38. *Explosive Activities of Volcano Kusatu-Sirane during 1937 and 1938.* (*Part I*).

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Introduction.

The Kusatu-Sirane volcano, which has two sulphur spring areas, Kusatu and Manza, at it's south-eastern and south-western feet, lies only 25 km north of the Asama volcano. From our Asama Volcano Observatory to the craters on the summit of Kusatu-Sirane it takes only three or four hours via the Kusatu Hot-springs.

The writer has been engaged in observing the orifice temperature and the rate of flow of these two hot springs since 1934. In July and August, 1937, he[1] surveyed the magnetic dip at 40 stations on the volcano in order to bring out clearly the variation in the earth's magnetic field accompanying volcanic activity. As just stated, being especially interested in the volcanic phenomena of Kusatu-Sirane, he was putting himself in readiness for the phenomena upon the outbreak of activity. The volcano, however, had been quiet for about 5 years since the explosive activities of October 1932, on which H. Tsuya had made field investigations. An explosion of the volcano occurred on November 27, 1937, 4 h 10 m. It occurred in Yugama, the Y-crater, one of the three craters on the summit of the volcano, the others being Karagama and Mizugama. From our Asama Observatory, we could see the vapour and volcanic ash ejected from the Y-crater. On November 29, 1937, the writer visited the volcano and began field investigations in the neighbourhood of the Y-crater and, at the same time, measured the magnetic dip at the two stations on the floor of Yugama and Karagama. The aspects inside and outside the Y-crater on 29 November, two days after the first violent explosion of November 27, are shown in the reproductions of the photographs.

Following the first explosion, explosion swarms occurred in December 1937, and January, February, 1938. In these explosions volcanic ash frequently rained in the region south-east of the volcano, in

1) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **16** (1938), 117.

Agatuma-Gun, Gumma prefecture, in the centre of which lies the Kusatu Hot-springs. During these activities, the snow on the summit of the volcano was 4 metres in depth and the air temperature 20° below freezing point, as the result of which, field investigations and observations with the aid of various instruments could not be executed satisfactorily during the winter. The writer fortunately obtained details of the dates and places of the explosions, and other information concerning the phenomena near the Y-crater from the mine watchmen living in a cottage near the crater. Since April, 1938, he has made topographical surveys and resurveys of the magnetic dip near the active crater. Early the following month, we set up a seismograph at a distance of 150 m SW of the Y-crater, a pair of clinographs in the K-crater (Karagama), and two pairs of electric poles in the Y-crater, and outside it, and the volcanic earthquakes and pulsations, changes in the inclination of the earth's surface, and the variations in the earth current were continuously observed. At the same time, the geothermal temperature on the bottom of the Y-crater, and the water temperature and water level of the Y-crater were measured notwithstanding almost insuperable difficulties. This paper reports the explosions that occurred in 1937 and 1938, together with the results of our observations.

2. Outline of the Present Explosions.

Since the occurrence of a swarm of explosions on December, 1927, the Kusatu-Sirane volcano exploded about twenty times during the first 27 days of October, 1932. Since the activities of 1932, the volcano was quiet un il the Autumn of 1937, without any small explosions or any volcanic earthquakes that could be felt by the villagers at the foot of the volcano. As H. Tsuya has told in his papers, from historical times the explosions have changed their places with every activity, sometimes it was inside and sometimes it was outside of the Y-crater, and sometimes in the neighbourhood of Yumiike, a small crater lake, 500 m south of the Y-crater. The present activities were confined to the inside of the Y-crater.

In the first explosion of November 27, 1937, 4 h 10 m, three watchmen in the mine cottage at a distance of 400 m south of the seat of the explosion, were roused from sleep by the explosion, earthshaking, and the sounds of falling volcanic detritus on the roof. The villagers at Kusatu Hot-springs were aware of the explosion by the rain of volcanic ash 30～40 minutes after the occurrence. According to investigation by means of post card questionaires that were sent to 100 villages in the neighbourhood of the volcano, neither earthshaking nor air vibration were felt in the villages except in two, in Agatuma-gun, Gumma prefecture, the one Imai, 8·3 km south-west of the crater, and the other, Iwasima, 16·3 km south-east of the crater, where the villagers found the sliding doors shaking as the result of the air pressure raised by the explosion.

In the various features of volcanic phenomena, the explosion of Kusatu-Sirane volcano are in striking contrast to those of the Asama volcano. For one thing, the intensity of the sound of the explosion in the former is much smaller than that of the latter, as a consequence of which, most of the explosions of the Kusatu-Sirane become known to the villagers only by the fall of ash at the foot of the volcano. Besides, there is the topography, which prevents the craters from being easily seen by the villages at the foot, whence it is natural to suppose that some of the explosion in historical times rained volcanic ashes in uninhabited regions, thus escaping record.

In the following Table I will be found the dates and times of the explosions with their roughly estimated magnitudes.

Table I. Explosions occurred during Nov. 27, 1937 and Dec. 31, 1938.

No.	Date	Time of occurrence	Scale
		h m	
1	Nov. 27, 1937.	4 10	III
2	Dec. 1, 〃	10 10	III
3	Dec. 28, 〃	17 40	III
4	Dec. 30, 〃	20 20	II
5	Dec. 31, 〃	15 5	II
6	Jan. 1, 1938.	unknown	II
7	Jan. 2, 〃	unknown	II
8	Jan. 8, 〃	8 45	II
9	Feb. 7, 〃	4 10	II
10	Feb. 8, 〃	23 40	III
11	Feb. 13, 〃	13 10	II
12	Feb. 16, 〃	16 5	II
13	July 22, 〃	unknown	I
14	Sept. 22, 〃	6	I
15	Sept. 26, 〃	7 55	I
16	Oct. 5, 〃	5 25	II

Scale of magnitude III. Volcanic detritus and ash are ejected from the crater. A part of the volcanic detritus reaches to distances of 500～1000 m from the crater. Ash falls in Gumma and Nagano prefectures.

Scale II. Volcanic detritus and ash are ejected, but the quantity and the maximum distance to which they are thrown are smaller than scale III. Most of the volcanic detritus falls into and near the crater.

Scale I. The ejecta are largely volcanic ash and small detrital fragments. The explosions are known only to those in the neighbourhood of the crater.

Of these sixteen explosions, numbers 1, 2, 3, and 10 were very violent and ejected large quantities of volcanic detritus to a distance 800 m south of the Y-crater. Most of the detritus ejected by explosions numbers 4, 5, 6, 7, 8, 9, 11, 12, and 16 fell inside the Y-crater. Explosions numbers 13, 14, and 15, which were very small, ejected only small fragments of detritus. Explosions of scale I must have occurred also during the most active stage of the present activity, but there are no records.

The Explosion crater (Aa_1) of inverted cone shape, which was newly formed on the north-west floor of the Y-crater at the time of the first explosion, is shown in Figs. 1 and 18.

Fumarole (F) on the southern outer slope of the crater-wall, from which steam was issuing before the present activity, poured out steam in increased quantities after the first explosion.

The quantity of hot water that gushed from the south-east corner of the Y-crater increased with the result that mineral charged water of high temperature accumulated in a hollow in the Y-crater and formed a hot spring pond. On the line connecting the explosion crater Aa_1 with the hot spring, appeared several fumaroles, from which issued hot water, mud, and steam, with a period of about twenty seconds. These were the aspects in the Y-crater on November 29, 1937, two days after the first explosion. Since then, explosion swarms occurred in succession until February, 1938, and enlarged the crater Aa_1, more and more, until it eventually joined the new explosion craters a_2 and a_3, as the result of which, a large explosion crater A was formed, as shown in Fig. 1. In the midst of the most active stages of January and February, 1938, new explosion craters B, C, and D were formed in a line on the south-eastern side of crater A. At the same time that the explosion craters A and B were formed, fumarole F suddenly stopped its violent ejections of steam — the outstanding phenomena of the present activity. On the other hand, the hollows in the explosion craters C and D filled with the hot water that issued from S, mixed with rain water. The issuing hot water contained much sulphur, which precipitated in the bottom of the reservoir. A part of the ash that was thrown out by these explosions accumulated, 30∼50 cm deep, on the bottom of the Y-crater, particularly, on its south-east floor; the rest had scattered in a south-east direction toward Kusatu. The thickness of the ash was 2∼3 cm at Yosigadaira, 1 cm at the Kagusa Hot-springs and 0·5 cm at the Kusatu Springs. But, in regions north-west of the crater, the ash was very small; at the Manza Hot-springs, a distance of only 2 km south-west of the summit, no trace of ash was found throughout the present activity. The ash of Asama scatters, as a rule, almost eastward of the volcano.

In order to ascertain the intensity of the gas pressure at the moment of explosion, the writer investigated the distribution of volcanic detritus projected by the present explosions. Although the distribution of these detritus, as shown in Fig. 2, gives only those that fell farthest from the crater, much more fell at nearer distances. Its fall was largest on the south side of the Y-crater, the reason for which is that, since most of the volcanic detritus from the Y-crater came with the ejecta from explosion crater A, the north-west periphery of explosion crater A was bordered by sharp cliffs of the crater-wall, so that the angle of emission of the volcanic detritus in projecting from the crater north ward, beyond the crater-wall, was limited in range. The volcanic detritus that is projected northward owing to this limited range cannot reach as great a distance as when it is projected southward. These phenomena just described developed near the Y-crater during April, 1938. As already described, one horizontal component of a seismograph, a pair of clinographs, and other instruments were installed near the active crater in April 1938, while the various volcanic phenomena that presented themselves near the crater were recorded by observers staying at the mine cottage. The following is an abstract of events since April.

April 1938.

The emission of vapour and gases from explosion crater A in the Y-crater, as seen in Fig. 1, was not so violent in the three holes a_1, a_2, and a_3 while the interior of explosion crater A became filled with boiling water. Explosion crater B emitted vapour most violently. Explosion crater D was full of boiling water, while from explosion crater C, a small quantity of vapour issued.

May 27.

In the south-east corner of the Y-crater, that is near explosion crater C, a new fumarole E was formed.

May 30.

Although countless volcanic micro-earthquakes were recorded during 2 h and 9 h by the seismograph set near the crater, there were no changes in the emission of vapour and no particular phenomena worth mentioning in the Y-crater.

June 1.

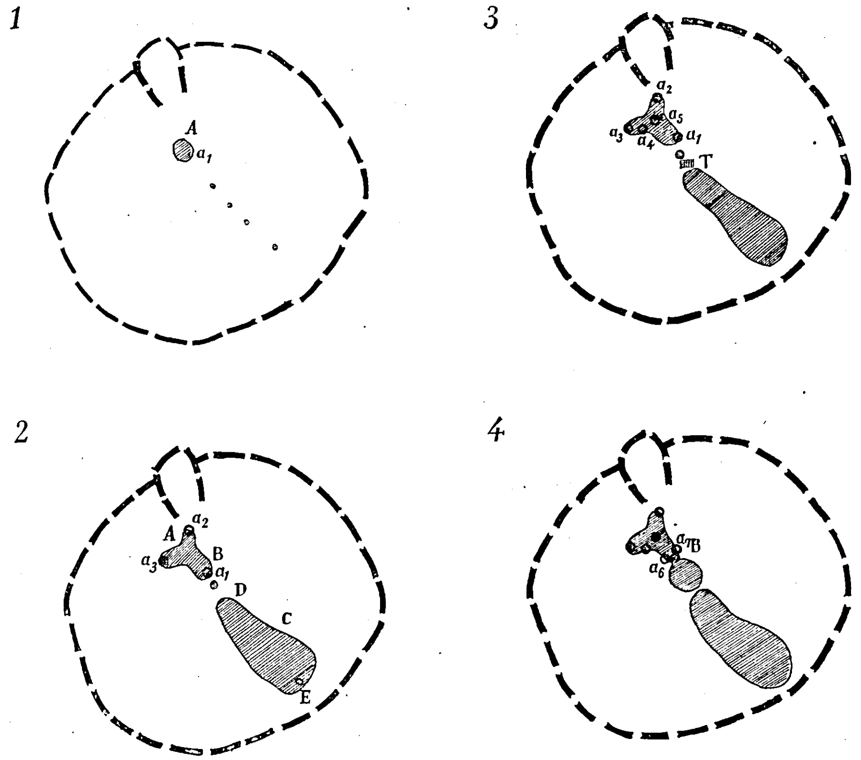


Fig. 1.

1 The explosion crater Aa_1 formed Nov. 27, 1937.
2 The explosion craters A, B, C, D, formed in Jan. and Feb. 1938.
3 The explosion craters Aa_4 and Aa_5 formed in July and Sept., 1938.
T; place of measurement of geothermal temperature.
4 The enlarged explosion crater B by the explosion of Oct. 5, 1938.

The quantity of vapour from fumarole E was more marked than that from explosion crater B. The vapour from explosion craters A and B contained large quantities of dry sulphur, in consequence of which the colour of the vapour turned yellowish.

July 21.

At 13 h, fumarole E suddenly stopped emitting vapour which had been issuing ever since May 27. On the other hand, explosion craters A and B threw out small quantities of sulphurous acid vapour.

July 22.

About 4 h, violent rumblings from the crater were heard at the mine cottage situated 200 m south-east of the crater. From the investigation made at 5 h 30 m, it became clear that a small explosion had occurred. The ash that was ejected at a furious rate, accumulated in the crater about 3 cm deep. In this explosion, a new small explosion crater a_4 was formed in explosion crater A. From a_4, ash was violently thrown out, together with steam, sulphurous acid gas, and dry sulphur. As the result of formation of the new explosion crater a_4, gaseous vapours from explosion crater D stopped with decrease from explosion crater B. As described above, the point of emission of the vapour moved along to line XY, which passes through the center of the Y-crater.

It may be considered from these observations that, if the free ejection of vapour is disturbed at the mouth of the explosion crater, the pressure of the accumulated vapour under the ground increases and produces a new explosion crater by breaking out from some weak spot, in this case on fissure line XY. During 6 h and 11 h, the seismogragh recorded volcanic micro-earthquakes.

July 27, 28.

Fumarole E, began to fill with hot water of a bluish-green hue, containing sulphur.

August 18.

Both explosion craters A and B showed diminution in the vapours emitted and in the sulphur content.

August 20.

The quantity of gas from explosion crater A gradually diminished.

September 6.

Ash fell near the Y-crater.

September 13.

The issuing gas from explosion craters A and B increased slightly in quantity. A small quantity of ash was thrown out by the latter.

September 19.

Ash and small fragments of detritus issued from explosion crater B.

September 21.

