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Recent Activity of Volcano Me'akan-dake*

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The volcano Me'akan-dake erupted several times during the period Nov. 19, 1955 - July 8, 1956. The writers studied development of new craters, flight of ejecta, temperature of ejecta, variation in underground temperature, and volcanic earthquakes. Though the explosions were classified at steam-explosions, seismic activity preceded the strongest explosion. Volcanic tremors and explosion-earthquakes were also studied.

§ 1. General Descriptions

Volcano Me'akan-dake (1503 m) is situated at the south-western rim of the Akan Caldera in Hokkaido (Fig. 1). It consists of several

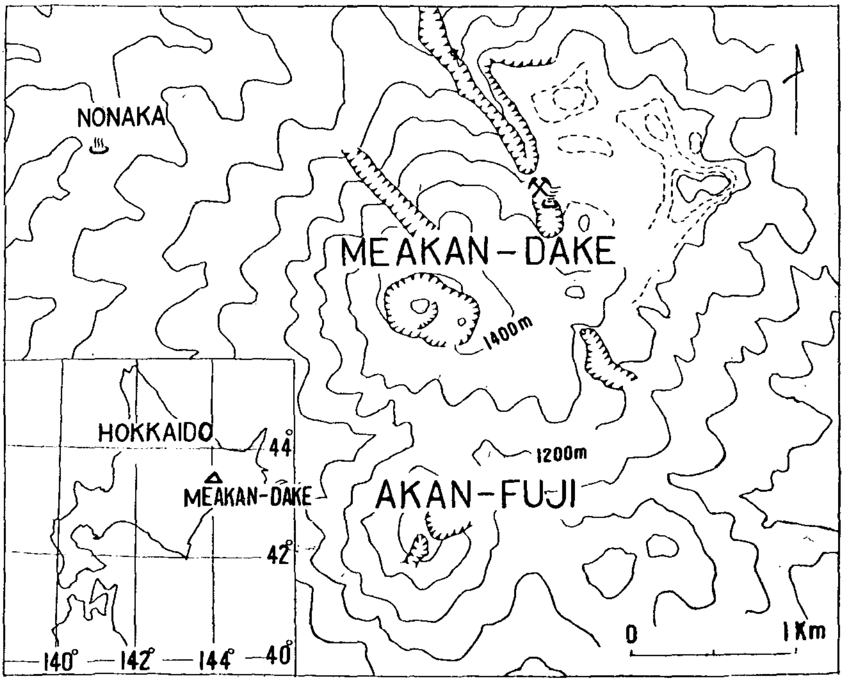

Fig. 1. Geographical position and topography of Volcano Me'akan-dake.

* Part 4 of "Geophysical Studies of Volcanoes in Hokkaido."

old and new volcanic bodies. One of the youngest of those bodies, "Pon-Matuneshiri" which rises on the southwestern part of the main mountain body "Naka-Matuneshiri", is the site of the activity now taking place. The volcano is composed of lavas and fragments of two-pyroxyne-andesite[1]. As it stands in a thinly populated area, very little is known concerning its volcanic activity in the past, except for certainty that there has been no remarkable change in the state of the crater throughout the immediately past 100 years. After such repose, Me'akan-dake broke out in a sudden explosion in the evening of Nov. 19, 1955 at the southern bottom of its top-crater[2]; it has been emitting thick smoke of water-vapour mixed with slight SO_2 and H_2S since then. Explosions took place now and then to July of the next year*, and the new craters were enlarged in width and in depth more and more. Volcanic ash fell in the region in the direction from north to southeast of the volcano. Through the entire period the activity has been of

TABLE 1

Brief description of the explosions.

No.	Date of explosion	Remarks
1	Nov. 19, 16 h 50 m	Sounds like a rushing train, at 1.1 km NE. Black smoke rose 300 m. Ash fell as far as 26 km WSW.
2	March 18, —	Ash-precipitation at 11 km WSW.
3	May 19, 11 h 20 m	Moderate detonation at 1.1 km NE. Black smoke rose as high as 2 km. Ash fell to the north to a distance of 60 km.
4	May 29, 20 h 32 m	Weak sound and slight ash-precipitation at 1.1 km NE. Ash-precipitation at NE foot.
5	June 10, 12 h 30 m	Black smoke.
6	June 15, 16 h 25 m	Rumblings with rapidly increasing intensity at 1.1 km NE. Weak sound at 2.3 km NW. Height of smoke did not exceed 1 km probably. Ash fell to the west as far distant as 100 km.
6′	June 15, 16 h 26 m	Black smoke.
7	June 20, night	Ash-precipitation at 1.1 km NE.
8	June 29, —	Black smoke.
9	June 30, 6 h	Slight ash-precipitation at 11 km WSW.
10	July 8, 10 h	Black smoke.

* After completion of this paper, it was reported that another explosion of minor scale took place on October 31.

the steam-explosion type that occurs near the earth's surface, not being accompanied with ejection of incandescent materials. Among the ten explosions, the 6th was the most violent, that is, the amount of ejecta was the most abundant and the distance of flight of ejecta was the greatest.

The writers have been engaged in observing the changes in the topography at the site of the explosions and volcanic micro-earthquakes. The present paper is an outline of the results of these field works.

