NEW ERUPTION OF USU VOLCANO, HOKKAIDO, JAPAN, DURING 1943-1945

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1. INTRODUCTION

Usu volcano is situated at a distance of about 30 kilometers NNW of Muroran city in Hokkaidô, Japan, between Funka Bay (meaning Eruption Bay) and Tôya Lake. (Figure 1) It belongs to the Nasu volcanic zone, and is one of the noted active volcanoes in Japan. It's height is only 725 meters above sea-level. Remarkable eruptions have occurred in the past, of which the most recent explosion was in 1910. Since then, no noticeable change has been observed until the present eruption of 1943-1945. The new activity commenced at the end of December, 1943, accompanied by strong earthquakes, and ended in September, 1945, with completion of a dome formation at the east foot of the volcano. The newly formed mountain was named Shôwa-Shinzan (meaning new mountain in the Shôwa era). This type of volcanic eruption is considered to be extremely rare, not only in Japan, but also in other parts of the world.

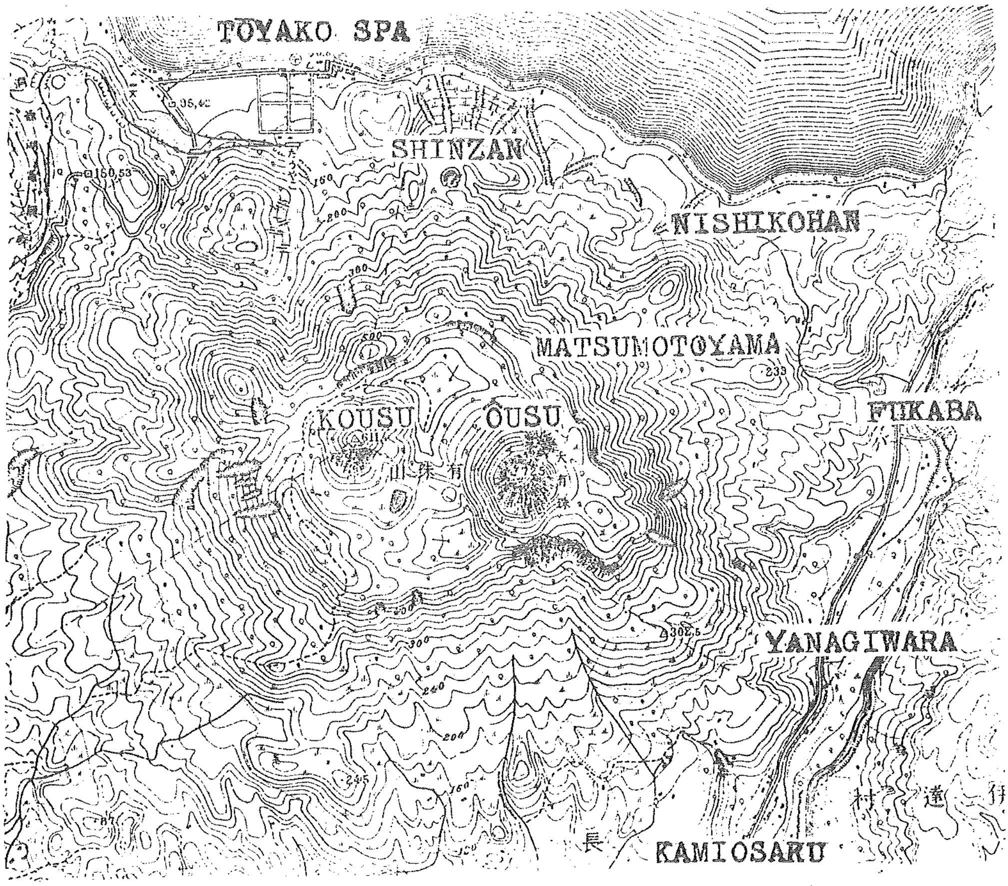

FIGURE 1. Topographical map of Usu volcano prior to the 1943-45 activity. Nearly 1/50,000

At the time of activity, investigations were made from various standpoints, some of which have been completed and published.[48)-(63] Members of the Earthquake Research Institute, Tôkyô University, were among the first to visit the scene of activity in 1944. Dr. T. MINAKAMI observed the topography, volcanic earthqurkes, and eruption in general.[51),(54),(62] Dr. T. NAGATA's geomagnetic survey, Dr. S. OMOTE's leveling,[53] S. MIYAMURA's observation of ground deformation,[53] A. JITSUKAWA's observation of topographical changes[49] were also made at around the same time. Dr. T. FUKUTOMI, Low Temperature Research Institute, Hokkaidô University, measured the subterranean temperature distribution in this area in 1944, determined the height and growth of the dome, and also completed a topographical map of the new volcano in 1945.[(48),(51)] H. TANAKADATE, former Professor of Tôhoku University, observed the eruption in 1944, and investigated the completed dome in 1947.[(57)] Assistant-Professor K. YAGI. Tôhoku University, made a petrological study of this new dome and chemical analysis of the new dome lava in 1947.[(57),(63)] In the same year, a geochemical study of the volcanic ash from Shôwa-Shinzan was undertaken by Dr. Y. UZUMASA and Y. KITANO, Dept. of Chemistry, Hokkaidô University.[(54)] Professor S. NAKAMURA, Dept. of Geophysics, Tôhoku University, is engaged in a geomagnetic study of Shôwa-Shinzan since 1946, and has also measured the temperature of the new lava in 1947.[(60)] Professer Y. KATÔ and assistant Professor R. SHÔJI. Dept. of Geophysics. Tôhoku University, undertook seismic prospecting on Shôwa-Shinzan in 1947.[(57)] J. OKAMOTO, student in the Dept. of Geography, Tôhoku University, prepared a detailed topographical map by the plane table method during 1946-1947.[(57)]

It should also be acknowledged that M. MIMATSU, Postmaster of Sôbetsu village, Hokkaidô, made excellent descriptive sketches of the morphological development of the mountain in considerable detail throughout the period of activity.[(51),(54),(55)] (Fig. 11)

The author made investigations in the area of the new volcano several times during its activity and after its subsidence from the morphological, geological, and petrological standpoints.[(48),(55)] The development of the activity of Shôwa-Shinzan is only briefly treated in this paper, as there are many points still requiring clarification.

The author wishes to express his gratitude to Dr. J. SUZUKI and Dr. Z. HARADA, Dept. of Geology and Mineralogy, Hokkaidô University, for their kind encouragement, and also to assistant Professors M. FUNABASHI and S. HASHIMOTO for their assistance in the investigation during 1945. Much of the effort in obtaining essential data should be credited to Messrs M. MIMATSU, H. TANAKADATE, T. FUKUTOMI and T. MINAKAMI, to whom the author is grateful for their timely advices in preparation of this report.