Volcanic micro-earthquakes were felt. Violent rumbling was heard outside the crater.

September 22.

A small explosion occurred about 6 h. During the morning, ash rained in the streets of Kusatu, large quantities being thrown out from the crater. This explosion occurred in the small explosion crater Aa_3. In the afternoon, the ejecta became reduced to steam only.

September 24.

Although the small explosion craters a_1, a_2, a_3 and a_4 were all quiet, crater B gradually increased its discharge of vapour. The level of hot water in explosion craters C and D receded. From several places on the fissure line, mud and hot water blew up to a height of about 1 m.

September 25.

Volcanic earthquakes occurred.

September 26.

A small explosion occurred at 7 h 20 m. Although slightly more violent than explosions Nos. 13 and 14, it was on a much smaller scale than the other explosions. Volcanic detritus, about 10 cm in diameter, scattered in the Y-crater. Ash accumulated to about 3 cm on the floor of the Y-crater. A new explosion crater a_5, the diameter of which was about 80 cm, was formed in the explosion crater A by the present explosion. The hot water which filled the interior of explosion crater A, had evaporated before the explosion occurred. It is supposed that the hot water evaporated owing to geothermal rise under the bottom of the Y-crater. As the result of this explosion, Aa_1 ceased emitting vapour, a_2 ejected less gas and a_3 increased its vapour discharge.

September 27.

Hot water began to gush out from a point 2~3 m south-east of explosion crater B. A small quantity of vapour issued from near explosion crater D.

October 1.

The quantity of vapour and gas from explosion craters A (a_1-a_5) and B greatly diminished. From several points on the line of the fissure (XY), hot water and mud were thrown to a height of about 1 m.

October 4.

A marked change in the earth-current was observed at 12 h.

October 5.

At 5 h 25 m, an explosion occurred with detonation and rumbling. It was the most violent since the active period of January, February, 1938. The centre of this explosion was a spot south-east of explosion crater A, from which mud and hot water had gushed out since September 27. The explosion crater formed by the present explosion, united with the explosion crater B, as the result of which crater B increased to almost the same size as crater A. At the same time, small craters a_6 and a_7 appeared at the south-east side of crater A. Volcanic ash accumulated to about 10 cm in the interior of the Y-crater. The volcanic detritus fell almost straight down on the floor of the Y-crater, only a small part of it dropping outside the crater-wall. Considerable vapour issued energetically from the new craters a_6 and a_7 until October 12, after which they declined in force. On the other hand, the enlarged crater B together with crater a_5, threw out large quantities of vapour on November 11 and during January 1938. Although after the last explosion on October 5, ash was thrown out and volcanic pulsations occurred on several occasions until the end of 1938, no remarkable phenomena appeared.

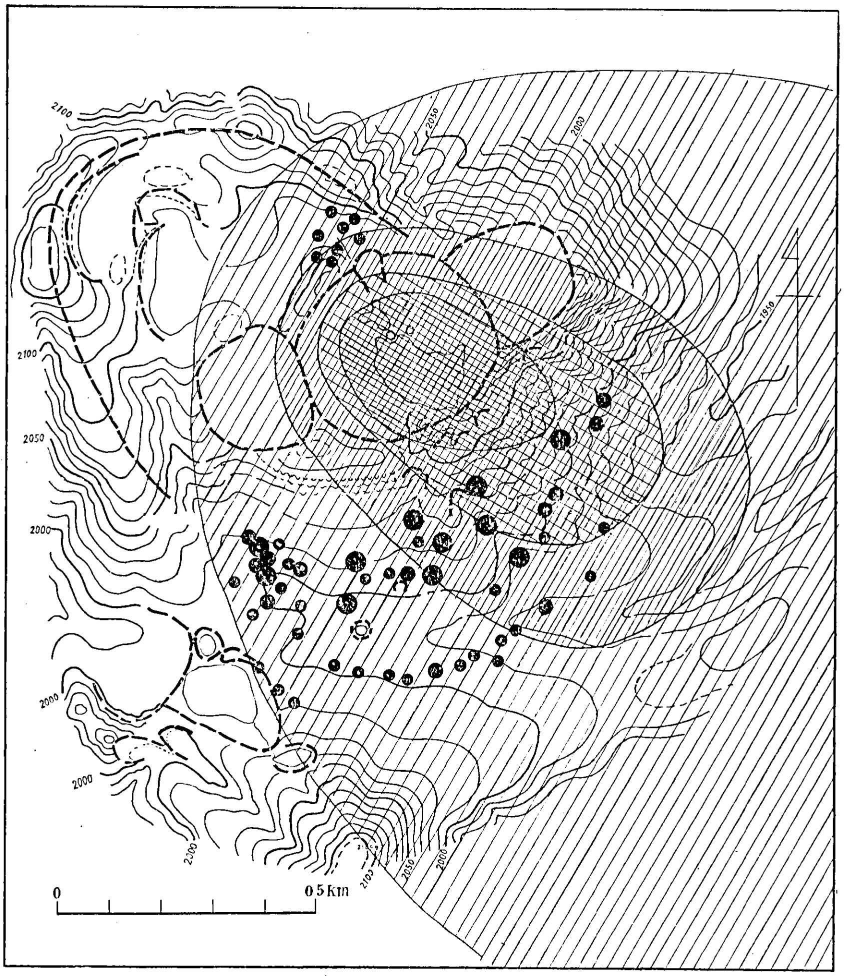


Fig. 2. Distribution of ash precipitation and volcanic detritus.

>0cm, >5cm, >10cm, >30cm

● =2 r > 50 cm ● =2 r > 30 cm • =2 r > 20 cm
2 r = diameter of volcanic detritus.

Generally speaking, these sixteen explosions presented the following features. Explosion craters A, B, C, and D that opened at the main stage of the present activity in December 1937 and February 1938, as shown in Fig. 3, are arranged almost in a straight line XY running SE—NW in the Y-crater. The small explosion craters and fumaroles that appeared since April 1938 are on the same line XY. In addition,

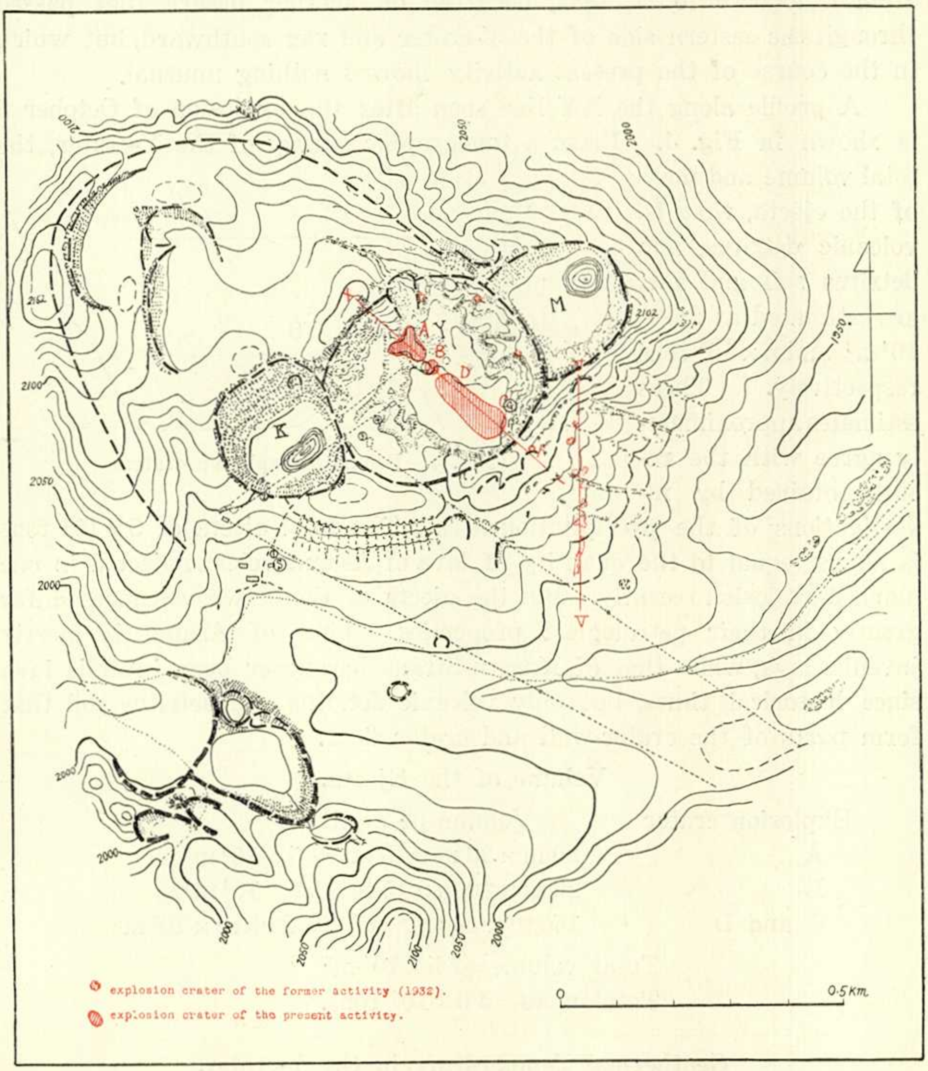


Fig. 3.* Topographical map near the summit of Volcano Kusatu-Sirane.
M=Mizugama, Y=Yugama, K=Karagama.
F=fumarole, G=hot-spring. S=seismological station.
①, ②, ③, ④=electrodes.

fumarole F, which existed outside of the Y-crater before the present activity, lies close to an extension of line of XY. From the positions

* Topographical map drawn by S. Watase and T. Takeda in April, 1938.

of these explosion craters and fumaroles, it will be seen that they all lie on the line XY of the crater indicating that it is a line of weakness of the volcano. According to H. Tsuya,[2] the previous activity from October 1 to 27, 1932, occurred on another fissure that passed through the eastern side of the Y-crater and ran southward, but which in the course of the present activity showed nothing unusual.

A profile along the XY line soon after the explosion of October 5 is shown in Fig. 4. From a topographic survey of the Y-crater, the total volume and mass of the ejecta, that is, volcanic detritus, and detritus soil and ash, are estimated at $2{\cdot}5 \times 10^4 \mathrm{m}^3$ and 5×10^5 tons respectively. These estimates approximately agree with the result obtained by investigations of the precipitation area. The total ejecta of 5×10^5 tons is almost equal to the quantity of lava of Asama volcano ejected in one marked explosion recently. But the ejecta of these two volcanoes differ greatly in their petrological properties. That of Asama is mostly juvenile lava, while that of Kusatu-Sirane has never been juvenile lava since historical times, but only volcanic detritus and detritus soil that form parts of the crater-wall and crater floor.

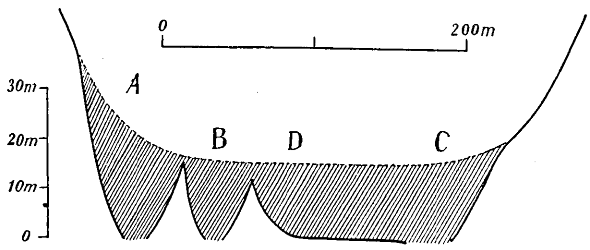


Fig. 4. Profile of explosion craters.

Volume of the Ejecta.

Explosion crater	Volume of ejecta.
A	$30\,\mathrm{m} \times 30\,\mathrm{m} \times 15\,\mathrm{m} = 1{\cdot}4 \times 10^3\,\mathrm{m}^3$
B	$20\,\mathrm{m} \times 20\,\mathrm{m} \times 15\,\mathrm{m} = 0{\cdot}6 \times 10^3\,\mathrm{m}^3$
C and D	$150\,\mathrm{m} \times 100\,\mathrm{m} \times 15\,\mathrm{m} = 22{\cdot}5\,\mathrm{m} \times 10^3\,\mathrm{m}^3$

Total volume $= 2{\cdot}5 \times 10^4\,\mathrm{m}^3$
Total mass $= 5{\cdot}0 \times 10^5$ tons.

Geothermal Temperature in the Y-crater.

In order to ascertain the geothermal distribution in the Y-crater, and its variations in the course of the present activity, measurements were made of the geothermal temperature 1 m below the surface, for which purpose 100 points were selected on the floor of the Y-crater and

2) H. TSUYA, *Bull. Earthq, Res. Inst.*, **11** (1933), 82.
H. TSUYA, *Zisin*, **5** (1933), 71. (in Japanese.)

the measurments at each of these point repeated 40 times on May 30 and on October 1. The measurments were made as follows. A hollow brass tube 1·5 m long and 2 cm inner diameter, one end of which was made in the form of a spear head, was driven 1 m into the ground. A thermometer with a capillary tube was placed in the bottom of this hollow tube. A wooden stake was driven into each measured point as indications for later observations at the same point. According to the geothermal survey of June 13, an isothermal line of 60°C, 1 m under the surface, was found at a distance of almost 1 m from the margins of the active explosion craters A, B, C, and D, with also one of 25°C at a distance of 8 m from the margins. At greater distances from the margins the geothermal temperature could not be distinguished from that outside the Y-crater. Where the explosion of October 5 occurred, the measured points were taken much closer to one another during the period above described. The geothermal distribution of this small region (*T*) on June 7 is shown in Fig. 5. From these measurements, the isothermal lines are almost ellipses with their longer radius coinciding with the fissure line XY. It therefore seems evident that the coincidence of position of the isothermal line with the line of explosion craters and fumarole F suggests the presence of a fissure under the crater bottom directly below these lines, from which the heat was supplied from the reservoir to the surface.

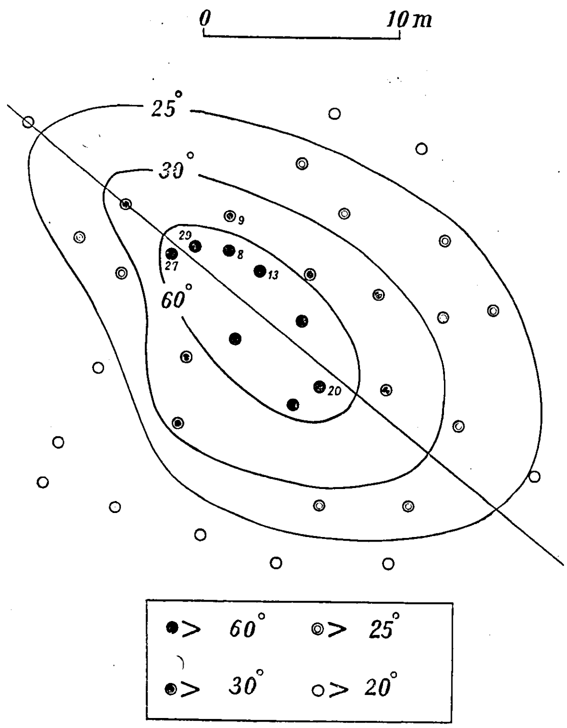


Fig. 5.
Geothermal temperature at T (Fig. 1) on June 7, 1938.