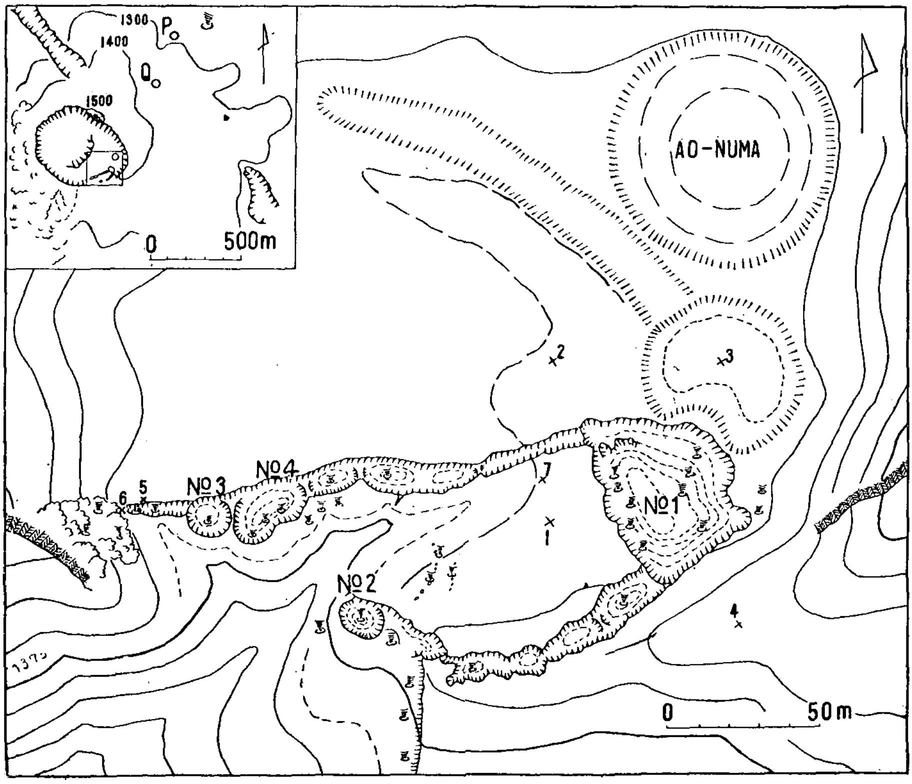

Fig. 2. Position and form of the new craters, after Nov. 19, 1955. (SAKUMA, KATSUI, SUZUKI and MURASE)

Q: electromagnetic seismograph.

P: ISHIMOTO seismograph.

Small figure: No. of pipes for ground temperature-measurement.

§ 2. Changes in Topography and Other Phenomena, Observed at the New Craters.

Soon after every important explosion, detailed observations of the craters were carried out.

i) Nov. 19, 1955. As will be seen in Figs. 2 and 3(a), the explosion resulted in the opening of four main craters and two fissures on the southern bottom of the top-crater of Pon-Matuneshiri. The No. 1 crater was the largest; its depth was about 25m. Its western wall was almost vertical and other walls were 30°-50° in inclination. It was difficult to observe the bottom, since it was hidden from sight by the yellowish-white smoke issuing from many fumaroles on it. The temperature of the fumaroles seemed to exceed 150°C, according to the apparent nature of sublimates around them. The southern fissure took the form of a series of small craterlets. The fissure ends at the wall of barranco. Crater No. 2 was about 10 m in diameter. The length of the northern fissure running from NW to wards E was about 150 m, and there were many weak fumaroles in it. The fissure lies between crater No. 1 and craters No. 3 and No. 4. Faint fumarolic activity could be seen also on the flat old crater bottom between the two fissures. It was noted that

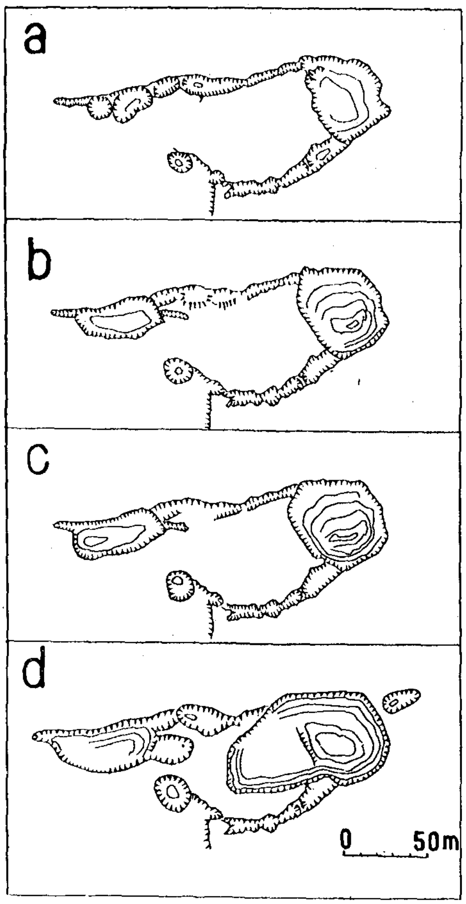

Fig. 3. Form and development of craters.
(a) after Nov. 19, (b) after May 19,
(c) after May 29, (d) after June 15.
Contour interval: 10 m.

there were also new weak fumaroles on the SW slope of Pon-Matuneshiri, nearly in the direction of the new fissures.

ii) May 19, 1956. This explosion enlarged and deepened crater No. 1. The form of the deepest part elongated in E–W direction, suggesting the existence of an intrinsic fissure in that direction. The two craters No. 3 and No. 4 were joined together by this explosion, and resulted in one large crater (Fig. 3 b).

iii) May 29, 1956. Crater No. 1 was extended slightly to the west and east (Fig. 3 c).

iv) June 15, 1956. The area of the crater No. 1 became twice what it was before. The new western part is a little shallower than the eastern part. A part of the northern fissure was emitting vapour so vigorously that it was named No. 5 crater, but the strong issue of steam did not last long. Another new craterlet No. 6 was formed to the northeast of No. 1 crater (Fig. 3 d).