2. THE GEOLOGY AND GEOLOGICAL HISTORY OF THE FORMATION OF THE USU VOLCANO

The general geology of this district, including Usu volcano, was first studied by Dr. T. KATÔ,[(6)] and later by Z. HARADA and S. SASAKI.[(35),(46)] The geological map of this volcano shown in Figure 2 was prepared by the latter two geologists.[(46)] The geological history of district is as

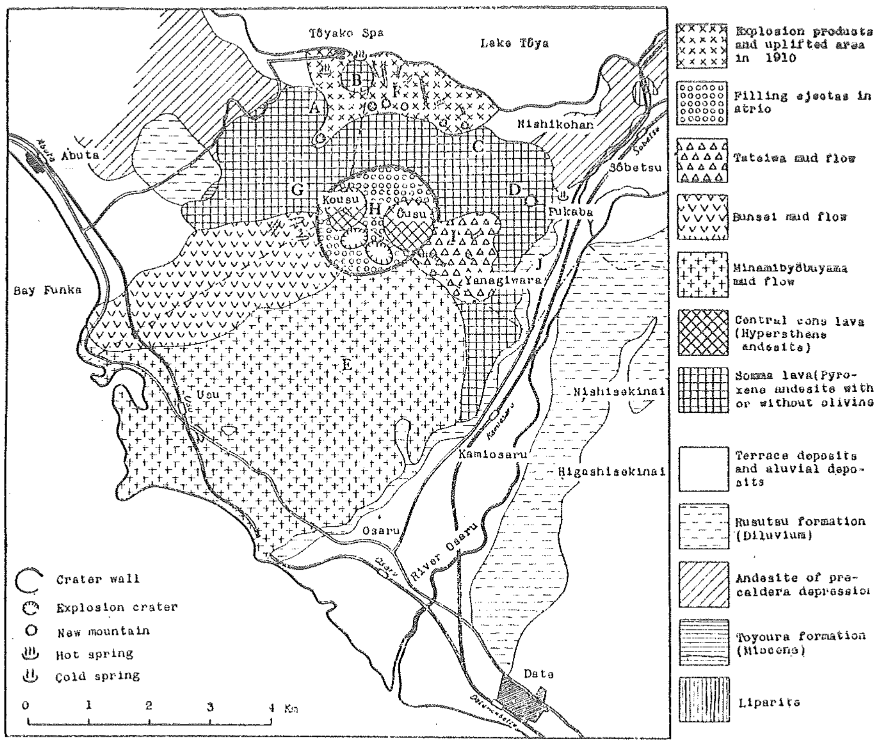

FIGURE 2. Geological map of Usu volcano before activity of 1943-45 (By HARADA and SASAKI, 1935.)

follows:

a. Effusion of rhyolite in Miocene or pre-Miocene.
b. Deposition of Toyoura formation in Miocene.
c. Effusion of andesites in Pliocene.
d. Deposition of gravel bed and Rusuttsu formation in earlier Diluvium.
e. Uplifting of the land in Diluvium.
f. Depression of the Tôya caldera in late Diluvium.
g. Formation of two volcanoes of Tôya-nakajima and Usu since the end of the Diluvium until the present day.

Among the sedimentary formations mentioned above, the Rusuttsu formation is mostly composed of volcanic ashes and pumices. Considering this fact with other examples of caldera formation, there generally exist abundant mud flows or explosion ejecta as ash or pumice around calderas which have been caused by depression in Japan. The emission of abundant explosion ejecta is therefore considered as an important factor in causing the caldera depression in this case. Compensating this depression., two new volcanoes, the Tôya-nakajima and the Usu were formed at the center and on the southern wall of the caldera respectively in a north-south direction, which nearly parallels the trend of the Nasu volcanic zone.

The Usu volcano is considered to have been formed in the following sequence of events:

1. Formation of Somma: The somma is composed of lava flows and fragmental ejecta. Rocks are two pyroxene andesites with or without olivine, sometimes with large crystals of anorthite.[45] The silica content ranges chemically from 51.34 to 52.40 percent.[38],[47]

2. Formation of central cones: These are two domes, the Ôusu and the Kousu, in the central crater on top of the somma. They are both composed of hypersthene andesitic lavas, sometimes with a little quartz and hornblende. The Ôusu lava has a silica content of 68.26 percent.[38]

3. Explosion at the foot of the Ôusu dome. Accompanying this explosion, the Minami-byôbuyama mud flow was emitted.

4. Explosion at the foot of the Kousu dome in 1822. On this occassion, two craters were formed and the Bunsei mud flow was noted.

5. Explosion at the eastern part of the Ôusu dome in 1853. A part of the Ôusu dome was blasted off by this explosion, and the Tateiwa mud flow was noted.

6. A remarkable explosion at the north foot of the volcano in 1910. Accompanied by this explosion, the "Shinzan" (meaning new mountain) was built.

Lastly, the recent activity of 1943–1945 caused formation of "Shôwa-Shinzan" (meaning new mountain of Shôwa era) at the east foot of the original Usu volcano.

3. RECORDED ERUPTIONS OF USU VOLCANO.

Well known eruptions of the Usu volcano of which there are records, number five since 1663, and are listed as follows[7],[10],[11],[39],[40],[5]:

August 16, 1663 (Kanbun era)
January 23, 1768 (Meiwa era)
March 9–July, 1822 (Bunsei era)
April 13–May, 1853 (Kaei era)
July 19–October, 1910 (Meiji era)

No records have been discovered sofar regarding eruptions prior to 1663, as Hokkaidô was scarcely populated in those ages. It is possible to assume that unrecorded erptions or some of older eruptions may have been more violent and causing extensive destruction than the recent eruption. In 1822, abundant mud flow completely destroyed the village of Abuta (Present location of Tokotan.).

A fairly comprehensive study of the 1910 eruption was made by Japanese scientists.(7)-(23) In this eruption, a violent explosion occured at the north foot of the volcano, that is, at the side of lake Tôya, six days after earthquakes were felt. Explosions were repeated from July to October, and 45 craterlets were formed alined in the direction parallel to the foot line of the volcano. A new mountain of 211 meters height above sea-level was built by about 150 meters elevation of the ground during the eruption. It is not an accumulated mountain, but a roof mountain(24) elevated by an underground cryptodome. No lava from the new magma was observed, though mud flows and fragmental ejecta were produced in abundance.

Also in other past eruptions, strong explosions occurred at the foot or on the sides of the two domes in the central crater, accompanied by a large amount of mud flows. The common characteristic phenomena in past eruptions are the frequency of eathquakes preceeding an eruption, the repeated violent explosions, and the comparatively long duration of volcanic activity in gereral.

4. MT. USU ERUPTION OF 1943-1945.

The entire process of the recent eruption of Mt. Usu may be conveniently divided into the following three stages of activity:

A. Earthquake stage: (From the time of occurrence of the first earthquake to the day preceeding the first explosion) December 28, 1943–June 22, 1944.

B. Explosion stage: (From the first to the last explosion) June 23–October 31, 1944.

C. Dome building stage: (From the day directly after the last explosion until completion of the dome) November 1, 1944–Approximately September, 1945.

A. EARTHQUAKE STAGE

The first indication of the new eruption was the series of strong earthquakes felt in the entire area around the Usu volcano on December 28, 1943. And earthquakes increased in frequency and intensity till December 31 of the same year, occurring as many as 200 per day at maximum. The frequency of the earthquakes decreased abruptly after this period in all areas except in the neighbourhood of Yanagiwara and Kamiosaru villages at the east foot of the volcano, where no laxation in the frequency and intensity of earthquakes was noted. Tremblings accompanied by earthquakes were first imagined to originate at the deep volcanic center, but which gradually shifted to directly beneath the above two villages. Simultaneously, vertical trembles accompanied by earthquakes were experienced.

It is assumed that the new magma tried at first to advance through the central crater vent, causing strong earthquakes to be felt in the area all around the volcano. The magma, however, soon moved towards the weak zone at the east foot of the volcano, or the intersection of the Ôusu-Kousu line with the peripheral tectonic zone, as the two domes plugging the crater vent prevented the upward advancement of the magma. This was followed by elevation of the ground, opening of cracks in the ground, and a decrease in the water level of wells in the Yanagiwara and Kamiosaru villages. These phenomena finally culminated in causing destruction of irrigation ditches, houses, critical lack of drinking water and damages to other property. The water of the springs at Fukaba to the north of this area, increased twice in volume. This is presumably due to changes in the underground water system accompanying elevation of the ground and opening of cracks in the earth.