The geothermal temperature variation at several points are shown in Fig. 6 (a) (b). The points of Nos. 8, 9 and 13 are not near the radius of the isothermal ellipses, while Nos. 20, 21, and 27 are near line XY. On June 7, these points indicated temperatures of 60°C and 55°C respectively, whereas on September 2, their

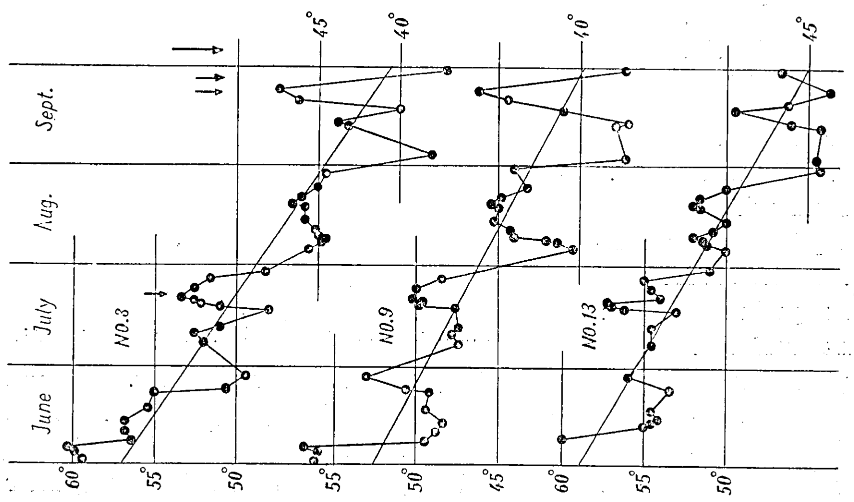


Fig. 6 (a).
Geothermal temperature variations of points Nos. 8, 9, and 13.

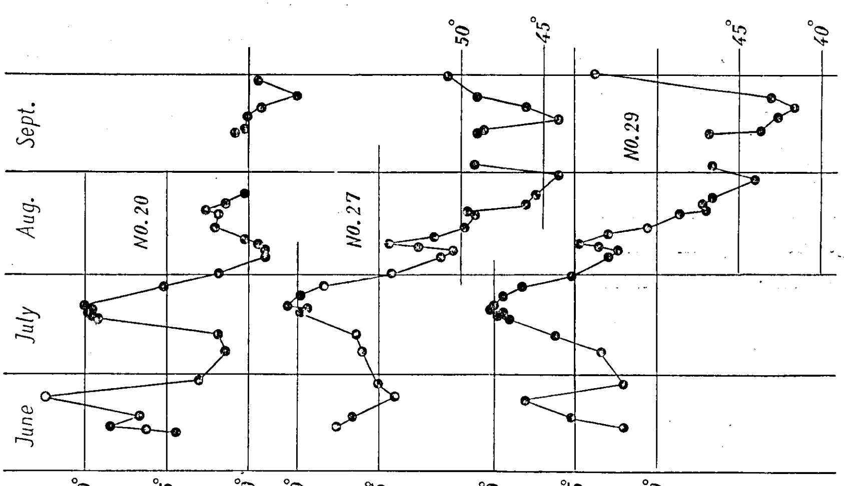


Fig. 6 (b).
Geothermal temperature variations of points Nos. 20, 27, and 29.

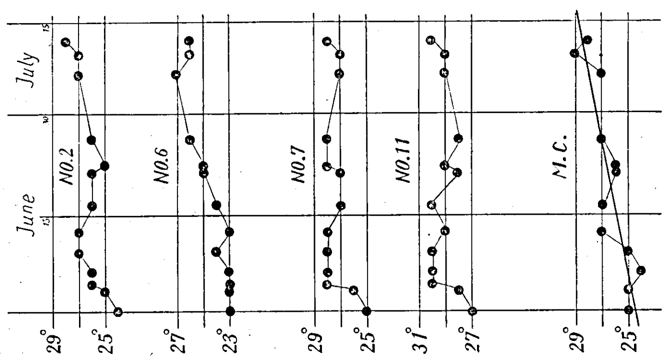


Fig. 6 (c).
Geothermal temperature variations of points Nos 2. 6, 7, 11, and the mean curve of these variation.

temperatures dropped to about 45°C. On the other hand, the geothermal temperatures of points Nos. 2, 6, 7, and 11 (in Fig. 6 (c)), which were 23·7°C, 22·5°C, 25·0°C, and 27·0°C in June, gradually rose to 27·5°C, 25·5°C, 27·5°C, and 30·0°C on July 12. From these results, it may be suspected that the geothermy which reached maximum during the most active stage of the present activity lost their heat by conduction, particularly those points that are not on the line XY, which indicate simple declines. If the heat is being lost by steady conduction, the change in temperature is expressed by the relation

$$\frac{dT}{dt} = -AT$$

$$T = T_0 e^{-k't} \doteqdot T_0 - kt. \tag{1}$$

From the observed values of points Nos. 8, 9, 13, the following relations between the geothermal temperatures and their variations are derived by means of the method of least squares.

$$\left.\begin{aligned} T_c &= 56{\cdot}8^\circ - 0{\cdot}132^\circ t \quad \text{(No. 8)} \\ T_c &= 52{\cdot}6^\circ - 0{\cdot}105^\circ t \quad \text{(No. 9)} \\ T_c &= 58{\cdot}9^\circ - 0{\cdot}113^\circ t \quad \text{(No. 13)} \end{aligned}\right\} \tag{2}$$

(unit of time = one day)

The geothermal temperatures of points Nos. 20, 27, 29 that are near the line do not indicate such simple variations as the former, which may be due to the supply of heat from along fissure XY. But, the changes in the geothermal temperatures even at the former points are only small fluctuations. In order to study these small variations, we took the differences of the observed values and those calculated by equation (2),

$$\Delta T = T_0 - T_c.$$

These deviation curves (ΔT) of points Nos. 8, 9, 13, as seen in Fig. 7, resemble one another. Consequently, the mean curve of these three curves retain the main characters of the individual curves. On the other hand, it may not be unreasonable to conclude that the resemblance of these three curves is due to the fluctuations from the same cause, for which reason the mean fluctuation curve is compared with the rainfall. Although in these two kinds of curves, the peaks of the one correspond fairly well to the negative peaks of the other, the phase of the geothermal temperature curve lags about 2 days in the mean.

After a rainfall, there is usually a decline in the geothermal temperature in proportion to the precipitation. On the other hand, there is a corresponding rise in the geothermal temperature after continued fine

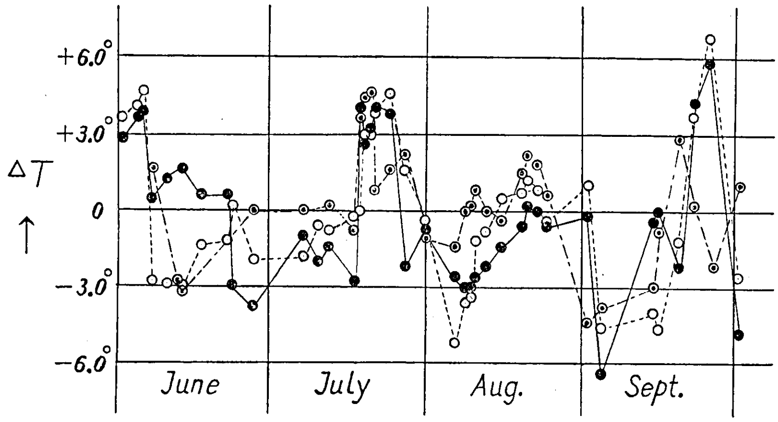


Fig. 7. Deviation of geothermal temperature.
$\Delta T = T_0 - T_c$ T_0=observed value. T_c=calculated value.
● =No. 8 ○ =No. 9 ⊙ =No. 13

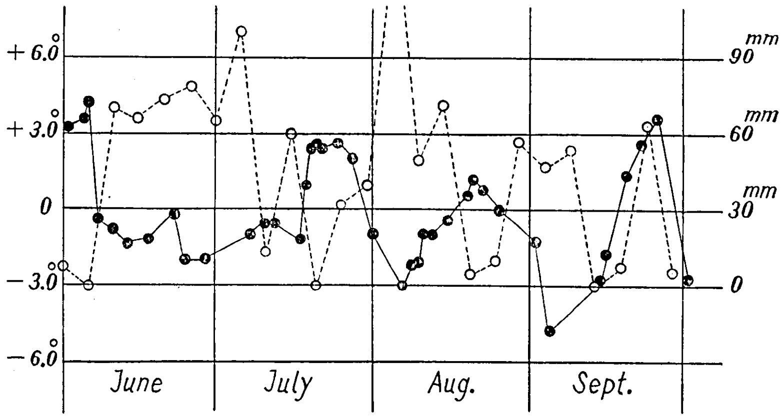


Fig. 8. Deviations of geothermal temperature (ΔT) and precipitation.
● =mean deviation of geothermal temperature.
○ =sum of precipitation of successive five days.

weather. On the occasion of heavy but short rains, such as that on August 1, the drop in geothermal temperature is not so marked as may be expected from the amount of precipitation, as the result of which it may be considered that the geothermal temperature near fissure was owing to the heat from the gas issuing up along the fissure during the most active stages of January and February, 1938, while after April, 1938, the temperature gradually declined by conduction, and by rainfall and other causes. The geothermal temperature near fissure line XY suggests supply of heat along the fissure. It is probable that the rise in geothermal temperature since September 10 was due to recovery of volcanic activity, which was followed by the explosions of September 22, 26, and October 5.

Moreover, the variation curves of these geothermal temperatures resemble that of the hot-spring in the Y-crater, as shown in Fig. 9.

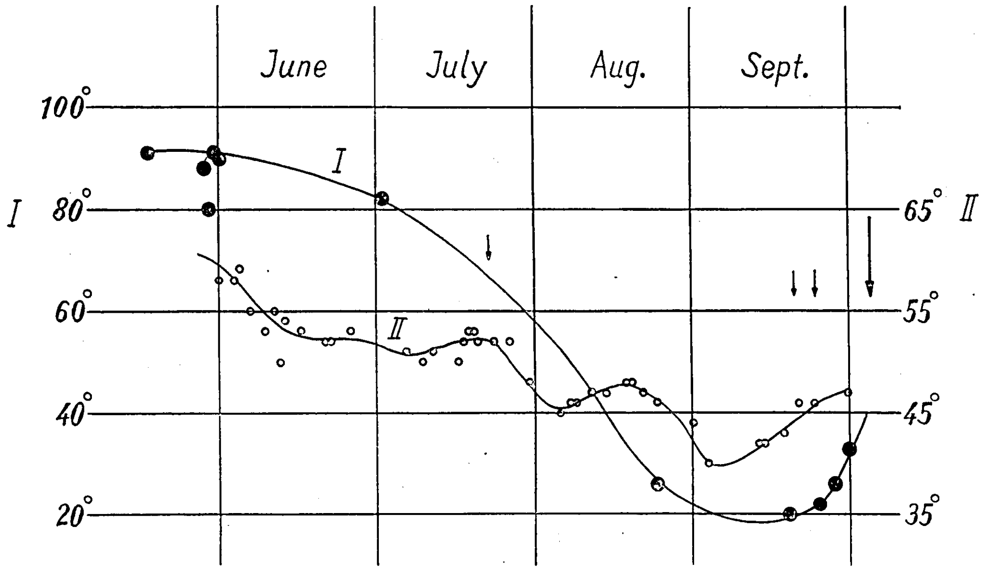


Fig. 9. I Temperature of hot spring pond in the Y-crater.
II Mean geothermal temperature of points Nos. 8, 9, and 13.
↓↓ = explosions.

Although the latter temperature in the end of May and early June was about 70°C, owing to rainfall and other dissipations of heat, the temperature of the spring declined to a minimum of 25°C on September 10, after which it began to rise again.

Water Level of the Hot Spring in the Y-Crater.

As above described, a hot spring always issues from the south-east corner in the Y-crater. This water contains sulphur and its compounds accumulated in the explosion craters C and D. All the rain water that falls into the Y-crater find its way down into this pond of hot water, with the result that the water-level of the pond changes with the rainfall and with the rate of issue of the vapours. Although no continuous observations of the water-level of the pond have been made, it is reported that in activities in the past, the water-level sank markedly prior to an explosion. From field investigations made during August and

October, 1937, that is one or three months before the present activities, there was almost no hot water in the reservoir. Unfortunately, the writer did not systematically measure the water-level to the extent of enabling him to detect any conspicuous relation between change of water-level and the occurrence of the first explosion of November 27, 1937. An attempt made in April, 1937, to make clear this relation was frustrated by violent ejections of sulphurous acid gas and hydrogen sulphide, so that direct observations were made by measuring the water-level by means of four wooden graduated stakes driven in the pond. Twenty-three observations were made in the face of great difficulties in the period between May 28 and September 29. No doubt, rainfall greatly affected the water-level, so that for the first approximation it may be reasonable to ascribe the changes in the water-level to two causes, rainfall and issue of hot water. We have then equation

$$\Delta H = \Delta h + k \cdot p, \tag{3}$$

where ΔH = change in water-level.
Δh = change in water-level due to the issue of hot-spring and seeping.
p = amount of precipitation.
k = coefficient of precipitation.