The total volume ejected by each explosion was estimated from the topographical surveys described above (Table 2).

§ 3. Distribution of Ejected Materials

i) Volcanic ash. Although the smoke column of the explosions could not be seen sometimes because of thick cloud, ash fell to the foot of the mountain soon after every explosion. The height of ash-laden smoke was never so high that the smoke was blown by the wind near the earth's surface at the time (Fig. 4).

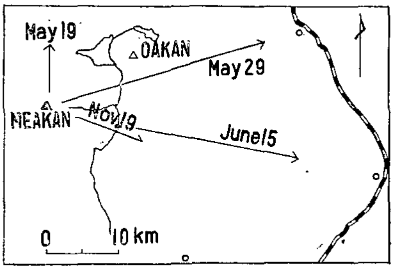

Fig. 4. Direction of ash-fall.

ii) Lava-blocks. Lava-fragments and detritus were also ejected by the explosions. The position of fall of a large lava-fragment could be identified by the hole which it made upon striking the ground.

(a) Explosion of Nov. 19. Warm lava blocks about 20 cm in diameter were hurled out over the north wall of the old crater. Maximum horizontal distance of flight was about 400 m.

(b) Explosion of May 19. Lava-blocks about 50 cm in diameter fell as far as 600 m east of the new crater. Fragments of 20 cm

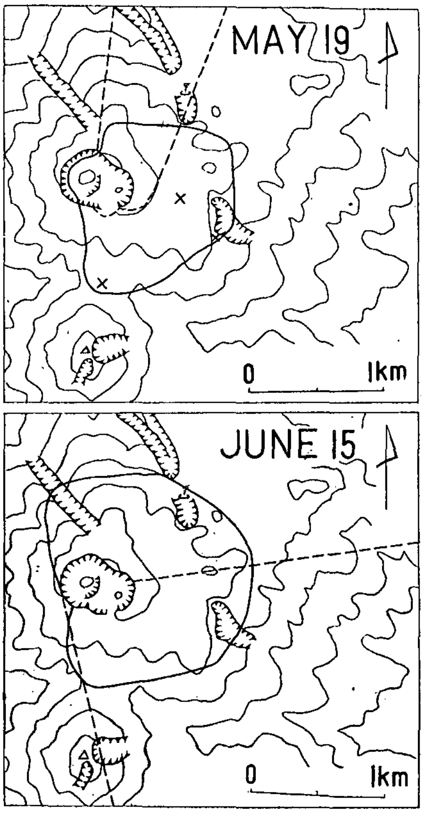

Fig. 5. Area of fall of lava-blocks (dia>20cm). dashed lines: ash-precipitation area, cross: place where a prairie fire took place. (ISHIKAWA, KATSUI, MURASE and SAKUMA).

size arrived at 1.0 km towards the east and south. No block flew over the western wall of the old crater (Fig. 5a).

(c) Explosion of June 15. Many large lava-blocks were scattered around the new craters. Those of a size of ca. 40 cm fell to the distance of 1.1–1.2 km in the eastern and northern directions. Many fragments flew over the western wall of the old crater also (Fig. 5b). Another minor explosion took place about 40 sec after the first one. Lava-fragments fell on the upper part of the mountain.

The initial velocity (v_0) of ejecta could be estimated at values shown on Table 2, from the distance of flight of the large blocks. Because the total volume of ejecta could be estimated as described above, the kinetic energy necessary to hurl out the mass with the estimated initial velocity could be calculated approximately by the following formula[3].

TABLE 2

Amount and velocity of ejecta.

Date of explosion	Volume (m^3)	Initial velocity (m/sec)	Kinetic energy (ergs)
Nov. 19	3×10^4	50	8×10^{17}
May 19	4×10^4	80	3×10^{18}
May 29	0.2×10^4	50	5×10^{16}
June 15	7×10^4	100	7×10^{18}

$$K.E. = \frac{1}{2} M v_0^2 .$$

The strongest explosion among those of the present series was that on June 15; its kinetic energy was less than 10^{19} ergs.

§4. Character of Ejecta

The ejecta of the first explosion were lava-fragments and detritus which had accumulated at the bottom of the old crater. Some of the material had been altered by solfataric action. In the explosions in 1956, less altered lava-blocks with fresh appearance were ejected. However, they were not juvenile rocks which consolidated directly from the magma, but angular fragments of the old lava-beds which lie at some depth beneath the crater-bottom.

§5. Temperature of Ejecta

Some lava-fragments of the first explosion were warm a few hours after their fall.

By some of the ejected lava-fragments of the May 19 explosion, withered plants (*Gankoran*; *Empetrum nigrum*) were carbonized on rare occasions or burnt to flames. A part of a sulphur deposit was ignited by the fall of ejecta at that time. Some of the lava-fragments which fell on snowy valley went deeply into the snow, perhaps due to melting of snow by their heat. In view of these facts, it may be reasonable to estimate the highest temperature of the ejecta of May 19 explosion at above 250°C. But there was no evidence for the belief that the ejecta were red-hot.