The ground was elevated for a distance of about 3 kilometers along the road from Kamiosaru to Yanagiwara, 30 centimeters a day in height at maximum and averaging about 24 centimeters per day. The total amount of elevation at the center of the elevated area attained 16 meters by the beginning of April, 1944.[51],[52] But the center of the elevated area shifted northward towards Fukaba from the middle of April. Before the first explosion, corn fields near Fukaba were elevated as high as 50 meters above their normal height of 130 to 160 meters above sea-level. (Point 1 in Fig. 3) Numerous cracks of various sizes and forms, such as faults, steps, round holes or roofed tiles originated at random. (Fig. 3) Earthquakes were usually experienced more than a hundred times a day at Fukaba village around the middle of June, and 250 times a day preceeding the first explosion. The rate of elevation was more than 20 centimeters per day at the beginning of June and nearly 150 centimeters a day by the middle of the month.[51]

The shift of the center of elevation is considered as having been

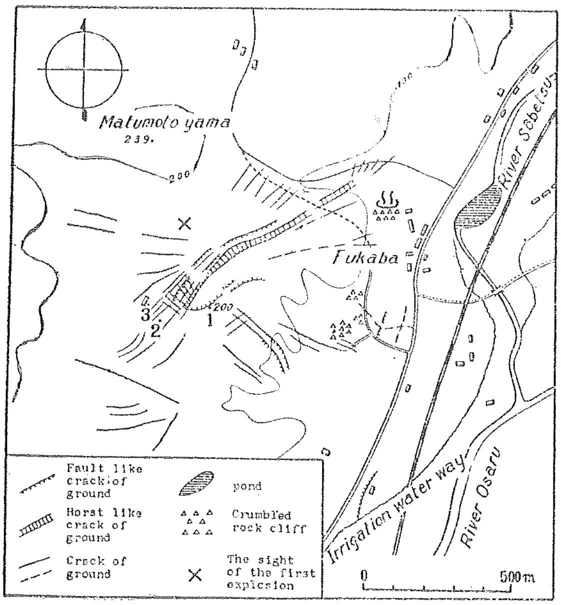

FIGURE 3. Map indicating the cracks caused by land upheaval in the neighbourhood of Fukaba village at the beginning of June, 1944.

caused by the movement of new magma through the weak zone at the periphery of the volcano. This rare phenomenum in the present new eruption suggests that the present position of the old roof mountains at the foot of this volcano may be located quite distant from the point where magma first intruded. Also the linear arrangment of the 45 craterlets on "Shizan" at the north foot of the volcano, suggests that in the 1910 eruption the magma moved through the weak zone at the periphery of the volcano, not before, but after the first explosion.

B. EXPLOSION STAGE

The first sign of smoke were observed by local villagers at about 8.30 a.m., Japanese standard time, on June 23, 1944. The smoke was first seen rising from corn fields to the south of Matsumotoyama noiselessly and considered to be water vapor escaping through fissures in the ground. Violent explosions were repeated since this time until October 31. The explosion stage of activity may be conveniently divided into three sub-stages: (a) water vapor explosion substage; (b) ash and water vapor explosion sub-stage; and (c) strong explosion sub-stage.

(a) Water vapor explosion sub-stage: smoke grandually increased quantity, and mud ashes and blocks were hurled up at approximately 10 a.m. on June 23. Mud flows also were poured out from the crater, which dimensions were 50 by 35 meters in the two diameters. The smoke was composed only of water vapor and did not contain sulphur fumes.

Explosions occurred intermittently, and after each explosion the new crater subsided into a calm, smokeless state, with only muddy water remaining at the bottom of the crater. After a few hours, water vapor commenced to rise again, followed by spouting of muddy water like a geyser. (Plate 1, Fig. 2) This grew stronger with each successive detonation, and blocks were thrown up to a maximum of 300 meters above the crater rim accompanied by muddy water. (Plate 1, Fig. 1) The collision of blocks in midair resounded like thunder. The intensity of the activity subsided rapidly after reaching the climax, after which a calm, smokeless state was assumed. It is interesting to note that this phenomenum could be observed from a position as near as 300 meters from the active crater for a period of a half to one hour at a time.

Explosions of the type related above occurred intermittently for 9 days from June 23 to July 1. (Fig. 4) The largest explosion occurred on the morning of June 27, when the second crater (Fig. 8, B) was formed near the first. This type of explosion resembles the geyser type but on a larger acale: that is, it is not caused directly by the pressure of the gas from the new magma, but by the pressure of the water vapor converted from underground water by the tremendous heat emanated from the new magma. Accordingly, as soon as the accumulated water vapor is exhausted, the explosion ceases. When the vapor pressure attains sufficient pressure again, an explosion immediately occurs. As it takes several hours for this vapor to accumulate, the explosions also occur at corresponding intervals of time.

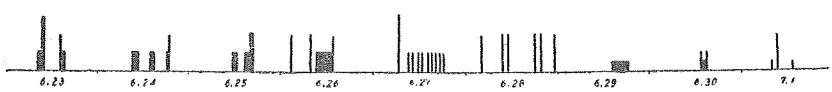

FIGURE 4. Occurrence of explosions during the water-vapor explosion sub-stage of the explosion stage. The height of the lines indicate the relative intensities of the explosions.

We now need to determine the source of the underground water related to the current eruption. There formerly existed a group of springs at Fubaka village, which water was once used for salmon and trout hatching because of its constant temperature and abundant supply. The village name "Fukaba" means "hatchery station." There was also a spring amidst the corn fields, supplying drinking water to the farmers. It is concluded that the underground water source exists in this area. The first explosion was caused by this underground water vapourized by the heat of the approaching magma. It can be deduced that the source of the explosive force exists at a comparatively shallow

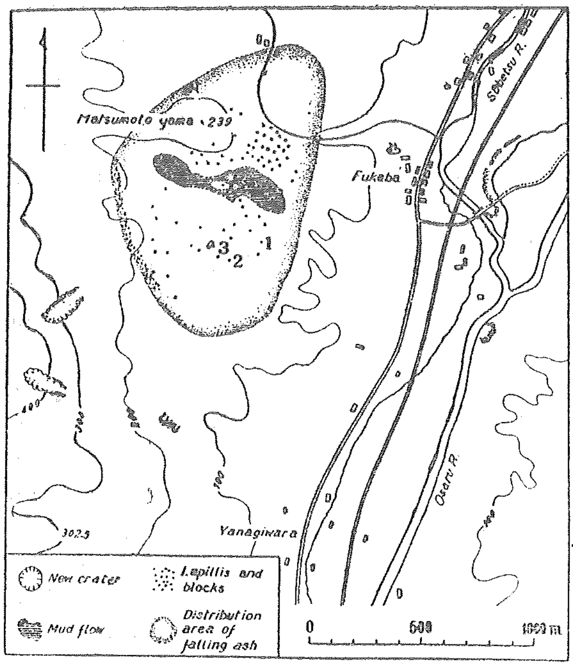

FIGURE 5. Map indicating the distribution of ejecta in the water-vapor explosion substage of the explosion stage. (points 1, 2, and 3 correspond to those in Fig. 3)

depth in this sub-stage of activity. The small scale of the explosions and also the narrow distribution of ejecta also confirm this point. (Fig. 5)

The small scale of the craters, and the soft, loose, and brittle geological formation around the craters, often hinder the passage of large amounts of water vapor, causing the vapor to accumulate slowly again after subsidence of each explosion. Earthquakes decreased abruptly from 250 times a day on June 22 to 110 times and 20 times a day on June 23 and 24 respectively.