Although in these quantities, ΔH and p were observed, Δh and k were determined by means of equation (3) by using two series of the values ΔH and p during 2 successive days, and by assuming that in the two days Δh and k did not alter. According to the calculation, the value Δh is in the range from -10 cm to -22 cm a day, while k is in the range between 8·7 and 9·5. Precipitation coefficient k means that a part of the rain water that falls over the total surface of the Y-crater, runs down into the hot spring pond. The surfaces of the former and latter are almost 10^5 m^2 and 5×10^3 m^2 respectively. As said above, the precipitation coefficient was approximately constant throughout the present observations, consequently equation (3) is integrated as follows;

$$H = \int \Delta H dt$$
$$= \int \Delta h dt + k \int p dt \tag{4}$$

The water-level calculated by equation (4) is shown in Fig. 11 with the observed value. Change in the water-level except that from rainfall is separated into two kinds of quantities, the one issuing as hot water and the other sinking underground through the floor of the crater. The value of Δh was always negative in the present observations,

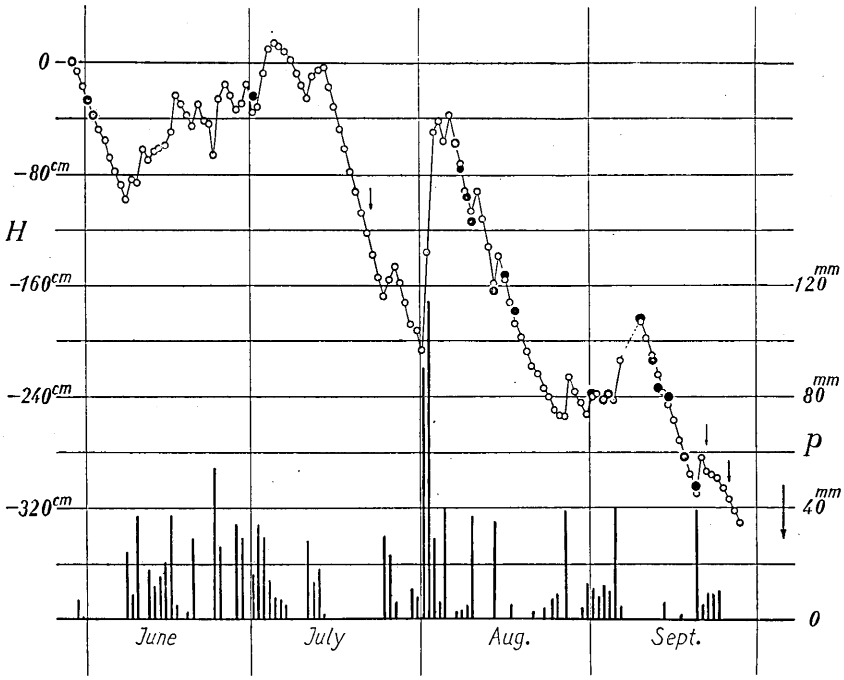


Fig. 10. Water-level (*H*) of hot spring in the Y-crater and precipitation (*P*)
• observed value of water-level. ∘ calculated value of water-level.

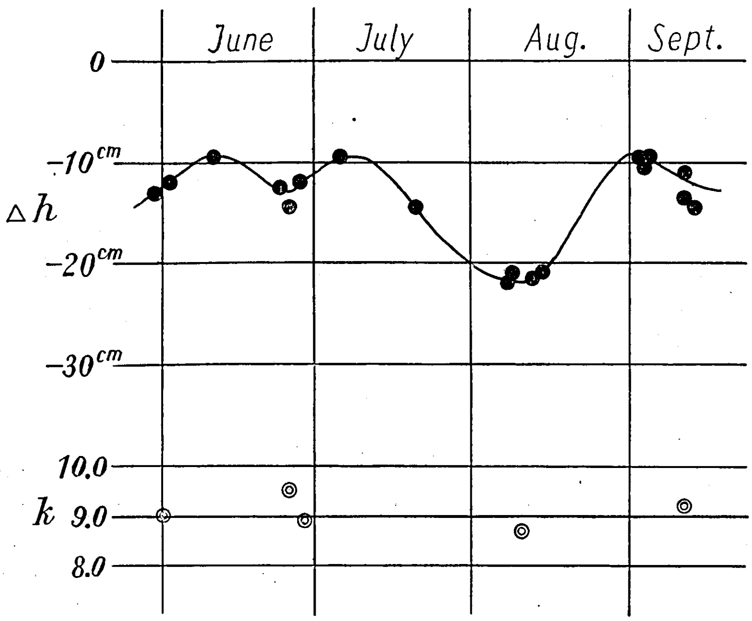


Fig. 11. Curves of Δh and k.

that is, more water was flowing out through the bottom of the pond than from the surface. On the other hand, boring in the Y-crater made clear the existence of layers of precipitated sulphur which prevented the water from filtering through, whence it is believed that the water flows out only through the fissures and the new explosion craters. The quantity of water flowing out under the ground amounts at least to about 1000 tons a day, if the value of Δh is taken as -20 cm a day. Whether this quantity of water corresponds to the amount of steam issuing without interruption from the fumaroles, and whether therefore it has any relation or not to the occurrence of explosions is an interesting question which only further studies can answer.

B. Koto,[3] 1915, from observations of the Kusatu Hot-springs, suggested that these springs which have their origin near the Y-crater of the Kusatu-Sirane volcano, go down for some depths under the ground to the foot of the volcano, after which it appears near the earth's surface at Kusatu.

Observations of the Earth-Current near the Y-Crater.

In May 1938, four electrodes were set inside and outside the Y-crater. The electric potentials between poles Nos. 1 and 2 outside the crater and poles Nos. 3 and 4 inside the crater, (fig. 3), were measured by means of a milivoltmeter three times a day, at 6 h, 12 h, and 18 h. Poles Nos. 1 and 2 were buried 1 m under the ground, their buried ends soldered to a lead pipe laid flat in a spiral, the span between poles Nos. 1 and 2 being about 100 m. Poles Nos. 3 and 4 were soldered to short copper rods with their lower ends immersed in super-saturated solutions of copper sulphate in order to avoid changes in the property of the electrodes from the effects of sulphurous acid gas and sulphur vapour always issuing from the ground. The span of poles Nos. 3 and 4 was about 50 m. As to the earth-current of poles Nos. 1 and 2, the latter, which was set at a position some 10 m higher than the former, always indicated a higher potential. As will be seen from Fig. 12, marked changes in potential occurred, reaching the very large range of from 3·0 mv to more than 170 mv. There seems to be some relation between the small changes in the earth-current and precipitation. Throughout the present observations, the most remarkable change in earth-current occurred on October 4, at 12 h, namely, 17 hours before the occurrence of the explosion of October 5. Although the electric po-

3) B. KOTO, *Bull. Imp. Earthq. Inv. Comm.*, **78** (1915), 32. (in Japanese.)

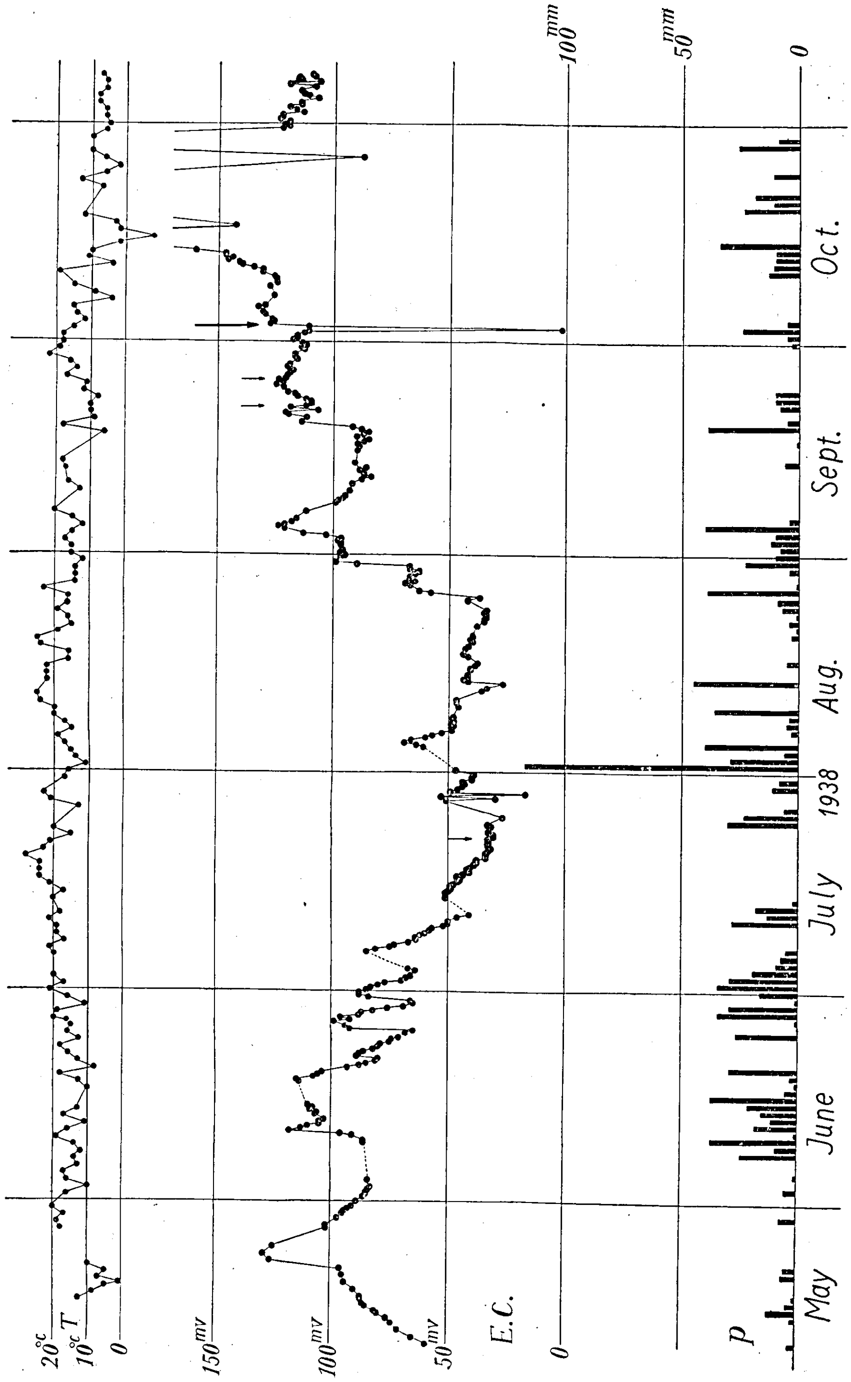


Fig. 12.

Electric potentials between poles Nos. 1 and 2 (E. C.), precipitation (P) and air temperature (T).

tential between poles Nos. 1 and 2 at 8 h on October 4 was 111·0 mv, it changed by only 3·0 mv at 12 h the same day, recovering its original value at 18 h. On the other hand, the earth-current between poles Nos. 3 and 4 indicated wider variations throughout the present observations. These changes in earth-current of the two series of poles, on the whole are similar in form to each other. The remarkably large earth potential that occurred between October 10 and 27, probably had something to do with the activity of the Y-crater, seeing that in the same period there were explosions, with rise in geothermal temperatures and in the water of the hot-spring in the Y-crater.

Although the marked variations in the earth-current that appeared inside and near the active crater were not unexpected, the changes in the earth-current at 12 h on October 4 are notable. These unusual earth-currents, which were frequently observed during the active stage of the Asama volcano, and which were also observed in the present activity of the Sirane volcano, deserve study. It is probable that these changes in the earth-current that appeared during volcanic activity are related in some way to the changes in ionization due to ejection of various vapours and also to geothermal changes.

Volcanic Micro-Earthquakes and Volcanic Pulsations.

Volcanic activity is usually accompanied with volcanic pulsations or tremors. A typical study of volcanic pulsations is that made by K. Sassa[4] in connexion with Volcano Aso. He divided the volcanic tremors that were observed at Aso into four kinds of surface waves. However, in the recent continuous observations at Asama, a number of volcanic micro-earthquakes occurred as well as volcanic pulsations. There were many micro-tremors which, from the seismograms, it was impossible to say whether they were volcanic pulsations, or whether they were micro-earthquakes. The late F. Omori,[5] in 1910 and 1916, set up seismographs at Yunotaira, 1·5 km SW of the crater of Asama. The seismograms obtained showed clearly two kinds of volcanic tremors.

F. Kishinouye[6] ascertained the occurrence of these two kinds of volcanic tremors at the time of the great activity of Volcano Komagadake, Hokkaido, in June, 1929. In the present activity of Kusatu-Sirane, a seismograph was set up only 100 m from the active crater and records taken since May, 1938, from which the presence of two

4) K. SASSA, *Memo. Coll. Sci. Kyoto Imp. Uni.*, **18** (1935), 256; **19** (1936), 11.
5) F. OMORI, *Bull. Imp. Earthq. Inv. Comm.*, **6** (1912~1914); **7** (1914~1919).
6) F. KISHINOUYE, *Bull. Earthq. Res. Inst.*, **8** (1930), 274.

kinds of volcanic tremors were clearly established from the seismograms, and that they occurred independently of each other.

On May 30, 1937, during the hours from 2 h to 9 h, a swarm of several hundreds of micro-earthquakes occurred. In these micro-earthquakes the P phase and S phase were distinguished, being about 10^{-3} cm in maximum amplitude, and of about 4 seconds duration. Although such large swarms came only once in six months, there were sometimes a few micro-earthquakes. There were usually more volcanic pulsations than micro-earthquakes.

From investigations of the duration of the preliminary tremors, a part of the micro-earthquake swarm on May 30 (consisting of about 50 micro-earthquake) it was found that in numbers of micro-earthquakes, their preliminary tremors were 0·2 seconds and 0·7 seconds in durations as shown in Fig. 13.

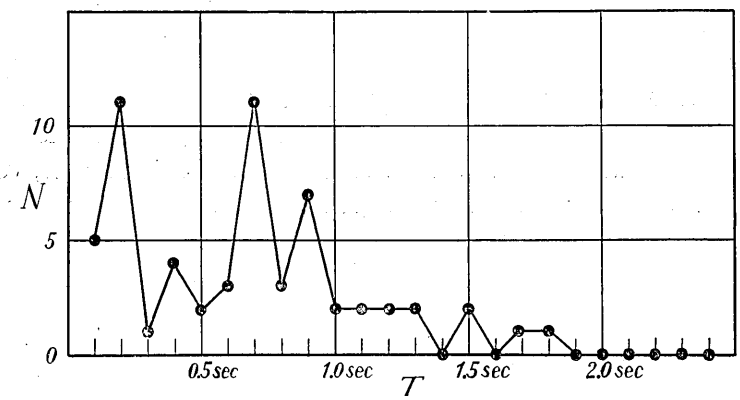


Fig. 13. Durations of preliminary tremors of volcanic micro-earthquakes occurred on June 30, 1938.
T=Duration of preliminary tremors.
N=Occurrence numbers of volcanic micro-earthquake.

As these seismic observations were made by only one component of the seismograph and at only one station, it was impossible to determine their hypocentres from the results above mentioned. But, if the epicentres of these micro-earthquakes whose durations of preliminary tremors have the large range from 0·1 second to 1·0 second, are assumed to be in a small region, the hypocentres of these earthquakes are approximately determined from Omori's formula $R=K\cdot T$. The distance factor K was taken at 2·5 in the present case. Judging from the results of seismic observations of Volcano Mihara by R. Takahasi and T. Nagata,[7] the value of K is a reasonable one for our purposes.