At the time of the explosion of June 15, the writers measured the temperature of lava-blocks just after their fall, directly by thermometers and indirectly by the method of calorimetry. The procedure in the indirect method is: to measure the rise of temperature of water in a vessel after putting a piece of hot ejecta in it. Thus estimated temperature of ejecta did not exceed 300°C.

§6. Temperature of Fumaroles and Temperature in the Ground

Temperature of fumaroles has been measured repeatedly by various authors including the present writers[2]. Measurement of temperature at the exactly same position and under the same condition is not always possible, and accordingly it would be a difficult matter to deduce a certain conclusion from the results.

In order to investigate possible variation of the underground temperature, measurements were made at a depth of 1 m below the earth's surface. Iron pipes were driven into the ground at 7 points around the new craters for the purpose, as shown in Fig. 2. Though the results are tabulated on Table 3, it seems that the observed variations have little connection with approaching explosion.

TABLE 3

Temperature at 1 m depth (°C). (cf. Fig. 2)

Date \ No.		1	2	3	4	5	6	7
May	28	15.0	11.9	21.8	27.2	27.0	—	—
June	1	16.0	17.0	23.5	27.5	28.0	21.0	78.0
	3	17.0	18.5	20.0	28.0	28.0	19.0	82.0
	14	15.5	10.7	20.4	28.5	24.0	20.2	78.0

§ 7. Seismometric Observations

For the purpose of investigating volcanic tremors and earthquakes of ordinary type which take place before and during volcanic activity, a horizontal seismograph of the improved ISHIMOTO type ($T_0=1.0$ sec, magnification$=1.5\times10^2$) was installed at 1.1 km NE of the crater after the first explosion. Only one very small earthquake was registered during the week from November 23 to 30, 1955. Observation was interrupted by the cold winter weather until May 20. Observation has been carried out without interruption from May 21, 1956 to this date, by the above described seismograph up to September and by another one of similar type but higher magnification ($\times$ 300) to the present. From July 13, 1956, a seismograph of moving coil type was also put in operation at 0.6 km NE of the crater. The seismograph was set so as to record the horizontal component of motion in the direction towards the crater. It is connected by a cable (0.6 km long) to a recording galvanometer. Magnification and frequency characteristics can be controlled by adjusting the electric circuit (Fig. 6). The instrument was used in magnification of about 1.5×10^4 on June 13 and 14. However, the magnification was reduced to 4×10^3 after the June 15 explosion. Another electromagnetic seismograph of the same type was used temporarily (July 25–Aug. 29) for the purpose of studying the essential nature and place of origin of tremor[4]. One more seismograph of mechano-optical magnification ($T_0 = 1.0$ sec, magnification $= 3 \times 10^3$) was operated in August at NONAKA hotspring, 2.3 km NW of the top of the volcano. Accordingly, simultaneous observation was carried out at four stations for about 20 days in the summer.

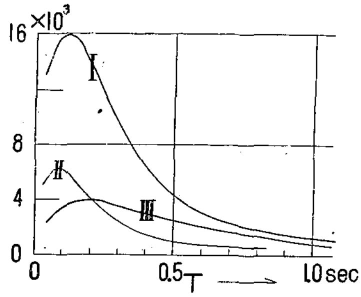

Fig. 6. Frequency characteristics of the electromagnetic seismographs.
I : used in June 13–15, at 1.1 km NE of the crater,
II : used in June 15–Sept., at 1.1 km NE of the crater,
III: used in July 25–Aug. 29, at various places to learn the amplitude and period of tremor, and to learn phase difference.

Several important facts were brought to light by the present seismometric studies. Earthquakes of ordinary type (but of volcanic origin), volcanic tremors and explosion-earthquakes[5] were recorded by the seismographs during the period. The outline of the seismic activity will be presented here.

(i) Earthquakes of ordinary type. It was reported* that many earth-sounds (rumblings) were felt at the northeastern foot of Me'akan in 1927, 1950–51[6] and early in 1954. The rumblings must have been swarms of earthquakes of shallow origin. Though no perceptible earthquake took place during the present volcanic activity, non-perceptible earthquakes of ordinary type, that is, with identifiable seismic phases, were recorded frequently by the seismographs. Of coures, the number of recorded earthquakes is dependent on the characteristics of the seismograph. Two series of observations by two sorts of seismographs are reproduced in Fig. 7. Nearly parallel relation between the two will be noticed easily, in spite of difference in the counted numbers. The most important feature in Fig. 7 is that the strong explosion on June 15 was

* Literatures are listed in Ref. 2).