(b) Ash and water vapor explosion sub-stage: A tremendous explosion suddenly occurred at 0.30 a.m. on July 2. A large amount of ash was scattered mostly to the north east of the active crater. (Figs. 6 and 7), and totally covering the Sôbetsu village. Ashes were deposited up to 30 centimeters thickness at Fukaba, and reached as far as Tokushunbetsu village. The total amount of ejecta was 2,000,000 metric tons, the energy of the explosion being estimated at 1.4×10^{20} ergs according to T. MINAKAMI.[51] This explosion is clearly attributed to the gas pressure energy of the new magma, indicating that its source lies deeper than in the preceeding sub-stage. Larger blocks were also scattered in the neighbourhood of the crater. Sulphur-contained ashes rendered considerable damage to corn and potato fields, and forests near Matsumotoyama.

No significant crater was created by the explosion on July 2, meaning that exhaustion of the accumulated gas was probably not complete. As a result, another severe explosion occurred at 8.30 a.m. on the next morning, throwing ashes over a large area, mainly towards

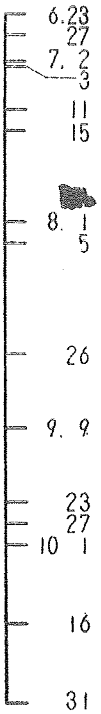

FIGURE 6. Dates of main explosions during the explosion stage.

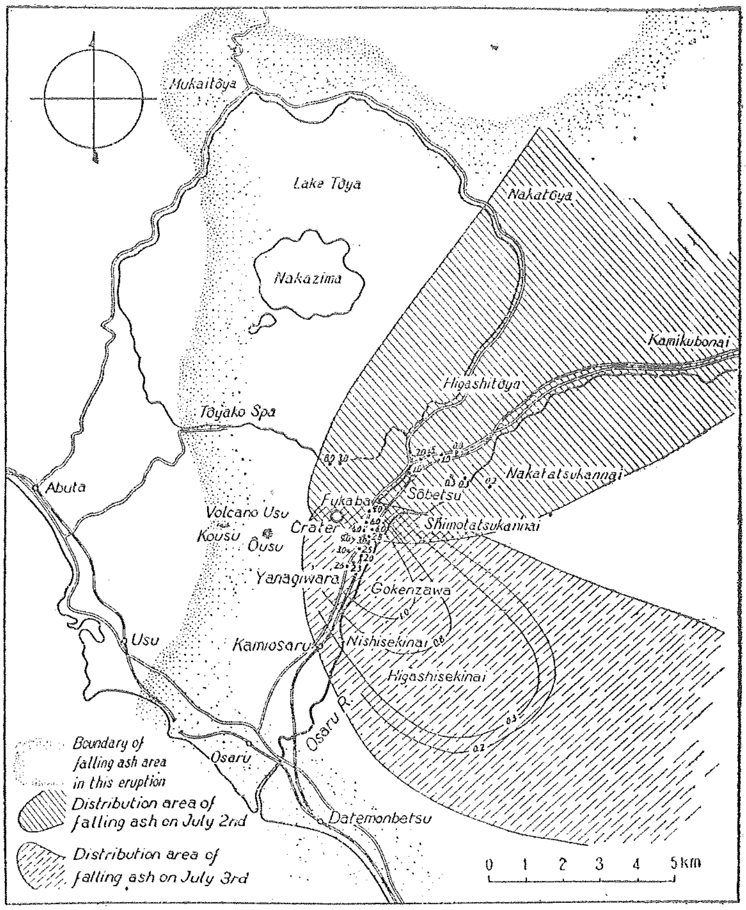

FIGURE 7. Map indicating the distribution of ejecta in the explosion stage. Numerical numbers indicate thickness of ash.

the southeast side of the crater. It seems that these two explosions practically exhausted the explosive energy, as large explosions were not observed until July 10 except for small scale intermittent water vapor explosions. (Fig. 6)

Smokes from the new craters ascended as high as 1,000 meters on July 2 and 3, and the temperature of the ejecta ranged from 500 to 600 degrees centigrade.[51] The distribution of ashes was far more extensive in area than in the preceeding sub-stage. (Fig. 5 and 7) The two violent explosions and also water vapor explosions all originated in the crater formed in the first sub-stage, however the type of explosion clearly distinguishes this sub-stage from the preceeding, a proper name for it being "the ash and water vapor explosion sub-stage." Villagers of Fukaba were compelled to abandon their abodes and take refuge with the danger increasing accumulatively in this period.

(c) Strong explosion sub-stage : A tremendous explosion finally opened a new large crater on July 11, from which columns of smoke mixed with ashes staining it brownish black, were continuously expelled. Violent explosions repeatedly occurred until the last main explosion on October 31, and five new craters were formed before October, namely (Figs. 8, 9 and Plate 2, Fig. 2), crater "A" on June 23, "B" on June 27, "C"on July 11, "D" on September 19, and "E" on August 26. In October, two other craters were newly added to the group, namely, one to the north of "B" crater on October 1, and another near or inside "C" crater, finally totalling seven craters.

Most of falling ash was distributed windely to the east side of the active center (Fig. 7) during this explosion stage. It is interesting to note that Nuée ardéntes or horizontal blasts were projected several times to the north, through Nishikohan (south side of Lake) and Tôya-nakajima to Mukai-tôya. Successive Nuée ardéntes broke windowpanes, blew off roof tops and also totally destroyed the potato fields at Nishikohan. However, the heat of the falling ashes was insufficient to burn anything in it's path. Well known examples of Nuée erdéntes are

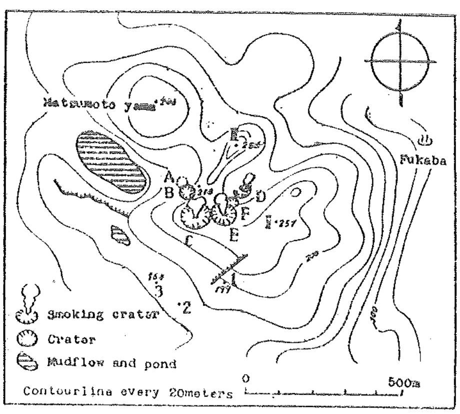

FIGURE 8. Sketch showing crater formations on September 23, 1944. The altitudes of the craters were measured with a barometer.

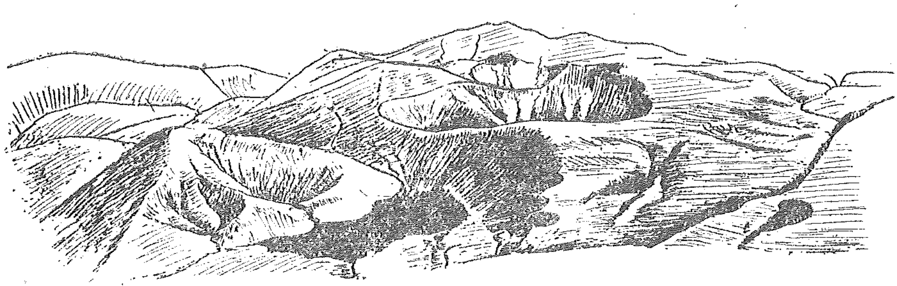

FIGURE 9. Craters sketched from the east somma wall of Usu volcano on September 22, 1944. Retouched by Y. SASAYA from the author's original sketch.

those of Mt. Pelee in 1902, Lassen Peak in 1915, Komagatake in 1942 and Sakurajima in 1939. The cause of nuée ardèntes is considered as most related with the existence of belonite or cryptodome, although the direction of gas emission from the crater vent and the concentration and property of gas may also be related factors.

