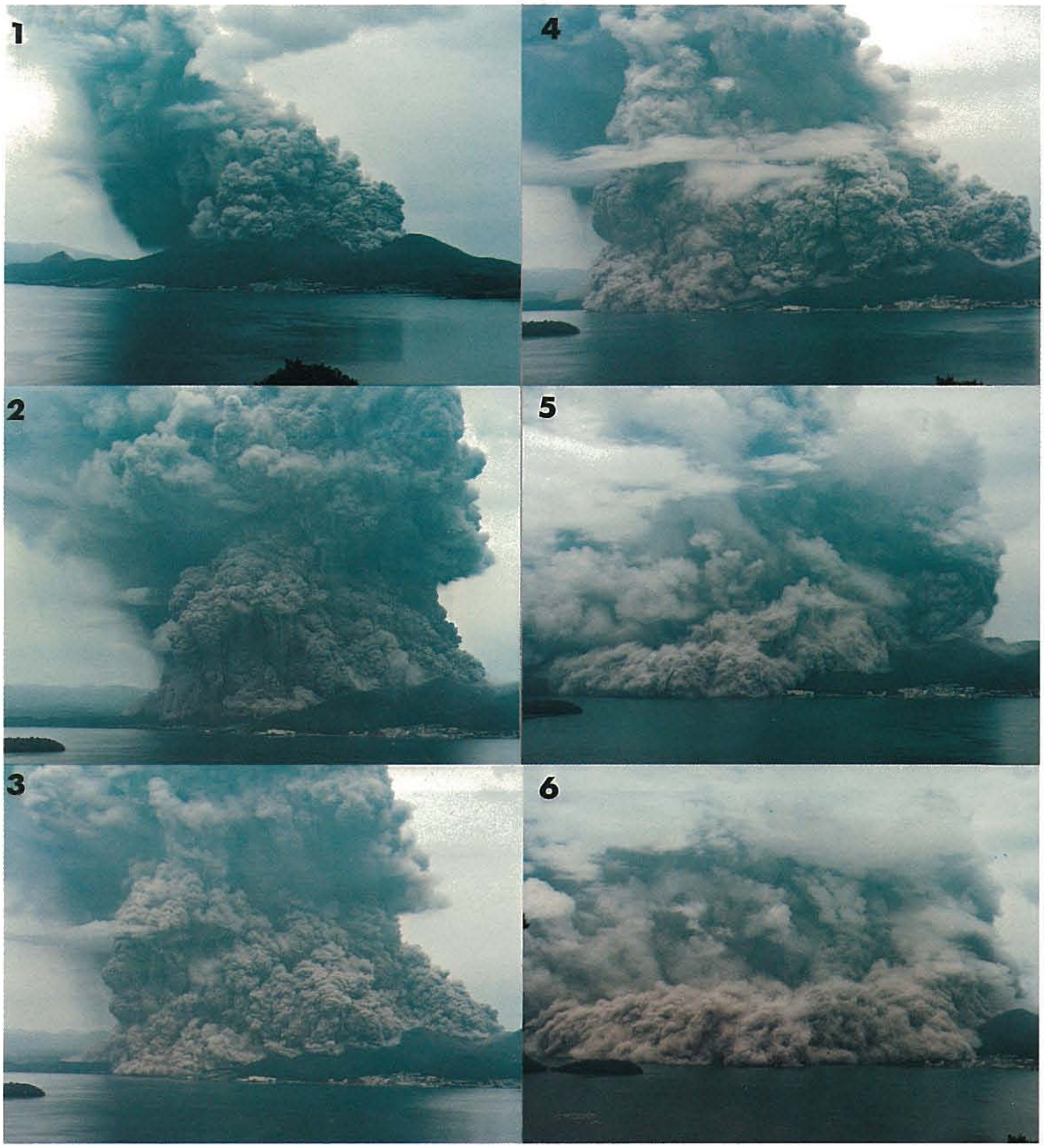
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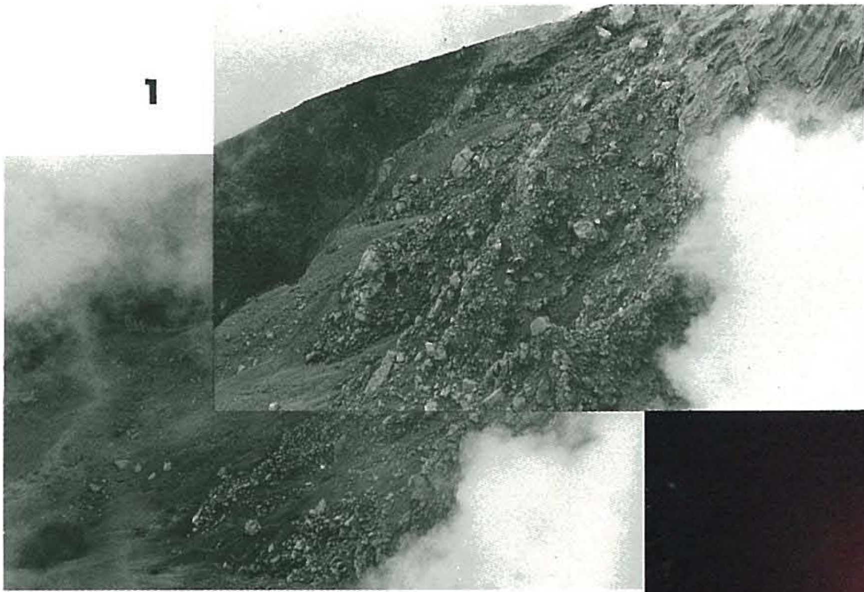

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4