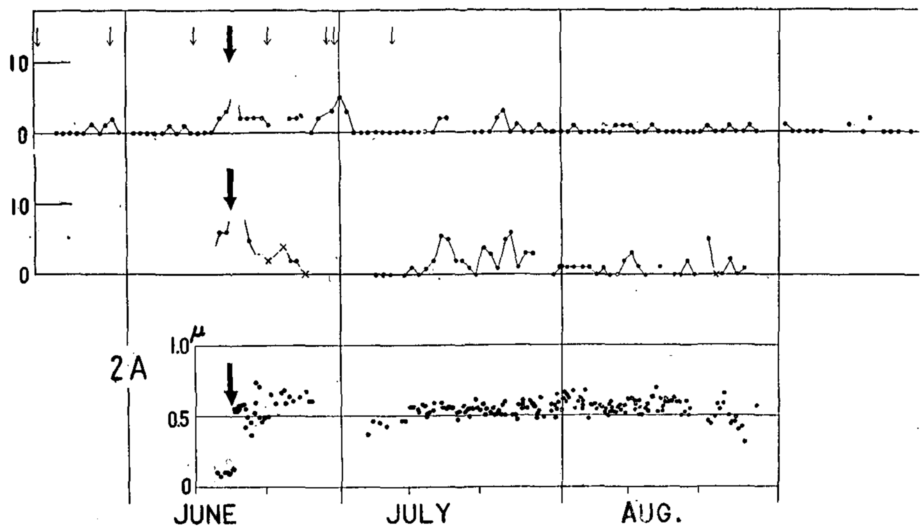

Fig. 7. Diagram showing volcanic and seismic activity through the period from May 20 to Sept. 20, 1956. Arrows indicate occurrence of explosions.

1st row: Frequency (at night) of earthquakes, by ISHIMOTO seismograph at P (Fig. 2).

2nd row: Frequency (at night) of earthquakes, by electromagnetic seismograph (4×10^3) at Q.
Cross: less accurate number on account of occurrence of tremor.

3rd row: Average max. amplitude of continuous tremor, by the electromagnetic seismograph at Q.

preceded by increase of seismic activity. This will be affirmed by the observation with the highest sensitivity on June 13–15. On the night of June 12, preliminary observation by the electromagnetic seismograph was made at 1.1 km NE of the crater. No remarkable event was noticeable on the seismogram obtained during the night, though weak, continuous ground vibration of artificial origin might have masked very small earthquakes, if any. Since June 13, when the seismograph was removed to the mentioned position, many earthquakes were recorded (Plate II a). (Unfortunately, some of the earthquakes in the daytime could not be distinguished from the vibrations caused by explosions of powders in the working sulphur mine not far distant, and the recording of the number of occurrences of natural shocks is not reliable in the daytime). Twenty or more micro-earthquakes took place during the night of June 13 and 14 respectively. Only the largest two or three among them were registered by the Ishimoto seismograph. After the explosion of June 15, tremors of amplitude of about 0.5μ ($2A=$) continued, and magnification was reduced unavoidably to 4×10^3. The number of earthquakes for June 13 and 14 as illustrated on Fig. 7 is the number of the larger earthquakes which should have been registered if the magnification had been 4×10^3 at that time.

The occurrence of swarm of earthquakes preceding volcanic activity is common to many active volcanoes[5)6)7)], but there has been no instrumentally observed example of that phenomenon concerning steam-explosion, like the present activity of Me'akan-dake, so far as the writers are aware.

It should be noted also that the observed frequency of occurrence of earthquakes is much less than those at Asama and Sakura-jima, which eject juvenile lavas.

The seismic activity was not always followed by surface activity. The seismic activity seemed to be decreasing gradually after July, though it showed ebbs and flows sometimes, when change was scarcely noticed in the state of smoke.

Determination of their foci was not carried out, partly because of lack of seismographs and partly because of the continuous tremor which rendered the identification of phase very difficult. In spite of the difficulty, some approaches could be done in the direction. Duration of preliminary tremor (P–S duration) was measurable at 29 earthquakes among 66 which were recorded during the period from June 13 to 19. The P–S durations of 24 among the 29 were less than 1.5 sec at the station 0.6 km NE of the crater (Fig. 8). If the distance-coefficient is taken as 3 on the basis of observations at other volcanoes[9)], it may be

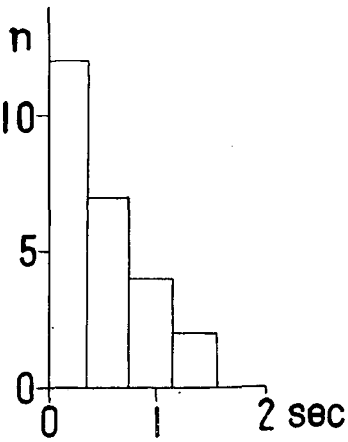

Fig. 8. Frequency distribution of P–S duration of 24 earthquakes.

concluded that the earthquakes occur within 4 km from the crater. In other words, the earthquakes originated within or just below the mountain body of Me'akan-dake proper. However, the phase S could be distinguished with much difficulty with respect to other quakes. Those shocks seem to have originated at a somewhat shallower part. Almost all of the seismograms which were obtained at Nonaka, 800 m below the top, were of complicated form. This fact may imply that the foci are not much deeper than the level of Nonaka even if they were below that level.

(ii) Tremor. Slight ground vibrations of a period of 0.5 sec were noticed on June 13 and 14. Just after the strongest explosion on the 15 th, another continuous vibration of the ground began and lasted for more than three months. Its amplitude fluctuated a little around 0.5μ and its period was mostly 0.2 sec. Minute investigations of the nature of the tremor were carried out in August; the results are published under another title[4]. In short, it seems that the tremor was caused by escaping vapour at about 300 m below the new craters.

(iii) Explosion-earthquakes. Those earthquakes which occurred in company with the explosions of May 29 and June 15 could be registered by the Ishimoto seismograph. Maximum double amplitude was 4.7μ and 214μ respectively (Plate II b).