7) R. TAKAHASI and T. NAGATA, *Zisin*, **11** (1939), 161. (in Japanese.)

After all, micro-earthquakes with preliminary tremors of 0·2 seconds in their durations have their hypocentres in a semi-sphere of 500 m radius, in which the present active crater is contained. That is, it is reasonable to believe that these earthquakes occurred near the bottom of the Y-crater, that is, near the active fissure XY. On the other hand, the swarm of earthquakes with durations of 0·7 seconds occurred 1·7 km under the bottom of the crater.

There is no doubt that these results give very interesting information concerning the structure of the volcano as well as on the mechanism of explosions.

Résumé and Conclusion.

Although the Kusatu-Sirane volcano, with the remarkable explosion that occurred on November 27, 1937, was very active during December 1937 and January, February, 1938, it became somewhat calm from April to August, 1938, but became active again from the later part of September, a rather violent explosion having occurred on October 5, 1938. After the last named explosion, it ejected large quantities of gas, while ash was scattered near the Y-crater. At the same time, volcanic pulsations and volcanic micro-earthquakes occurred on occasions, and they have not yet (Feb. 1939) ceased altogether.

A swarm of the present (Nov. 1937~Oct. 1938) explosions occurred on fissure XY which runs SE—NW inside the Y-crater. Consequently, the present active fissure differs from the fissure of the previous activity of October, 1932, that is so far as their situations on the earth's surface are concerned. From his field investigations at the time of the activity of 1932, H. Tsuya[8] suspected the existence of a fissure running N—S through the eastern side of the Y-crater. This fissure intersects the present active fissure near fumarole (F) on the south crater-wall. From the durations of the preliminary tremors of the swarm of volcanic micro-earthquakes that occurred in May, their hypocentres are supposed to lie 1·7 km under the bottom of the Y-crater and near the active fissure XY, which brings up the question whether or not the reservoir of the heat supplied in the present activity lies near these hypocentres, to answer which, however, requires further study.

According to the measurements of geothermy inside the Y-crater, the region of high temperature is restricted to the narrow zone along the active fissure, which fact suggests that the steam and hot gases rose from this fissure. From observations of the water-level of the hot

8) *loc. cit.*

spring pond in the crater, it was concluded that the quantity of water that filters through the fissure at the bottom of the pond amounts to at least from 500 to 1000 tons a day. And although the gas ejected from the crater in the course of the present activity was mostly aqueous vapour, on several days during May and October, 1938, large quantities of evaporated sulphur were emitted with the steam. As will be seen from the results of boring shown in Fig. 14, the floor of the Y-

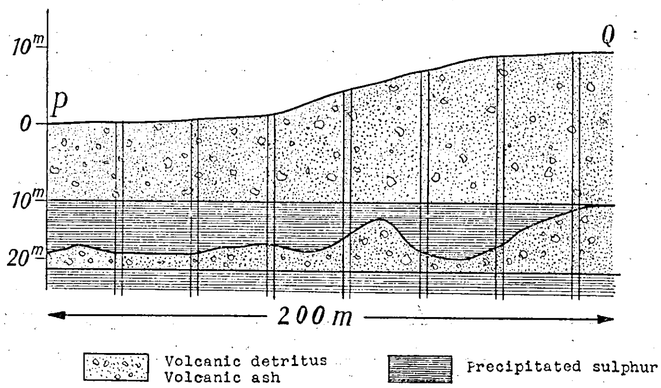


Fig. 14. The result of boring under the Y-crater.

crater was found to consist of alternate layers of precipitated sulphur, volcanic detritus, and ash. It may be supposed that the precipitated sulphur in the alternate layers was evaporated by a temperature exceeding the evaporation point of sulphur, seeing that the present active fissure cut through the sulphur layers. These phenomena give us some knowledge of the temperature of the issuing vapour at the time the vapour passes through these layers. On several days during the present activity, the temperature of the vapour reached the above evaporation point of 444°C; on most days the temperature of the vapour was estimated to be below this.

Such variations in the temperature of the vapour or in the geothermal temperature are due not only to increase and decrease of supply of heat from the subterranean origin but also to changes in the quantity of the water seeping through the crater floor. Needlees to say, a heat of 10^{11} calories is necessary to raise 1000 tons of water from a temperature of 50°C to a vapour of 100°C, at 1 atmosphere. Consequently, if this water mass does not flow outside down the foot of the volcano, but seeps through the crater floor and changing into steam, it usually issues from the crater and fumaroles, or is thrown up at the explosion. The quantity of water that seeps through the bottom will greatly affect the geothermal temperature and the pressure of the vapour.

Judging from the distribution of the volcanic detritus, the pressure of gas at the moment of the present main explosions was almost 150 atmospheres, which is slightly less than that of the explosion of October, 1932, as calculated by T. MATUZAWA.[9]

The various volcanic phenomena that were observed in the course of the activity suggest that the high gas pressure at the time of an explosion does not form suddenly from a low pressure at the moment of explosion, but that in the active stage of the volcano, the gas pressure which is already fairly high, is superposed by sudden pressure at the moment of explosion.

H. Tsuya[10] concluded from the geological point of view that the recent explosions of the Kusatu-Sirane volcano are phenomena that occur near the earth's surface resembling that of a geyser, consequently, it may not be possible to ignore the effects from the earth's surface, such as rainfall and atmospheric pressure, on volcanic activities such as those of Kusatu-Sirane. Volcano Asama ejected a large quantity of juvenile lava in the recent explosions accompanied with much greater heat than in the explosions of the Kusatu-Sirane volcano. Needless to say, the circulating waters influence the two kinds of volcanoes to a considerably varying extent.

In conclusion, the writer wishes to express his cordial thanks to Mr. Hideo Tino, director of the Kusatu Forestry Management Station, Mr. Yasuzi Tamino, superintendent of the Kusatu works of the Toyama Chemical Industrial Company, and Mr. Akizo Utizima for their numerous courtesies and their assistance in the course of these investigations.

9) T. MATUZAWA, *Bull. Earthq. Res. Inst.*, **11** (1933), 347.
10) *loc. cit.*

Table II. Geothermal temperature inside the Y-crater. (Yugama)
(a)

	No. 1	No. 4	No. 8	No. 9	No. 13	No. 20	No. 24	No. 27	No. 29
	°C	°C	°C	°C	°C	°C	°C	°C	°C
June, 1	45·6	56·2	59·5	56·2					
4	45·3	56·8	60·0	56·0					
5	45·2	57·1	60·2	56·8					
7	48·0	57·8	56·5	49·2	60·0				
10	47·5	57·6	56·8	48·8					
12					55·0	54·5	53·8		
13	48·0	57·2	56·8	48·5	54·6	56·3	55·0		
14					54·1	58·3	54·8	57·6	52·0
17	48·2	57·6	55·3	49·5	54·6	56·6	53·6	56·5	55·1
22	47·5	56·5	54·6	49·2					
23	49·0	58·0	50·8	50·5	53·5	62·4	52·7	54·0	57·9
27	50·2	57·6	49·5	53·0	56·0	53·0	47·5	55·0	52·0
July, 7	52·5	52·0	51·0	47·0	54·8	49·4	55·0	56·0	53·5
10	51·3	51·8	51·5	47·8					
12	50·0	51·0	50·0	47·5	54·6	49·9		56·3	56·1
17	48·6	54·5	48·0	47·6	53·0	59·1			59·0
18	48·2	49·5	50·9	47·7	56·2	59·5			59·8
19	51·2	53·6	52·2	49·7	57·0	59·8	57·0	59·9	59·6
20	51·6	54·9	52·6	49·6	57·1	59·6	57·1	59·3	60·1
21	52·2	57·5	53·3	50·1	54·0	60·0	57·8	60·5	60·0
24	51·8	57·0	52·6	50·0	54·6	61·3	56·6	59·8	59·4
27	51·0	58·0	51·6	48·3	55·0	55·3	55·3	58·6	58·2
31	48·0	50·0	48·2	45·6	51·1	51·9	50·1	54·1	55·2
Aug., 6	47·0	49·0	45·6	40·5	50·0	49·0	49·8	51·0	53·0
8	47·5	49·6	44·8	41·8	51·3	49·0	48·8	50·5	52·5
9	47·6	49·9	44·6	42·0	51·4	49·1	49·8	52·6	53·6
10	48·1	50·8	45·0	44·0	51·9	49·3	54·9	54·5	54·4
12	48·3	49·1	45·1	44·3	50·8	50·1	54·8	51·6	52·8
15	48·0	47·4	45·5	45·2	50·1	52·0	55·0	49·8	50·6
19	47·6	48·1	45·8	45·1	51·6	51·9	54·8	49·1	48·3
20	47·0	49·3	46·5	45·4	52·0	52·7	55·0	49·5	47·0
22	47·6	48·5	46·0	44·8	51·6	51·6	54·1	46·1	47·1
25	47·2	32·0	45·0	43·2	50·0	50·3	48·5	45·5	46·5
Sept., 1	44·0	44·5	44·5	44·0	44·1		43·9	44·0	43·9
3	38·2	38·1							
4	43·0	38·3	38·0	37·2	44·5		46·0	49·2	46·5
14	48·4	49·0	43·2	37·7	44·1	50·8	50·5	50·0	46·8

(to be continued.)

Table II.

(a) (*continued.*)

	No. 1	No. 4	No. 8	No. 9	No. 13	No. 20	No. 24	No. 27	No. 29
	°C	°C	°C	°C	°C	°C	°C	°C	°C
Sept., 15	48·1	49·2	42·8	36·9	46·1	50·1	50·0	49·6	43·6
19	47·0	49·1	40·2	39·9	49·4	50·0	49·9	44·0	42·6
22	44·0	50·1	46·1	44·5	46·3	49·1	49·1	46·1	41·6
25	43·2	51·0	47·4	47·2	43·6	47·0	49·5	49·1	43·0
Oct., 1	45·2	44·5	37·0	37·2	46·6	49·5	52·2	50·9	53·4

(b)

	No. 2	No. 3	No. 5	No. 6	No. 7	No. 10	No. 11	No. 12
	°C	°C	°C	°C	°C	°C	°C	°C
June, 1	23·7	21·0	28·5	22·5	25·0	28·2	27·0	
4	24·5	21·6	28·8	22·8	25·6	30·5	28·2	
5	26·0	22·0	29·6	23·3	27·5	30·1	29·5	22·5
7	26·4	21·4	28·1	23·2	27·5	30·1	29·5	23·2
10	26·5	21·5	28·5	23·8	27·8	30·0	30·0	23·2
13	26·5	21·0	28·3	23·1	27·5	31·4	29·1	24·0
17	25·5	22·0	27 9	24·3	26·8	30·1	30·1	23·5
22	26·0	21·6	28·5	24·6	27·3	30·8	27·5	23·1
23	24·9	22·3	29·0	25·0	27·5	31·5	28·6	23·4
27	25·6	23·5	29·2	26·0	28·0	30·0	28·2	23·6
July, 7	27·0	24·2	27·0	26·5	27·0	29 9	29·0	24·0
10	27·4	24·1	27·5	26·1	27·4	29·6	29·1	23·8
12	27·5	23·3	26·8	25·5	27·5	29·5	30·0	23·5

(c)

	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19	No. 21	No. 22	No. 23	No. 25	No. 26	No. 30
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
June, 7	33·9	23·3	22·4	22·6								
12	30·2	24·0	22·0	21·8	22·9	21·0	28·0	20·5	21·5			
13	30·6	24·1	22·3	22·0	22·8	21·4	28·0	20·7	21·6			
14	31·0	23·8	23·0	23·2	23·5	21·5	28·2	21·0	21·0	30·5	22·4	31·0
17	30·8	22·5	22·6	23·0	23·0	21·8	26·9	22·1	21·2	30·8	21·8	30·3
23	32·6	22·9	22·5	23·0	25·0	22·5	29·3	20·2	20·4	31·0	22·0	29·8
27	30·6	22·0	22·0	23·6	24·1	24·0	27·4	23·0	21·2	28·4	24·5	30·0
July, 7	32·0	23·0	23·0	24·0	26·4	22·0	29·0	22·0	22·8	29·0	23·0	29·0
12	32·5	24·1	23·5	23·6	25·1	22·6	29·8	23·6	21·9	29·6	23·8	29·2

Table III. Air temperature on the summit of Sirane volcano and the observed values of earth-current.