In the strong explosion sub-stage, the new magma advanced upwards accompanied by a gradual increase in the height of the uplifted ground or the roof mountain with repeated strong explosions. The rate of elevation averaged 15 to 20 centimeters a day, attaining maximum of 2 meters a day. The total elevation during July-middle of August, 1945 was 100 meters.(51),(62) (Plate 2, Fig. 1) Earthquakes, which had subsided abruptly directly after the first explosion, greatly increased in frequency again on an average of about 500 times per day, and attaining a maximum of 1000 times per day at Fukaba village around the middle of July.(51),(62)

The depth of the source of earthquakes was estimated at 500 meters at the time.(51),(62) Near the end of October, corn fields which were normally 130 to 160 meters above sea-level, were elevated to nearly 300 meters a. s. l. to form a flat dome-shaped volcano, 0.5 square kilometers in area. The height of the new mountain eventually exceeded that of Matsumotoyama (239 meters) and the amount of elevation is nearly comparable with that of "Shinzan" built in 1910. It is assumed that a similar process of mountain formation also occurred in the 1910 activity.

A phenomenum of special interest in the present eruption is the arrangement of the craters in the form of a half ring. (Fig. 8) These craters were situated at the periphery of the base of the dome, which later appeared above the earth's surface. As the explosions usually occur at the foot of the dome, so in the case of a cryptodome existing underground, the explosions may be expected to occur most frequently on the side face of the cryptodome. This means that the explosion craters would lie on the periphery of a circle or ellipse encircling the dome. Block ejecta and falling ash acattered by the explosions in this sub-stage caused severe damage to corn and potato fields, forests and houses in the vicinity. Fukaba village was ruined by the critical uplifting of the ground rather than from falling ejecta, which also severed the public road at Fukaba leading from Date-machi (town) and Sôbetsu village. The Iburi line railway running along the east foot of the volcano was deformed considerably by uplift of the ground and later by the lateral pressure from the active center, which compelled the railroad lines to be transfered towards the east.

C. DOME BUILDING STAGE:

No noticeable explosion occurred after November 1, 1944, however, a black mass was perceived in the vicinity of the craters from Nishikohan in the middle of November, and a peak of pyramid shape was observed even from Sôbetsu around the middle of December. It is concluded that soon after the last explosion on October 31, the solidified lava mass commenced extrusion above the earth-surface. It continued to develop both in height and mass until September, 1945. Mimatsu relates that there were often spontaneous uplifts of the dome during this period. It is highly possible that earthquakes accompanied these movements. The lava mass soon developed into a dome with a steeper slope on the south side.

Each of the craters formed in the preceeding sub-stage were either totally or partially eclipsed by the growing dome and it's talus deposits. The partly remaining craters were observed only on the southwest and east foots of the dome. (Fig. 10) Smoke rising from the entire surface, especially from fissures of the dome and remaining craters ususlly enveloped the dome until late in June. 1946., so that the profile and details of the entire dome could only be observed few times a month.

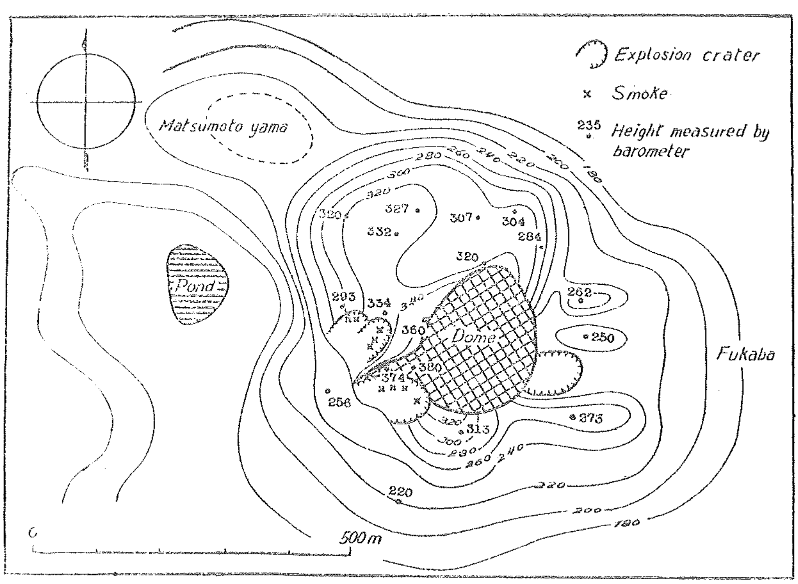

FIGURE 10. A sketched map of the new mountain "Shôwa-Shinzan" on June, 2, 1946.

It is worth mentioning that Mr. MIMATSU, Sôbetsu village postmaster, recorded the morphological development of the new volcano in considerable detail by a continuous series of descriptive sketches from the beginning of the activity, and thus expressing the line of growth of the dome by his characteristic method. (Fig. 11) Measurement of the height and area of the new mountain was accomplished by MIMATSU and FUKUTOMI. The maximum height of the dome was attained in September 1945, that is 404 meters above sea-level, or 110 meters higher than the roof mountain. The rate of elevation averaged 0.6 meters per day. The diameter of the dome's base was approximately 300 meters.[51] Since the dome started to appear, the actual elevation of the roof mountain was not noticeably accelerated, though the slopes of the roof mountain became steeper due to the lateral pressure exerted by the movement of the underground lava mass.

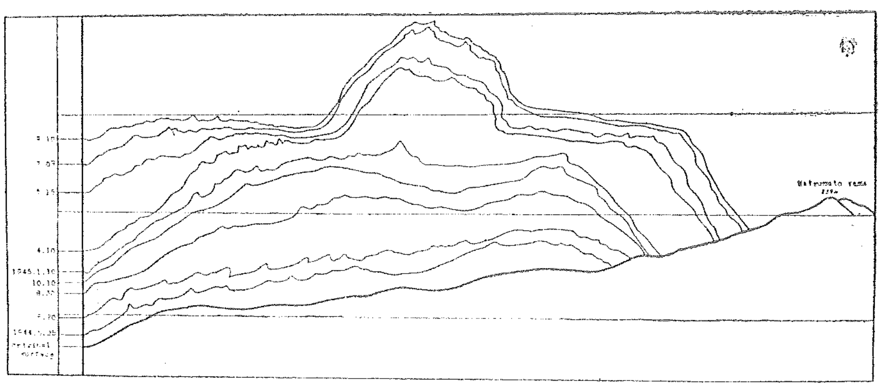

FIGURE 11. Figure indicating the line of growth of the Shôwa-Shinzan dome as drawn by M. MIMATSU. M. MIMATSU's original drawings of the line of growth are far much shorter intervals. Only the main lines of growth have been selected by the author in this figure.