Energy released in the form of an explosion-earthquake can be estimated roughly. The waves of large amplitude may be surface waves mostly. Depth of origin must be very slight in comparison with epicentral distance (r), and the surface waves represent probably most of the arriving energy. The following equation can be derived by assuming simply that the waves are of Rayleigh type[10].

$$E = \frac{2.5\pi^2}{(0.42)^2} \rho r \int c^2 \frac{A^2}{T} dt \qquad \text{ergs} ,$$

where T and A are period and amplitude of motion and c is the velocity of the wave. The energy of the June 15 explosion-earthquake was thus estimated at 1×10^{15} ergs by taking $c=1$ km/sec, $A=107\mu$, $T=0.15$ sec and $t=6$ sec. This is between 10^{-3} and 10^{-4} of the estimated kinetic energy of ejecta at that time. The seismic energy of the May 29 explosion-earthquake was about $1\times$

10^{13} ergs ($A=2\mu$, $T=0.5$ sec, $t=20$ sec) which is also between 10^{-3} and 10^{-4} of the kinetic energy. Though those figures represent only the order of magnitude, it seems certain that the energy released at the time of an explosion in the form of seismic energy does not much exceed 10^{-3} of that of kinetic energy of ejecta, even if dissipation is taken into account.

MINAKAMI[3] has obtained an empirical formula to estimate the kinetic energy of ejecta of an explosion of Volcano Asama on the basis of the maximum amplitude of the explosion-earthquake at a distance of 4.5 km from the crater. That is:

$$\text{K.E.} = (\text{const} + 4.50\,A + 0.70\,A^2) \times 10^{19} \quad \text{ergs},$$

where A is horizontal component of ground motion at 4.5 km in mm unit. Because the present writers' seismograph is similar in type to his, a trial calculation of the energy of the explosion of Me'akan-dake was made with this formula. By assuming that the small constant is zero and that the maximum amplitude declines in proportion to $r^{-\frac{1}{2}}$, the kinetic energy of the June 15 explosion was estimated at 3×10^{18} ergs, which is half of the value actually observed. Similarly, the kinetic energy of the May 29 explosion was estimated at 7×10^{16} ergs which is a little larger than the actual one. However, the agreement is rather surprising if one considers the accuracy of estimation of various quantities on both sides. It is to be noted that the same, or at least a similar, law of partition of energy is applicable to the explosions of different volcanoes. Conversely, maximum amplitude of an explosion-earthquake may be used as a magnitude scale common to all volcanoes of explosive type.

(iv) Ground vibrations just before and after the strongest explosion.

Strange continuous earth-shakings were also registered just prior to the strong explosion of June 15, by the sensitive electromagnetic seismograph (Plate II c).

As mentioned already, there were slight ground vibrations of 0.5 sec period in the epoch before the explosion. Another sort of continuous ground vibration took place initially about 3 minutes before the explosion. The tremor was very small in amplitude at the beginning and it could be distinguished only with difficulty.

But its amplitude became twice the level of the former vibrations (of period of 0.5 sec) just before the explosion. The period of the appeared tremor was 0.2–0.3 second mostly. It was succeeded by the commencement of stronger vibrations of shorter period, which must have been the first sign of the explosion-earthquake (Fig. 9). The vibration lasted for about 1.1 sec and followed suddenly by great vibrations (maybe of the main part of the explosion-earthquake) which could not be recorded by the equipped optical recording apparatus.

As the cable connecting the seismograph with recorder was cut at 10 places by falling ejecta, the observation with that sensitive instrument was interrupted for a while, and the only record of

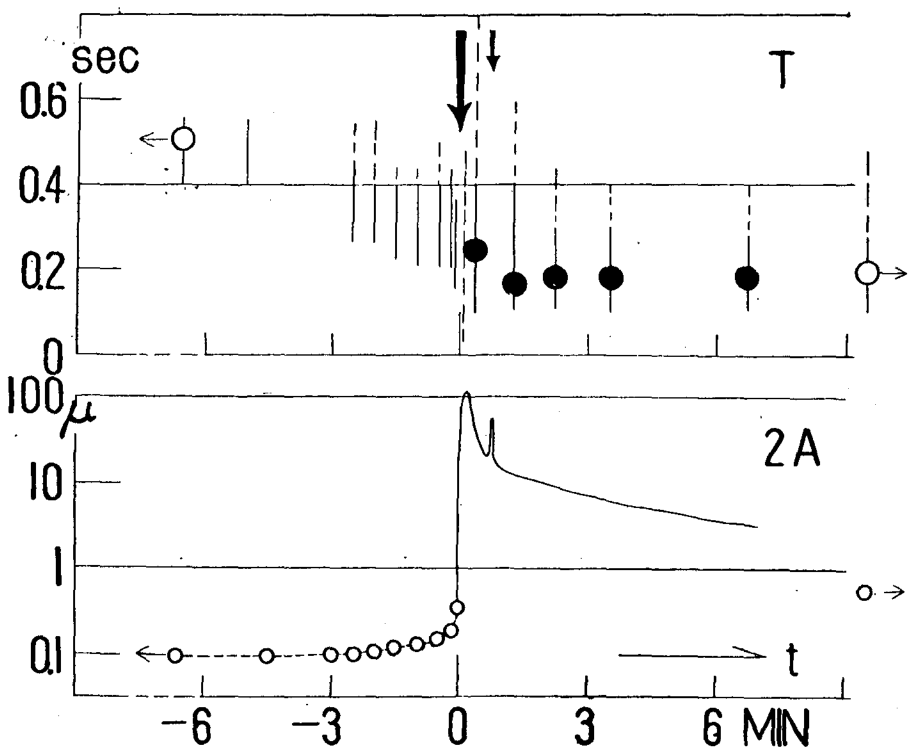

Fig. 9. Change in amplitude and in period (-range) of the ground vibration just before and after the explosion of June 15.
open circles: by electromagnetic seismograph.
solid line in 2A: by ISHIMOTO seismograph (not corrected for distance effect).

the explosion-earthquake by the ISHIMOTO seismograph was available for the study of the vibrations which came just after the explosion.