	Air temperature			Earth-current Poles 1~2			Earth-current Poles 3~4		
1938	6 h	12 h	18 h	6 h	12 h	18 h	6 h	12 h	18 h
				m.V.	m.V.	m.V.			
May, 13					64·4				
14						70·5			
15				74·0	75·9				
16				80·0	81·0				
17	°C	°C	°C	85·0	86·2				
18		12·8	7·0	86·8		87·2			
19	5·8	9·0	8·9	90·0					
20	2·0	5·0	2·0			94·2			
21	6·0		0·0	95·0					
22	6·0	7·0	4·0			95·5			
23	3·0	4·5	7·0		126·0				
24	4·2	10·0	10·2			129·0			
25	5·9			125·0					
26									
27									
28	10·4	18·0	10·2	102·0		101·6	m.V.	m.V.	m.V.
29	10·4	18·8	14·0			96·9			99·2
30	13·6	17·0	13·0	95·0	93·8	93·0	96·8	97·2	96·0
31	11·0	20·0	15·0	90·5	90·0	89·0	110·5	106·1	100·0
June, 1	12·0		16·5	85·6		85·0	99·6		94·0
2	13·9	16·0	16·0	84·6	83·5	83·0	95·0	94·0	94·0
3	3·6	10·6	6·0	84·0			83·5		
4	18·5	16·4	9·2						
5	11·8	17·5							
6			13·0						
7	6·4	13·5	10·4						
8	13·0	12·8	9·8						
9	11·0	14·1	12·2	86·0		86·0	113·0		41·0
10	11·4	19·0	13·0	91·5		97·2	125·0		
11	14·0	16·0	11·4	118·2	112·5	110·0	54·9	99.5	119·0
12	12·8	11·4	11·5	105·0	105·4	103·2	104·8	107·2	89·2
13	14·5	17·0	10·2		106·8	105·6		67·5	39·8
14	10·0	13·0	14·0	108·8	107·8	109·4	24·5	12·2	4·0
15	11·9								
16									
17	5·9	10·0	6·4		114·2	114·5		113·0	108·2

(*to be continued.*)

Table III. (*continued.*)

	Air temperature			Earth-current Poles 1∼2			Earth-current Poles 3∼4		
1938	6 h	12 h	18 h	6 h	12 h	18 h	6 h	12 h	18 h
	°C	°C	°C	m.V.	m.V.	m.V.	m.V.	m.V.	m.V.
June, 18	15·8	12·6	11·4	108·0	106·2	103·5	73·2	64·5	60·6
19	9·5	18·5	14·8		93·2	88·2		64·5	60·4
20	7·4	8·0	7·5	85·2	81·2	80·0	53·0	58·0	41·2
21	11·2	13·0	8·4	88·9	87·5	86·0	20·9	23·0	15·0
22	12·5	16·0	14·4	81·6	79·5	78·4	25·6	31·0	24·8
23	18·0	18·4	13·0	75·0	74·0	71·0	21·0	24·6	15·0
24	15·0	13·0	9·0	68·0		64·5	8·2		33·0
25	13·8	16·3	14·5	92·0	94·0	92·5	19·2	15·5	16·0
26	11·9	15·9	12·4	98·4	92·0	95·6	13·2	22·2	19·0
27	18·5	20·4		88·0	86·5	81·4	29·0	25·0	32·2
28		19·0	13·0	76·1		69·0	31·2		30·2
29	11·2	11·4	11·5	65 0	66·2	83·5	18·6	32·0	14·0
30	16·2	16·0	13·4	88·0	87·8	84·6	19·0	20·6	12·1
July, 1	13·0	21·2	14·2	82·4	80·2	77·1	11·0	17·0	16·0
2	12·1	16·8	13·9	69·4	68·2	66·1	9·5	9·2	5·4
3	12·5	19·9		64·2	66·4		2·4	3·4	
4									
5									
6	15·8	20·1	18·0	83·8		81·0			9·0
7	19·0	21·4	16·2	74·5	72·9	67·4	11·2	20·2	18·5
8	15·2	16·5	9·0	64·0	64·1	62·0	13·6	27·2	30·0
9	13·0	19·2	13·8	60·0	58·2	57·2	40·1	45·0	47·2
10	13·9	19·4	16·4	52·2	50·0	49·5	42·2	44·0	41·5
11	15·6	21·0	16·0	46·2		41·2	39·0		59·0
12	15·0	18·2							
13									
14	14·2	20·4	15·0	51·0		52·0			
15	14·4	16·8	15·0	51·0	49·5	49·1			
16	14·0	21·0	18·0	48·8	47·5	46·2			
17	15·5	24·2	18·4	45·0	44·6	43·5			
18	15·0	24·4	23·0	41·0	42·0	41·1			
19	17·4	24·2	28·5	39·2	38·0	38·2			
20	18·5	28·0	20·6	34·2	34·0	34·0			
21	17·0	23·4	19·0	32·9	32·2	33·0			
22	16·0	21·0	16·8	33·2	32·8	33·1			
23	13·6	15·0	12·0	31·2	31·0	33·2			
24	20·8	20·0	12·0	32·0	33·7				

(*to be continued.*)

Table III. (*continued.*)

	Air temperature			Earth-current Poles 1~2			Earth-current Poles 3~4		
1938	6 h	12 h	18 h	6 h	12 h	18 h	6 h	12 h	18 h
	°C	°C	°C	m.V.	m.V.	m.V.	m.V.	m.V.	m.V.
July, 25	11·2			27·0					
26	13·0								
27	12·4	13·2	13·3						
28	14·0	21·0	15·8	51·0	30·2	53·0			
92	14·0	23·0	17·7	17·0	49·0	46·2			60·0
30	17·0		15·2	43·8	43·0	44·0	6·0	26·2	10·0
31	15·6	17·2	15·6	40·0	39·6	39·0		6·1	
Aug. 1	15·7	16·2	13·2	47·0	45·2		4·2	5·2	
2	12·2	11·0	12·6						
3	13·7	14·0	14·4						
4	15·0	15·2	14·8			40·1			83·2
5	13·9	17·2	16·5			60·4	74·2		50·2
6	14·9	19·0	13·8	64·2	69·1	66·0	80~110	65~78	49·2
7	11·6	15·0	12·4	59·5	57·0	53·0	72·0	137·0	131·5
8	12·2	17·8	16·0	49·0	49·0	48·3	74·5	65·2	62·0
9	15·4	20·9	15·6	48·9	48·2	48·0	41·6	92·0	53·5
10	16·0	20·8	15·5	47·4	47·9	45·6	38·2	37·4	>170
11	21·0	24·4	17·0	45·5			51·2		
12	17·0	25·0		47·2	46·8		43·0	39·0	
13									
14	15·8	22·8	16·0		37·0	33·5		21·0	16·5
15	15·2	22·2	16·6	27·5		41·4	82·5		49·2
16	17·0	22·0	16·8	44·0	42·0	41·9	39·2	28·2	24·0
17	14·8	16·1	14·5	40·5	40·5		22·0		
18	14·8	16·4	16·0	39·0	38·0	38·9	13·4		27·5
19	14·5	23·8	14·8	42·0	44·1		25·2	15·5	
20	17·8	24·5	17·0	42·5	41·6		29·0	25·2	
21	14·0	19·4	15·4	40·0	40·4		5·2	15·6	
22	13·2	15·4		40·2	40·0		7·2	6·0	
23		16·8	11·9		38·0			2·1	
24	15·0	19·2	15·1	35·0		35·0			1·2
25	14·8	16·0	13·9	33·9	34·1	34·4	5·5	6·6	6·0
26	15·0	16·0	14·8	34·0		28·0	9·0		132·4
27	17·0	22·8	16·7	46·5	41·9		110·2	103·4	
28	12·1	14·0		57·6	62·8		150·0	>170·0	
29	10·5	14·4		72·1	74·2		156·5	139·5	
30	12·5	14·0	12·5	71·5	71·5	69·4	28·5	14·5	26·2

(*to be continued.*)

Table III. (*continued.*)

1938	Air temperature 6 h	Air temperature 12 h	Air temperature 18 h	Earth-current Poles 1~2 6 h	Earth-current Poles 1~2 12 h	Earth-current Poles 1~2 18 h	Earth-current Poles 3~4 6 h	Earth-current Poles 3~4 12 h	Earth-current Poles 3~4 18 h
	°C	°C	°C	m.V.	m.V.	m.V.	m.V.	m.V.	m.V.
Aug. 31	12·0	14·3	13·5	69·5	68·2	72·2	23·1	12·3	15·5
Sept. 1	14·1	15·0	16·0	72·3	90·2	98·1			>170·0
2	15·0	15·5	15·0	96·9	94·8		135·8	124·0	
3	15·3		17·2	97·1	96·4	96·5			
4	13·0	14·7	14·8	96·9	98·5	98·2			
5	12·2	12·2	12·1	96·6	103.2	113·2			
6	15·0	15·0	15·1	121·1	123·5	122·3		165·2	
7	14·9	19·6	12·9	120·6	117·9				
8	10·0			112·0					
9									
10	10·9	13·1		98·9	98·2	97·1			
11	10 3	16·0	13·9	95·9	95·2	93·0			8·0
12	9·5			92·0			19·2		
13	6·5	17·4	13·4		88·0	84·0		24·0	28·1
14	8·2	17·9		87·2	87·2	89·0	32·4	27·6	26·8
15	2·8			86·2	91·0		25·0	23·0	
16									
17			3·2			90·0			6·4
18	4·0	6·2	5·4	89·0	90·0	87·1	5·0	8·1	2·0
19	5·8	17·8	8·0	85·2	90·0	87·0			
20	7·2	9·0	9·5	85·4	88·0	92·0	101·9	154·2	157·5
21	6·0	10·1	6·4	105·0	114·0	112·0	134·9	134·5	133·0
22		13·4	9·8		112·5	121·0		117·0	115·0
23	9·4	8·1	9·0	103·2	119·1	112·0	114·1	101·0	99·8
24	9·6	12·1	9·2	110·0	110·2	112·0	87·0	86·1	81·5
25	3·8	11·2	5·0	116·0	117·2	120·1	48·1	51·2	59·1
26	2·0	16·8	7·0	121·8	124·5		62·0		62·9
27	5·0	14·2	11·0	122·0	123·4	121·0	61·0	60·5	59·4
28	6·2	16·2	12·0	120·0	119·0	118·0	56·2	54·6	54·2
29	8·2	22·0	13·0	118·5	119·9	117·5			
30	10·1	19·6	11·6	116·0	117·0	117·2		45·2	46·4
Oct. 1	5·9	18·4	11·2	113·0		114·0	47·0		48·2
2	10·8	18·9	12·9	113·2	114·2	118·0	53·5	57·0	63·5
3	12·3	15·0	12·2	116·0	115·5	112·5			6·0
4	11·8	12·0	9·0	111·0	3·0	116·5	22·0	9·0	27·0
5	6·0	14·0	11·0	128·2	127·0	127·0	39·5	40·3	42·1

(*to be continued.*)

Table III. (*continued.*)

	Air temperature			Earth-current Poles 1~2			Earth-current Poles 3~4		
1938	6 h	12 h	18 h	6 h	12 h	18 h	6 h	12 h	18 h
	°C	°C	°C	m.V.	m.V.	m.V.	m.V.	m.V.	m.V.
Oct. 6	12·4	15·2	8·0	130·1	130·6		>170·0	>170·0	>170·0
7	2·1	4·2	1·2		133·0	129·8	>170·0	>170·0	>170·0
8	−2·0	9·4	11·2	126·4			>170·0	>170·0	>170·0
9	5·9	15·8					>170·0	>170·0	>170·0
10							>170·0	>170·0	>170·0
11	10·2	19·2	15·6		128·0	125·1	>170·0	>170·0	>170·0
12	5·9	4·8	3·8	125·0		126·1	>170·0	>170·0	>170 0
13	9·0	11·2	12·0	131·2	131·1	135·0	14·0	15·0	14·0
14	12·2	10·8	7·2	139·9	141·0	147·2	21·4	20·1	27·2
15	4·0	2·0	1·4	145·0	147·0	147·0	24·5	44·0	123·0
16	0·0	−0·8	−3·1	160·0	>170·0	>170·0	>170·0	165·5	>170·0
17	−5·4	2·0	−0·1			>170·0			84·5
18	−1·4	2·8	3·0	>170·0	>170·0	143·0	63·5	59·0	43·0
19	0·8	12·0	4·1	>170·0	>170·0	>170·0	36·7	33·8	31·0
20			2·1	>170·0	>170·0	>170·0			
21				>170·0	>170·0	>170·0			
22			0·8	>170·0	>170·0	>170·0			
23	0·5	6·2	2·1	>170·0	>170·0	>170 0	54·2		61·0
24	1·0	12·5	3·9	>170·0	>170·0	>170·0	62·5	72·8	
25	3·0	6·0	1·0	>170·0	>170·0	>170·0	69·5	62·5	61·2
26	1·0	1·5	0·0	>170·0	>170·0	>170·0	59·0	94·0	94·5
27	0·2	6·0	5·0	>170·0	88·0	106·0	91·5	88·5	88·2
28	1·5	10·0	9·8	123·0	128·0	>170·0	78·1	73·5	72·0
29		9·5	6·0	>170·0	>170·0	>170·0		61·5	58·5
30	6·0	10·2	11·0	>170·0	>170·0	>170·0	90·5	120·0	117·0
31	6·0	5·8	2·0	>170·0	>170·0	>170·0	72·5	66·5	
Nov. 1	0·0	4·5	4·3	>170·0	>170·0	>170·0			
2	1·0	5·5	1·5	>170·0	>170·0	>170·0			
3	0·0	6·4	3·0	>170·0	>170·0	>170·0	47·5	46·0	45·0
4	0·3	8·0	4·5	>170·0	>170·0	>170·0	45·0	43·5	43·5
5	0·2	8·0	2·5	>170 0	122·5	120·0	44·5	44·0	43·0
6	0·3	6·0	1·0	121·5	120·0		47·0	48·5	
7	0·0	6·0	3·0	120·0	120·0	114·0	59·0	61·0	64·0
8	2·0	8·0	5·0	117·0	120·0	115·0	82·0	92·5	88·0
9	0·2	3 0	0·0	115·0	144·0	108·0	120·1	125 0	127·5
10	1·0	6·0	1·0	112·0	114·0	115·0	126·0	123·5	120·0
11	0·4	3·0	0·1	114·0	109·0	120·0	113·0	111·5	108·0

(*to be continued.*)

Table III. (*continued.*)

1938	Air temperature 6 h	Air temperature 12 h	Air temperature 18 h	Earth-current Poles 1～2 6 h	Earth-current Poles 1～2 12 h	Earth-current Poles 1～2 18 h	Earth-current Poles 3～4 6 h	Earth-current Poles 3～4 12 h	Earth-current Poles 3～4 18 h
	°C	°C	°C	m.V.	m.V.	m.V.	m.V.	m.V.	m.V.
Nov. 12	0·4	4·8	3·9	106·5	116·0	107·8	107·0	105·8	104·2
13	−5·2	2·0	−4·6	110·2	108·0	108·2	104·0	103·6	101·5
14	−6·8	3·0	−3·9	101·2	104·0	107·3		101·0	99·8
15	−6·5	6·2	−3·1	104·5	103·0	102·0	99·4	98·4	97·6
16	−5·6	7·5	−1·0	104·0	101·0	101·0	97·8	97·1	97·4
17	−3·0	−1·0	−4·0	101·4		105·5	97·4		99·0
18	−6·4	1·6	−5·2						
19	−8·0	6·1	0·1						
20	−2·4		0·4						
21	−3·8	1·4	−3·6						
22	−7·8		−4·0						
23	−7·0	5·0	−1·5						
24	−5·0	7·0	−2·9						
25	−8·0	−1·0	−8·2						
26	−9·2	−2·4	−9·2						