The dome brought up various rock fragments, gravels, and boulders, which constitute the basement of the volcano and the lower volcanic body. Somma lava flows, which formerly covered this area, were already broken up into numerous blocks by the uplifting of the cryptodome. Clayey and tuffaceous rocks were sintered into natural brick through contact with the hot lava, and found overlaying the entire surface of the new lava dome in thickness ranging from 3 to 10 meters. Clear striations were observed on the surface of this overlying layer due to frictional movement during the dome's expansion. (Plats 3, Fig. 1) Judging from the direction of these striations and MIMATSU's observations, the movement of the dome was not only in the vertical sense, but also a series of expansions in convulsive steps. Differential movements of parts of the dome were also often noticed, for instance, the projection of a large branch body on the south-west side of the dome. (Fig. 10 and Plate 3, Fig. 2)

Though the new lava is enveloped with a covering layer as related above, red-hot lava could be seen glowing through large cracks in this layer. Numerous spots of fire and emission of fiery columns of smoke present an interesting spectacle at night. The new lava, though solidified near the top, is probably still connected to the molten magma at lower depths. Being covered with a thick overlying layer, the lava cools slowly, thus lengthening its duration of movement. The temperature of the glowing lava was measured at 980°C at its maximum in September, 1947 by NAKAMURA.[60] In this respect, it differs considerably from the dome of the Tarumai volcano, where the lava immediately solidified upon effusion above the earth's surface through the crater vent in a molten state.

5. NEW VOLCANIC PRODUCTS

Solid materials produced in the present new eruption are classified into fragmental ejecta, mud flow, dome lava and it's covering rock. Among these, the dome lava is evidently juvenil. The other products consist of rocks forming the basement of the volcano and the lower volcanic body, which were hurled up by the explosions. Gravel, and other rocks covering the dome were brought up from the gravel beds and sedimentaries constituting the basement of the volcano, by the elevation action of the dome. No chemical or petrological studies have been made sofar on the mud flows and gas. The general properties of the various products are briefly described below, being classified into four groups.

(A) Ash
(B) Coarser fragmental ejecta
(C) Rock covering the dome
(D) Dome lava

(A) Ash: A great amount of ash was scattered mainly on the east side of the new active center primarilly during the explosion stage, though some ash was also ejected in the dome building stage. Ash emitted in the water vapor explosion sub-stage was muddy, though practically dry after the explosion on July 2, 1944. The dry ash is gray in color and extremely fine, most of the grain size being under 0.01 milimeters, though sizes up to a maximum of 0.2 milimeters could also be found. Under the microscope, the ash usually contains glass, plagioclase, quartz, augite, hypersthene, sometimes hornblende and olivine, A close chemical study on ash scattered on July 2 and 3 was undertaken by UZUMASA and KITANO.[58] The silica content of these samples of ash ranges between 57.18 and 57.36 percent, and differs from the composition of the new dome lava. It is consequently assumed that this ash originates chiefly from pre-existing volcanic matter, though part of it may be juvenil from the new magma.

(B) Coarser fragmental ejecta: Explosion ejecta are considered to be mostly fragments of rocks forming the base of the volcano and the old volcanic body. They vary in size and form, and are distinguishable into certain types. It seemed to the auther that there were no bombs nor other ejecta which could be judged as being juvenil. Coarser fragmental ejecta, ranging from small lapilli to blocks exceeding 1 meters in diameter, are classified petrologically as follows:

(a) Volcanic rocks:
Two pyroxene dacite
Augite dacite
Quartz bearing hypersthene andesite
Two pyroxene andesite (groundmass, glassy)
" " " (groundmass, hyalopiritic)
" " " (groundmass pilotaxitic)
" " " (groundmass cryptocrystalline)
" " " (groundmass microcrystalline)
Augite andesite (Compact)
" " (Pumiceous)
Olivine two pyroxene andesite
Olivine augite andesite
Olivine andesite

(b) Dyke rock: Two pyroxene porphyrite

(c) Plutonic rock: Granite

(d) Sedimentary rock:
Tuff (glass, quartz, hornlende, Plagioclase, augite)
Tuff (glass, quartz, plagioclase, hornblende, augite, hyperethene, olivine)
Tuff breccia (glass, quartz, plagioclase, hypersthene)

(e) Metamorphic rock: Biotite-plagioclase-quartz hornfels

(C) Rocks covering the dome: Clayey and tuffaceous rocks which had existed under this volcano, were sintered mostly into natural bricks by contact with the hot lava. Under the microscope, some of these rocks contain glass, quartz, plagioclase, augite, and hypersthene. The pebbles and boulders scattered throughout the crust covering the dome originate from the gravel bed constituting a member of the basement of the volcano.

(D) Dome lava: A specimen from the new dome lava could not be taken for several months after completion of the dome due to the thick layer covering the dome, the high temperature of the lava, and smoke emission from the entire surface of the dome. The author was able to collect a few specimens of the new lava on June 2, 1946 from the west side of the dome through breaks in the dome-covering crust. This lava is hypersthene andesite containing plagioclase and hypersthene phenocrysts, no glass in its groundmass, and is similar to the Ôusu dome lava in appearance and in mineral composition. The composition of the zoned plagioclase is An_{87} in the inner, and An_{18} in the outer zones.

OKAMOTO was the first to climb the new dome on August 18, 1946. Samples of the new lava *prosecured* by him on September 19 in the neighbourhood of one of the old craters at the south-west foot of the dome, were analyzed and microscopically examined by YAGI.[57],[58] The chemical composition of the new lava together with that of the Ôusu dome are shown in the following table:

	a/ wt. %	b/ wt. %		a/ wt. %	b/ wt. %
SiO_2	69.74	68.26	CaO	3.63	4.37
TiO_2	0.45	0.36	Na_2O	3.43	3.83
Al_2O_3	15.59	15.77	K_2O	1.36	1.29
Fe_2O_3	1.52	1.91	H_2O (+)	0.67	0.51
FeO	2.59	2.15	H_2O (−)	0.23	
MnO	0.08	0.31	P_2O_5	0.22	0.18
MgO	0.85	0.99	Total	100.36	99.93

a/ New lava analyzed by YAGI, 1947, Ref.[57],[58]

b/ Ousu dome lava analyzed by Geological Survey of Japan in 1928, Ref.[38]

It is interesting to note that the new dome lava resembles the Ôusu dome lava in chemical composition and that both are high in silica content. It should also be noted that the three domes of Ôusu, Kousu, and the new dome are all composed of hypersthene andesite, and that differ from the somma lavas which are pyroxene andesite with or without olivine, and containing between 51.34 and 52.40 percent of silica.[58] The new lava contains quartz and cristobalite in its groundmass[57],[63], while the Ôusu dome rarely contains corroded quartz and hornblende. Such a content of silica is similar to that of dacite or rhyodacite. The chemical characteristic of andesite in Japan compared to that of America or Europe, is that the former is generally rich in An percentage of normative feldspar, poor in Wo percentage of normative pyroxene, rich in normative quartz, and rich in al-alk, poor in c-(al-alk), rich in qz of Niggli's value. These chemical properties are also indicated in the mineralogical compositions of the lava, as the plagioclase is basic, the rhombic pyroxene abundant, and that silica minerals are often found in the groundmass. Such petrological characteristics are clearly observed in this new lava as well as that of the Ôusu dome. As SiO_2 and Al_2O_3 are considered as being closely related to the viscocity of the magma, an extraordinary addition of SiO_2 and Al_2O_3 in the primary magma may be one of causes in volcanic formations such as a dome or a spine.

6. TYPES OF ERUPTIONS OF USU VOLCANO

The mechanism of various types of eruptions of Usu volcano are discussed here in order to furnish a basis for the observations and conclusions in the preceeding paragraphs regarding the current volcanic activity of Mt. Usu.

Many volcanoes are known to have their own characteristic form of eruption. For example, the Shiretoko Sulphur mountain has enormous flows of native sulphur in each eruption. The Usu volcano also has its typical form of activity ever since the origin of the volcano itself. The geology of Mt. Usu and its past eruptions clearly indicate that each eruption is characterised by formation of a dome (genetically belonite), the emission of mud flows, repetition of violent earthquakes preceeding violent explosions, and the comparatively long duration of activity. All of these phenomena have been exhibited in the present eruption.