Continuous ground vibrations were discernible for about 10 minutes after the explosion even on the seismogram with low magnification. The range of the period of the vibration was at first broad (0.6–0.1 sec), then it became narrower and tended to become about 0.2 sec which is the same as that of the long-continued post-explosion tremor.

When all of the observed facts are summarized, the following conclusions may be stated. There was very weak vibrations of 0.5 sec at first, and the vibration of shorter period took place additionally just before the explosion. The vibration at the time of explosive activity contained waves of various periods, but only the tremor of period of 0.2 sec survived for a long time after the explosion. The origin of the last tremor could be inferred from the amplitude-distribution to be at about 300 m below the new craters. Vibration of period of 0.5 sec in the post-explosion tremor was considered as surface waves also on the basis of the study of tremor[4]; one might possibly well infer that the weak vibration of the same period represents also the surface waves, probably caused at or near the surface of the crater, but it is not satisfactorily certain whether the pre-explosion tremor of 0.3–0.2 sec is akin to the post-explosion tremor or not. The character of vibrations just before and after explosions would be a very important clue to the study of physical conditions of the interior of the volcano at the time of the explosions.

§ 8. Concluding Remarks and Acknowledgement

The present activity of Me'akan-dake may be characterized as steam-explosions (phreatic explosions) of minor scale, because no juvenile material has been ejected. But many interesting phenomena could be studied especially by seismographs. Observations are now being continued on the mountain.

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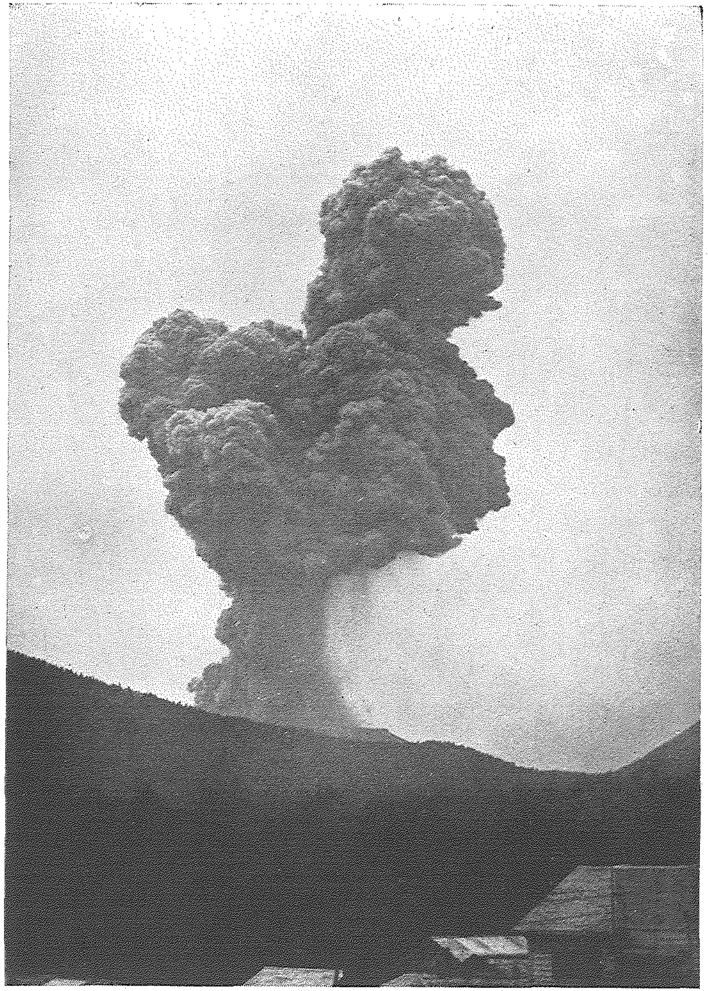

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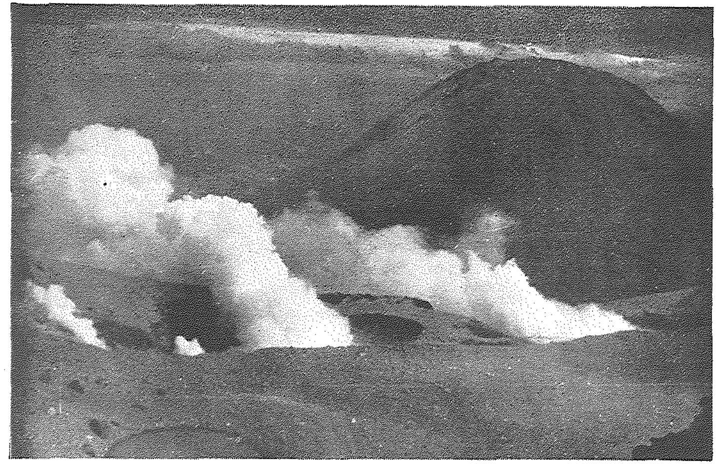