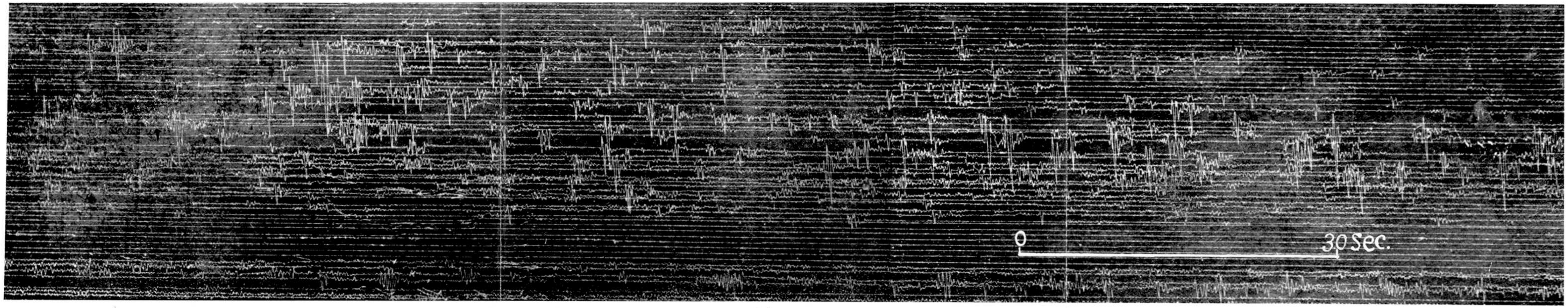
38. 最近の草津白根火山の活動（其の1）

地震研究所 水 上 武

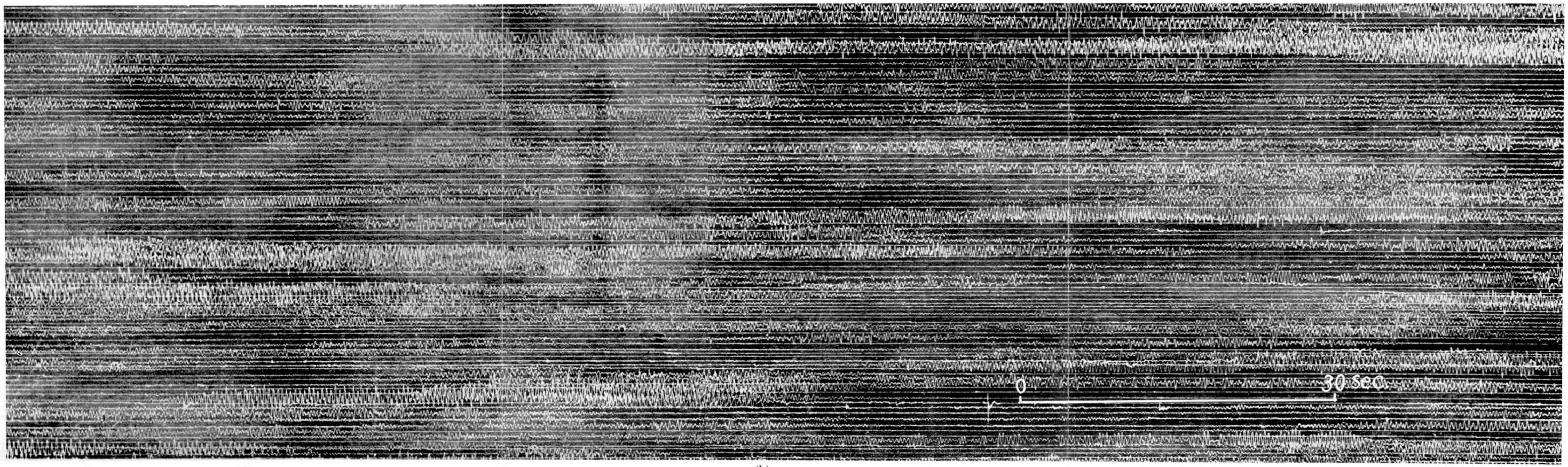
昭和12年11月27日に初まつた白根火山の爆發は昭和13年2月迄に最も著しい活動をなし，以後やゝ平靜となつたが，9月下旬より再び多少の活動を示し，10月5日にやゝ著しい爆發が起り，以後今日（昭和14年2月）に至るも未だ平穩とならず，多量の瓦斯の噴出と共に湯釜附近に火山灰を散布する狀態を示して居る．今回の爆發は總べて湯釜內の略中央を東南より西北に向ふ直線狀の裂罅に沿ふて發生した．昭和7年10月に發生せる爆發群とはその地表に於ける位置の上からは別個の裂罅上に發生せるものである．

昭和13年5月30日に發生せる多數の微震群の初期微動繼續時間より，湯釜內今回活動せる裂罅附近の地下約2粁の深さに多數の地震が發生せる事が推定され，或はこの附近に今回爆發に供給せる熱源の存在が想像される．

湯釜內の地溫測定の結果，高溫度を示す所は專ら活動の裂罅に沿ふて狹い地帶に限られて居る．此の事實は，今回の活動は，地表近くでは專ら裂罅に沿ふて水蒸氣の噴出を見たものと考へられる．



(a)



(b)

(Mag. × 1000)

Fig. 15. (a) Volcanic micro-earthquakes. (observed May 30, 1938.)
(b) Volcanic pulsations. (observed Nov. 15, 1938.)

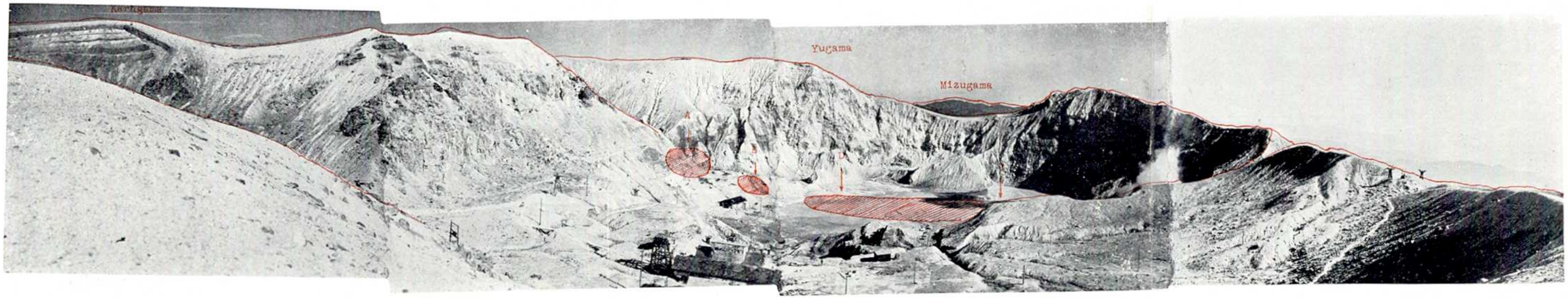


Fig. 16. The Y-crater (Yugama) October 25, 1937. (a month bebore the present activity.)

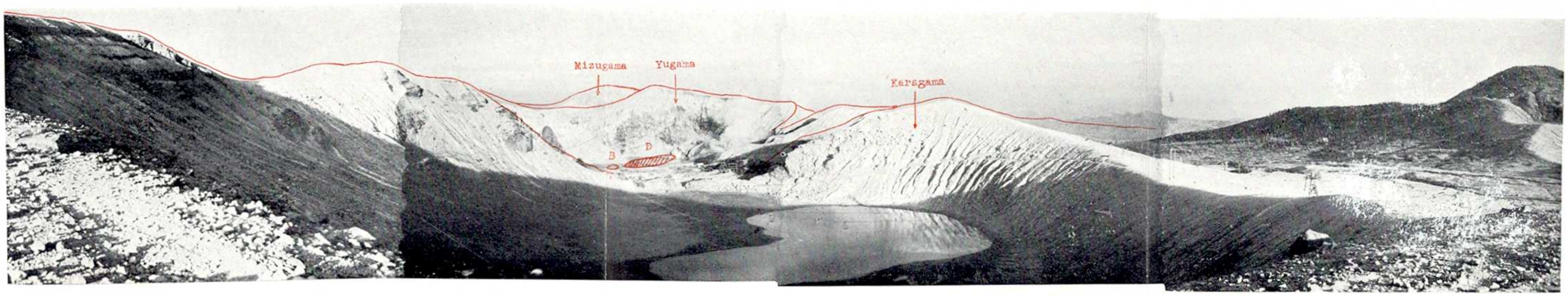


Fig. 17. The K-crater (Karagama) and the Y-crater (Yugama) October 25, 1937.

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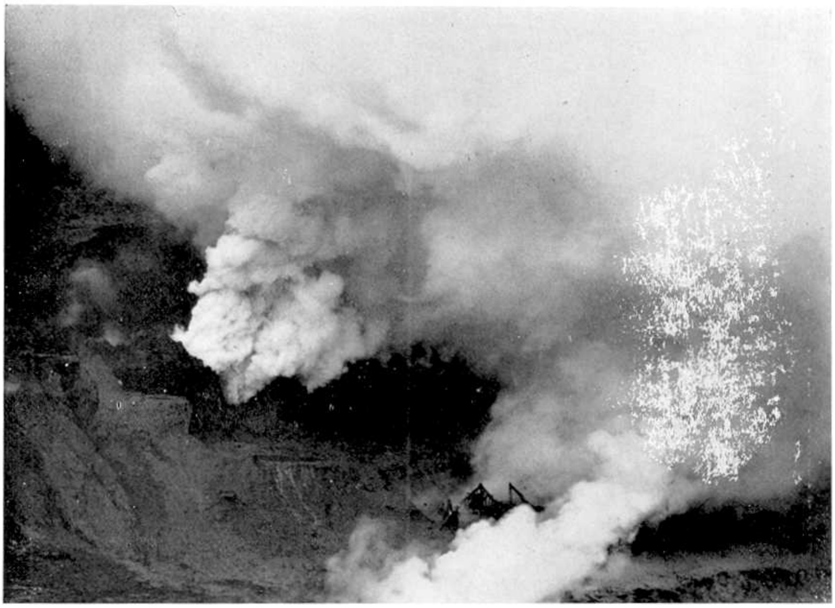


Fig. 18. (a) Explosion crater Aa_1, November 29, 1937.
(two days after the first explosion.)

Fig. 18. (b) The Y-crater, November 29, 1937.

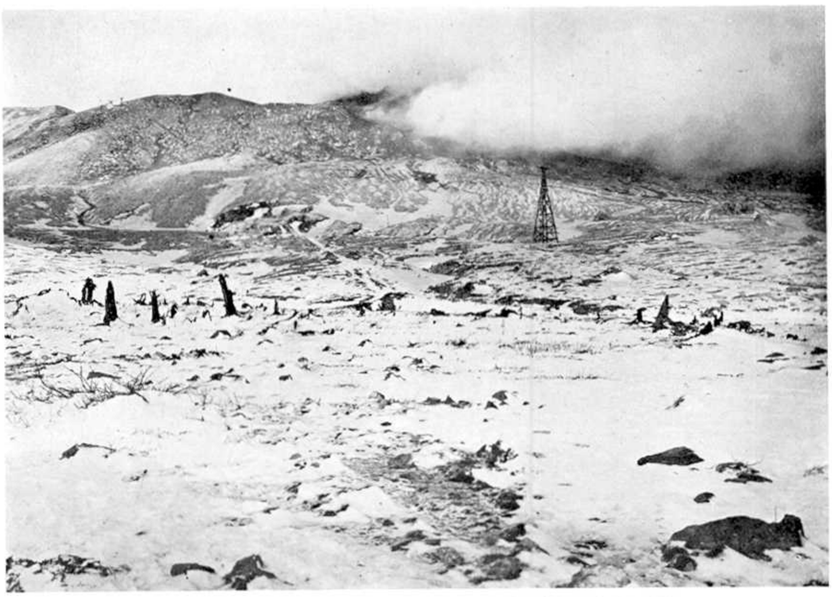
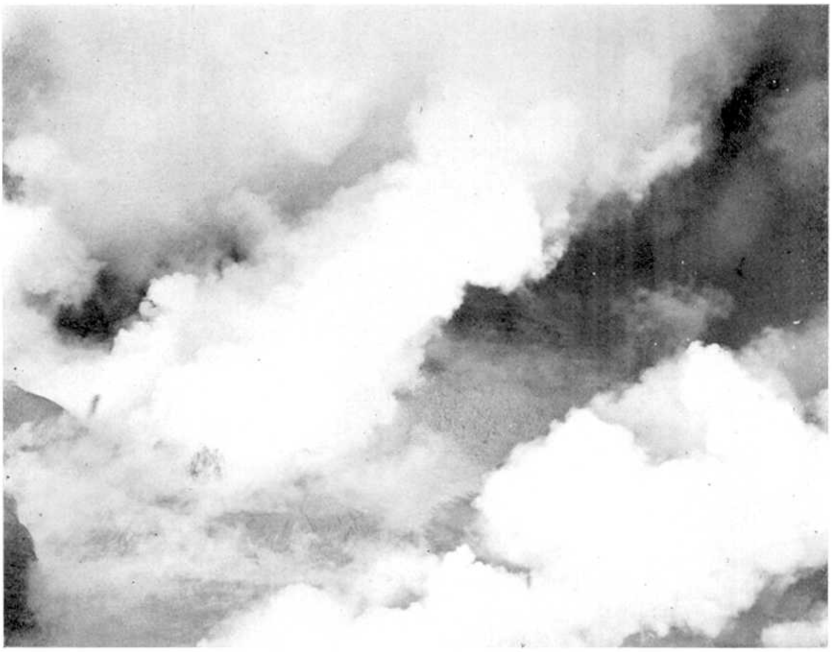


Fig. 19. The fumaroles (F) on the south side of the Y-crater.
(November 29, 1927.)