The existence of the two domes, the Ôusu and the Kousu, in the top crater clearly indicate that the same type of eruption occurred twice in the past. The present new eruption created the third dome at the east foot of the volcano. The process of dome building may be analyzed as follows.

The upper part of the volcanic magma may sometimes solidify while underground, especially if any accident occurs during the rise of the magma. The solidified upper part of the magma may then be heaved upwards by the rising thrust of the molten magma, which upheaval may even appear on the surface of the ground in extreme case. The Ôusu and Kousu domes are assumed as having been formed in this manner, and may therefore be termed belonites or spines in the genetical sense, or tholoides or domes from a morphological standpoint, where the diameters of the base of the lava mass exceed the height of it. H. TANAKADATE uses the term "Pseudo-belonites" for the Mt. Usu dome formations.[31]

Before the new magma can rise, the overhead crust is generally blown away by a series of explosions, which further facilitates the advance of the magma. However, when the upper part of the rising magma are more or less in a solidified state, the magma brings along with it pre-existing materials which are encountered on its path, either on top of the solidified magma, or on its side surface. In the case of Ôusu and Kousu, gravel, burnt clay, tuff, and other rock fragments are found distributed on the surface of the domes. The dome or spine obstructing the crater vent, causes gas to accumulate and leads to violent explosions. When the gas pressure is not reasonably high, fissures originate on the main body of the dome or spine, and explosion craterlets are formed at the foot of the dome, as is observed in the cases of Ôusu and Kousu domes. Accumulation of high gas pressure is sufficient to blast the entire dome in some cases.

Though volcanic magma usually issues through the central crater vent, it may sometimes invade a tectonically weak zone either on the side or the foot of the volcano, especially when the central crater vent is closed by a dome or spine as it is in this case. In 1910, magma intruded at the north foot of the Usu volcano. Sometimes, and more often when the upper part of the magma is solidified, the magma may not show itself above ground. Such a mass is termed a cryptodome, and the upheaved overhead is called a roof mountain. "Shinzan" (meaning new mountain), which was built in 1910, is a typical roof mountain.

There exist several other cone or dome shaped minor masses around the foot of this volcano; (Fig. 2) Konpirasan ("A" in Fig. 2) on the north-west side, Nishimaruyama ("B") to the north, Higashimaruyama ("C") and Matsumotoyama ("D") (239 meters height) to the east are such examples. Among these, Konpirasan and Higashimaruyama are regarded as roof mountains or cryptodomes by Omori. These masses are nearly arranged on the periphery of a circle having a center at the top crater. "Shinzan" ("F") is also located on this peripheral zone, indicating that this zone is tectonically weak. "Shinzan" may be defined as a cryptodome which intruded through this weak zone into a gap between pre-existing masses, as has been already related.

It should also be observed that the first explosion in 1910 occurred in the N-15°-E zone connecting the centers of the Usu and Tôya-nakajima volcanoes, and that the 245 meters high mass ("E") is also located within this zone. The direction of this zone is nearly parallel to the trend of the Nasu volcanic zone. This tectonically weak zone has been termed the Usu-Nakajima tectonic line by the author.

The Yanagiwara village, where land upheaval was first observed in the present activity, lies in a N-75°-W zone connecting the Ôusu and Kousu domes, which is nearly perpendicular to the Usu-Nakajima tectonic line. Ogariyama "G" to the west of the Kousu dome, another Ogariyama ("H") between the Ôusu and Kousu domes, and the knot-like mass ("I" in Fig. 2) on the east somma wall are all arranged in this zone. Ogariyama is a local name meaning "growing mountain." This phenomenum may be interpreted as being a change in the height of the roof mountain caused by movement of the underlying cryptodome. The fact that even the movement of a solidified lava mass can last for considerable long period, is clearly detected in the growth of the Ôusu dome in the historical age.[5] Though it may be that the Ôusu dome was formed in a pre-historical age of this district, sketches of the volcano as viewed from the south side of the top crater by a painter in the Kansei era (1780-1800) do not show the top part of the Ôusu dome projecting over the somma wall, which proves that growth of the Ôusu dome still continued after that era. This helps to describe the fact that the movement of the underground igneous mass may continue for a long period, provided that the lower parts of the mass are still in a molten state. The growth of Ogariyama may be considered in this light. The arrangement of domes and cryptodomes in the same zone supports the assumption that this zone is tectonically weak, which zone the author has arbitarilly named the Ôusu-Kousu tectonic line. Tsuya pointed out in 1943, that the parasitic cones of the Fuji volcano are arranged mostly in a zone parallel to the volcanic zone, and that another series of cones are arranged in a zone perpendicular to the former. These two lines or directions of a volcano represent the main tectonic lines, through which volcanic magma intrudes in most cases. The existence of several dome or cone shaped masses at the foot of the Usu volcano as has been already related, suggests that the peripheral zone is tectonically weak. The fact that the first movement was observed at Yanagiwara, and which gradually shifted northward along this zone towards the center of the present activity, and also the fact that 45 craterlets were formed in succession along this peripheral zone in the eruption of 1910, are worth attention.

This peculiarity in the volcanic eruptions of Mt. Usu is often the cause for formation of a dome or cryptodome. Also in the case of Usu, new magma is apt to select new courses other than those of past eruptions, especially when the former crater vent is obstructed by previous dome or cryptodome formation, which has resulted in the formation of a large number of domes and cryptodomes in this case.

Another interesting fact is that mud flows often occurred in past periods of activity. For example, the mud flows of Minamibyôbuyama and Bunsei (in 1822), and Tateiwa in 1853, as well as that in the 1910 eruption, are easily observed. This phenomenum is possibly related to the location of the volcano between Funka (Eruption) Bay and Tôya Lake, which supplies the underground water source. The fact that in the 1910 activity, the first explosion occurred within a period of several days after earthquake tremblings were experienced, and the this timelag amounted to half a year in the present eruption, may be attributed to the fact that the scene of the main volcanic activity was much nearer to Tôya Lake in the former case. Sufficient supply of underground water possiblly lead to an earlier explosion in the 1910 case, before the lateral movement of magma through the peripheral weak zone. In the present eruption, the new magma moved from Yanagiwara until its further advance was obstructed mainly by the Tôya caldera wall and Matsumotoyama, where it resulted in an explosion. The 1910 and the present eruption show a remarkable contract in this respect.

The frequent occurrence of earthquakes as a precursor of explosions in every recorded past eruption, is probably related with the existence of the two central domes which cap the central crater vent and prevent the escape of gas. The comparatively long duration of the activities of this volcano may be explained by the fact that this volcano has no open crater either on the top or other sides, which causes slow advancement of the new magma. This presents the possibility that the magma may solidify at or near its upper part before effusion. This further tends to slow down the advancement of the magma, and consequently causes a strong accumulation of gas, thus leading to violent explosions.

7. SUMMARY

The present new activity of the Usu volcano began with strong earthquake vibrations on December 28, 1943 and ended with maximum elevation of the dome in September, 1945, passing through an explosion stage of several mounth. The characteristic phenomena exhibited in this volcanic activity are rarely observed elsewhere on the earth, and are typically expressed in the case of the Usu volcano. The Usu volcano is known to have passed through similar, corresponding stages of activity as expressed in this present eruption, also in some past eruptions. A notable fact is that in this present activity, the new lava is rich in silica content, resembling that of dacite or rhyodacite, although it actually is hypersthene andesite as in the cases of the Ôusu and Kousu domes.