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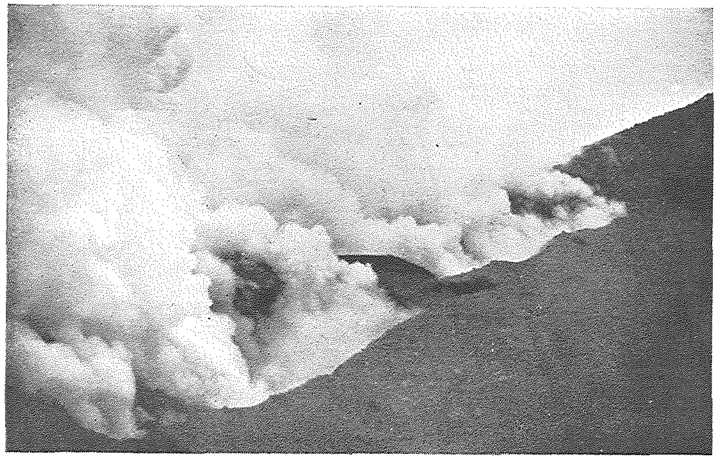
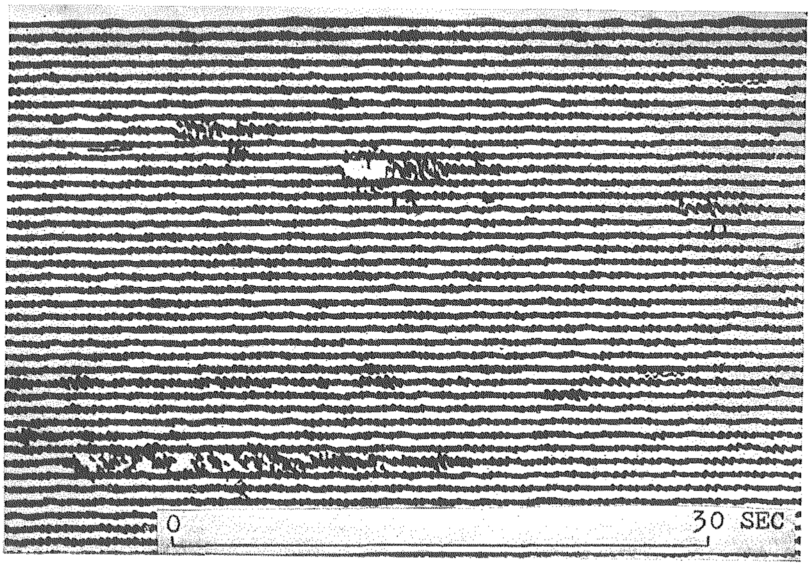
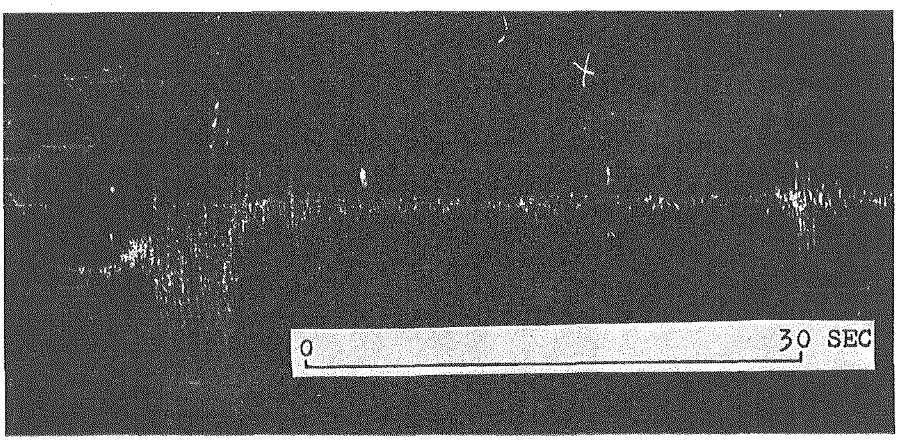


(c)

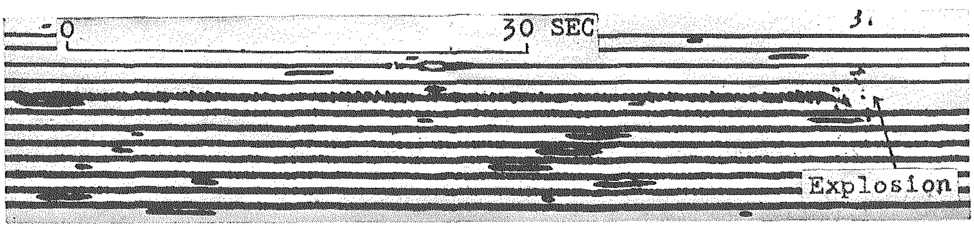
(a): May 19 explosion, seen from Lake-side (9 km NE). (Photo YAMAGUCHI)
(b & c): New craters, seen from north wall of the old crater (June 16, 1956).



(a)



(b)



(c)

(a): A part of seismogram of swarm of earthquakes on the night of June 14.

(b): Explosion-earthquake of June 15, at 1.1 km NE ($\times$ 150 seismograph).

(c): Strange tremor, just prior to the explosion. (electromagnetic seismograph at 0.6 km from the crater) (ca. 8×10^3)