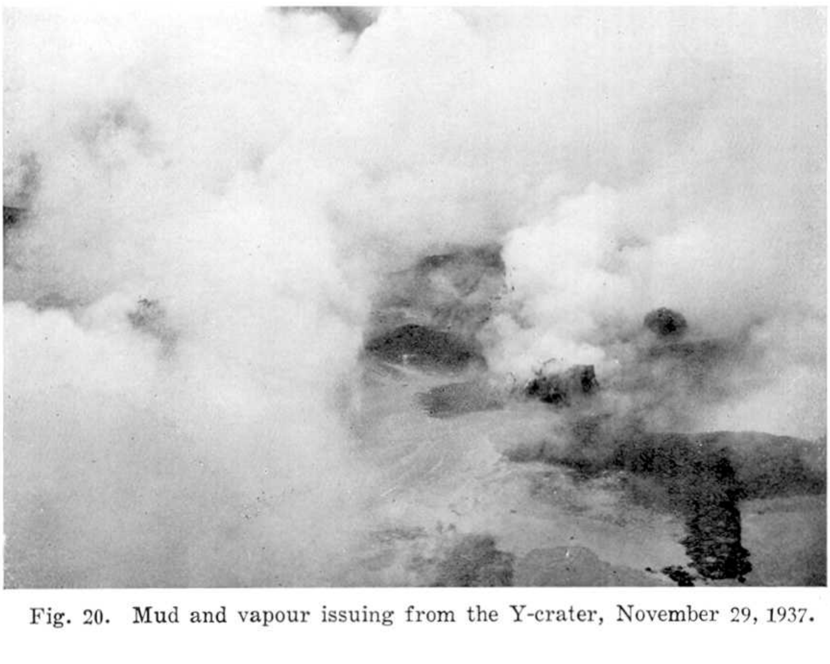
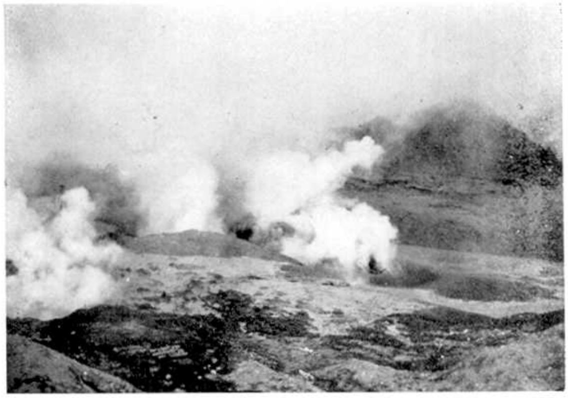
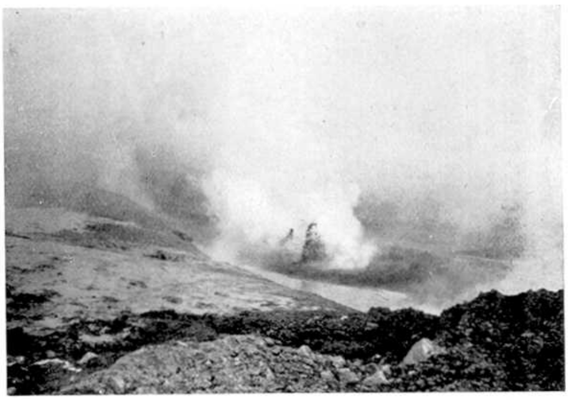


Fig. 20. Mud and vapour issuing from the Y-crater, November 29, 1937.





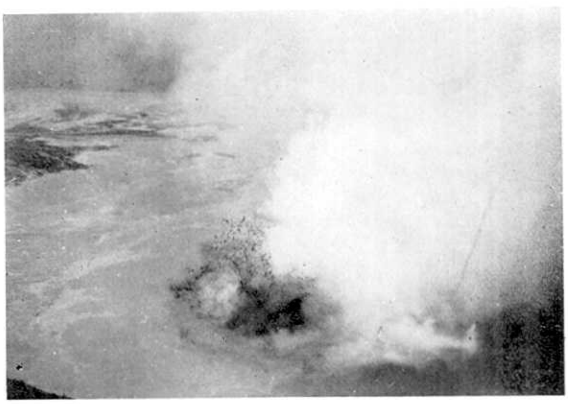
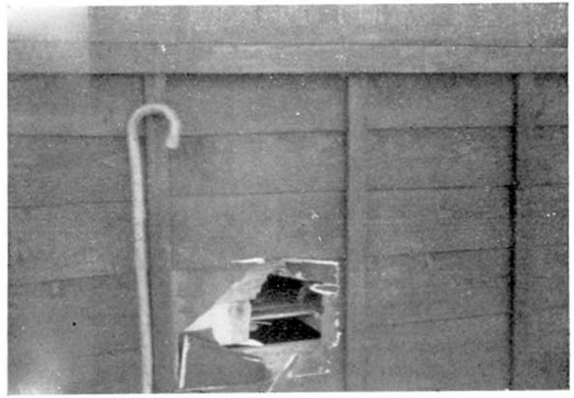


Fig. 21. Mud and vapour being ejected from the Y-crater.
(November 29, 1927.)

(a)

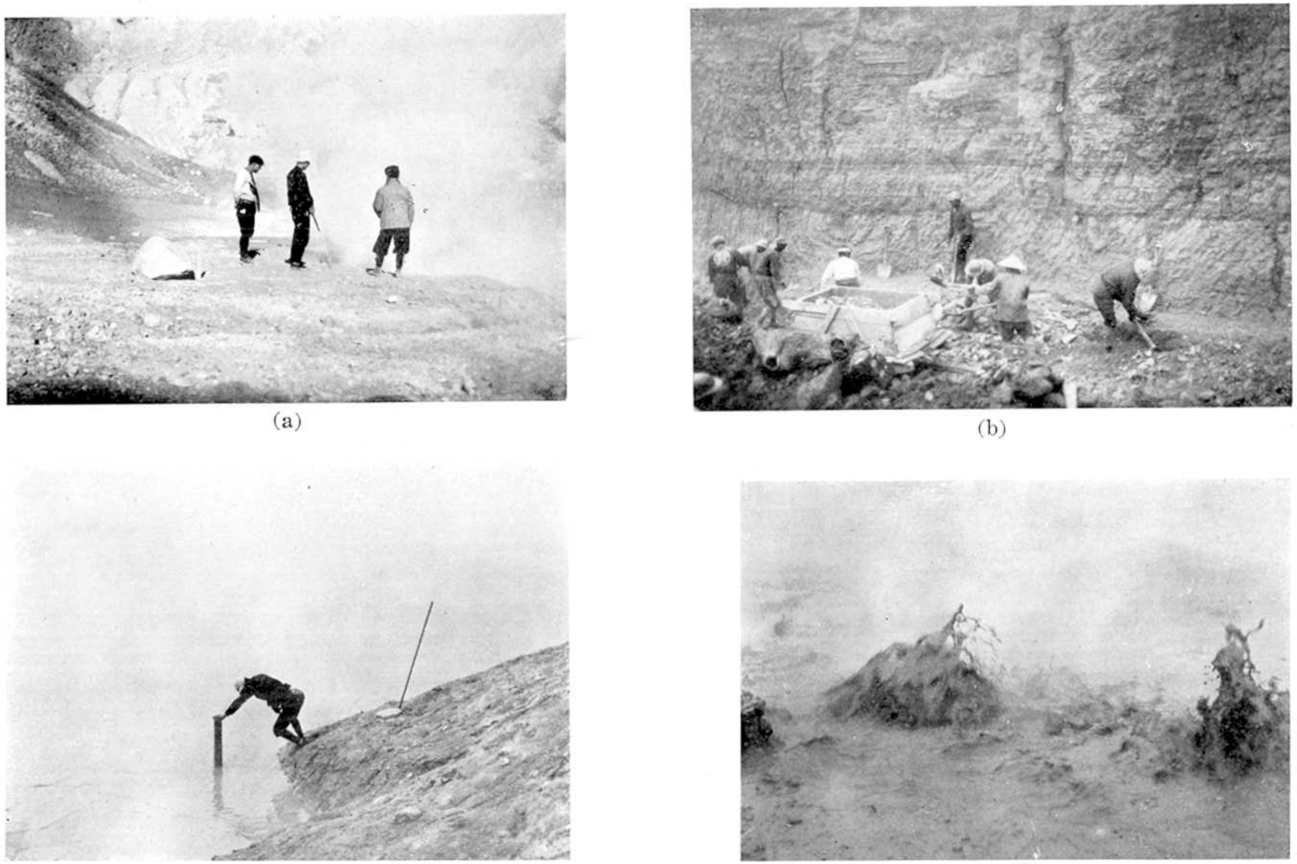


(b)

(c)

(d)

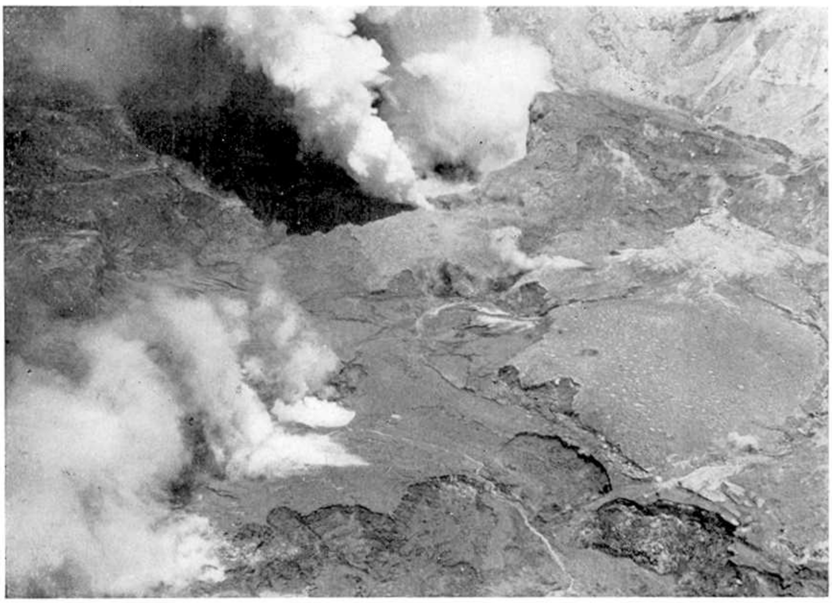
Fig. 22. (a)(b)(c) The mine keeper's cottage damaged by volcanic detritus. (d) A hole in the ground caused by the fall of volcanic detritus.



(a) (b) (c) (d)

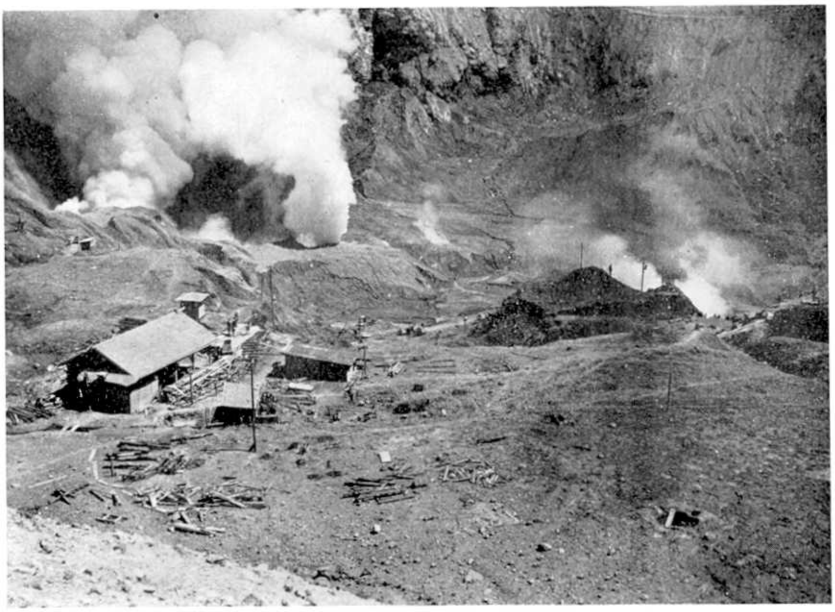
Fig. 23. (a) Hot spring in the Y-crater.
(b) Wall of precipitated sulphur in the Y-crater.
(c) Hot spring pond in the Y-crater.
(d) Mud and hot water being ejected from the Y-crater.

(a)

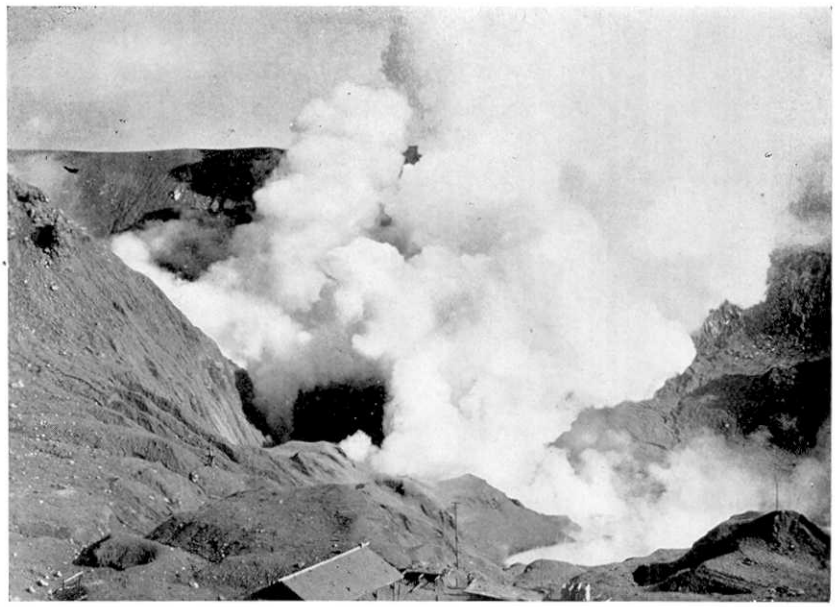


(b)

Fig. 24. (a) Karagama and Yugama (active crater), July 23, 1938.
(b) The fissure in the Y-crater, in which the present explosions occurred. (July 23, 1938.)



(a)



(b)

Fig. 25. (a) Explosion craters A and B, July 23, 1938.
(b) Explosion craters A and B, October 6, 1938.
(one day after an explosion.)

一方，湯釜内の溫泉池の水位測定より1日に少くも 10^3 乃至 5×10^2 噸の水が湯釜內裂罅に沿ふて地下に流入して居る事が判明した．

今回の活動中に於ける噴出瓦斯の大部分は水蒸氣であつたが，昭和13年5月より10月に亘る期間內の數日は水蒸氣と共に多量の昇華硫黄が噴出された．これはボーリングの結果より知られる如く，火口內の地層は，沈澱硫黄と火山灰，火山岩屑の互層より成り，活動せる裂罅は此の互層を切斷して居る爲め，噴出瓦斯中に含む昇華硫黄は沈澱硫黄層の硫黄鑛石が昇華されたものと考へられる．卽ち當期間內の數日は瓦斯が 444°C 以上の溫度となつて昇華硫黄の噴出を見たのであるが，大部分は昇華點以下の狀態に在つた事が推定される．此の地下溫度の變化は地下よりの熱の供給の增減のみならず上に述べた湯釜より浸入する水量の多少に依り著しく左右される．從つて侵入水量の變化は水蒸氣の壓力に重大なる影響を與へる事になる．

津屋博士は當火山の爆發は地表極めて近くで起る間歇溫泉的現象であると述べて居る如く，斯る種類の火山活動は地表よりの浸入水，氣壓等地表より與へられる影響を無視出來ない場合が多い樣に思はれる．然しながら，淺間火山の如く多量の新熔岩を噴出し，爆發に關與する熱量も前者の如き火山に比して甚だ大規模であり，而も循環水等の地表より與へられる影響は前者と同程度と推定される場合に，兩種の火山活動に及ぼす循環水の影響の多少は自から異なる事は言ふ迄もない事であらう．