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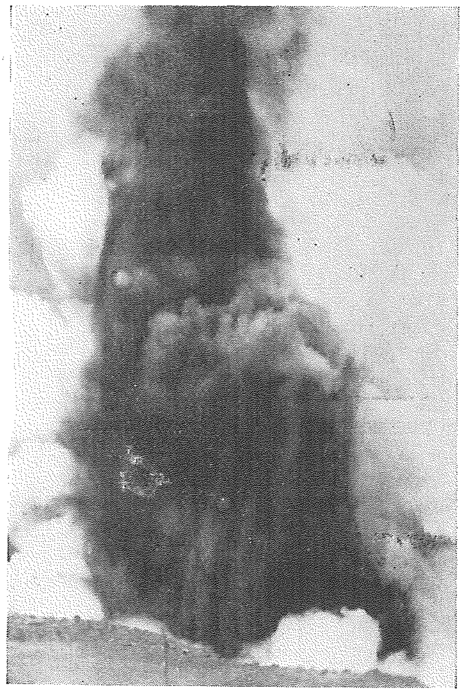
Plate I

Plate I

FIGURE 1. Explosion at it's climax on June 27, 1944, viewed from about 300 meters south of the crater.

FIGURE 2. Beginning of the explosion on June 25, 1944, viewed from the same point as in the above photograph.



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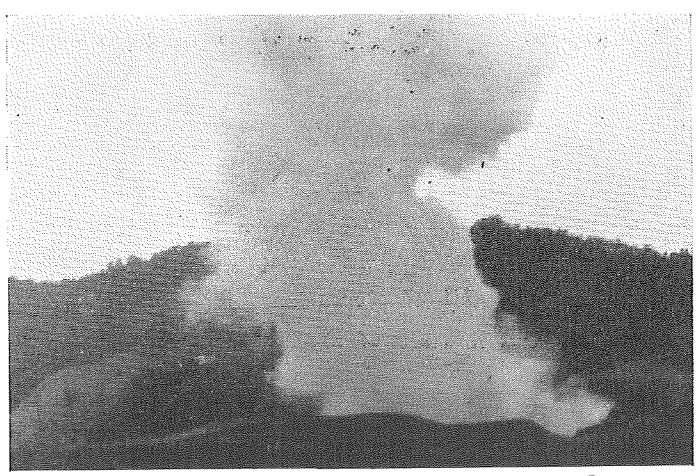

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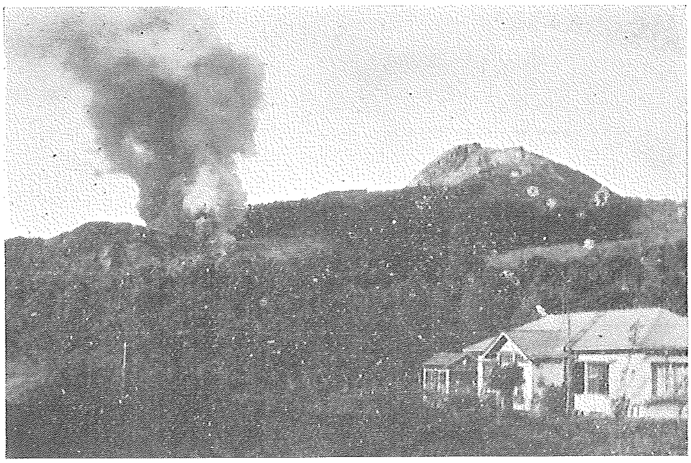
T. Ishikawa ; Eruption of Usu volcano, 1943-1945.

Plate II

Plate II

FIGURE 1. Roof mountain on September, 22, 1944, viewed from Sôbetsu station.

FIGURE 2. Craters on the roof mountain on September, 22. 1944, viewed from the east somma wall of Usu volcano.



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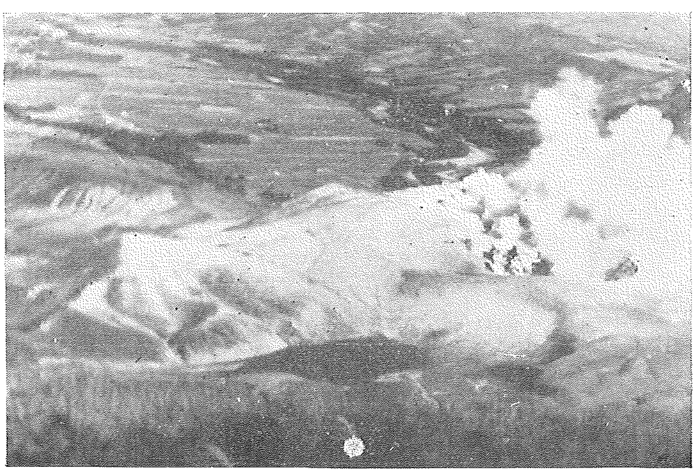

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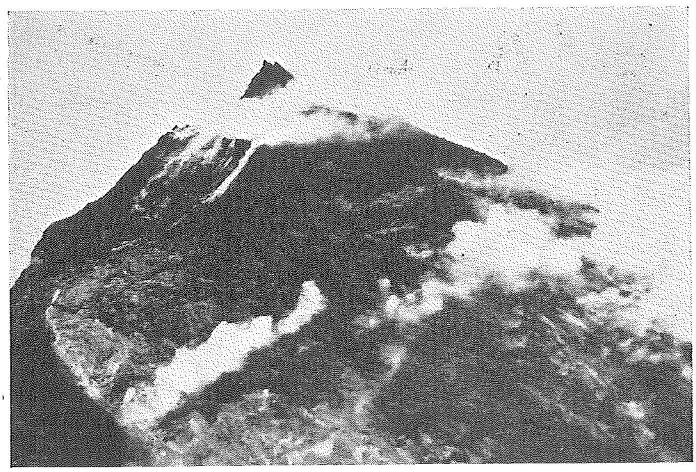
T. ISHIKAWA ; Eruption of Usu volcano, 1943-1945.

Plate III

Plate III

FIGURE 1. Top part of the dome, viewed from the east side on July 2, 1946. Note striations on the side face of the dome.

FIGURE 2. Entire view of Shôwa-Shinzan, located at the east foot of the original Usu volcano. Aerial photograph taken on November 6, 1947.



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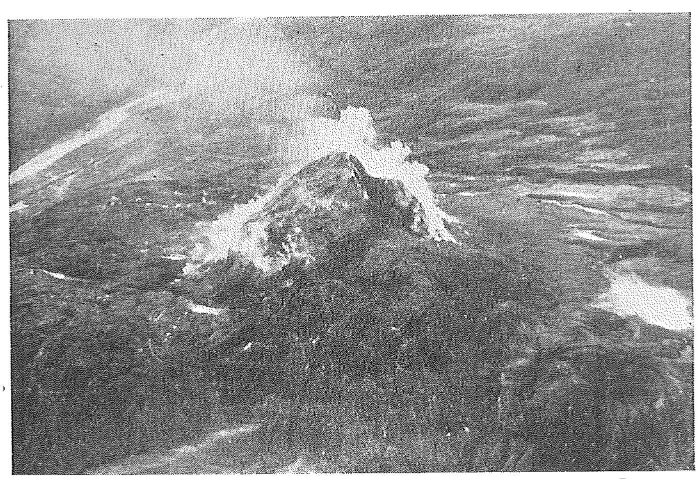

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T. ISHIKAWA ; Eruption of Usu volcano, 1943-1945.