# 22. *Recent Activities of Volcano Usu (III). Earthquakes at the Stage of Paroxysmal Eruption.*

By Takeshi MINAKAMI,

Earthquake Research Institute.

(Read Dec. 20, 1949.—Received Nov. 30, 1949.)

As already reported in the previous paper[1], the recent eruption of the Usu volcano began with marked earthquakes on December 28, 1943, and from that time on, the seismic activity lasted incessantly throughout the three stages of the recent volcanic activity, namely, pre-volcanic stage, stage of the paroxysmal eruption, and that of birth and development of the lava dome, though it often manifested some ebb and flow in frequency of earthquakes and their intensity.

For the purpose of precise investigations of earthquakes, seismographs of high sensibility were set at Tōya Hot Spring at the northwestern foot, Sōbetu at the north-eastern foot, the village Usu at the southern foot, Kami-Osaru at the south-eastern and Hukaba on the rising area at the eastern foot of the volcano. Seismometric observations were continuously carried out during the period from June to September, 1949, and particularly the observations at Tōya Hot Spring were continued for about a year from March 1944 to March 1945. Seismographs used in the present investigation, had been operated at the volcanic activities of Miyake-sima in 1940 and Sakura-zima in 1946, Asama since 1937, and for the observations of after-shocks of strong earthquakes. The instrumental constants of seismographs are 1.0 second in their period, and 350 or 200 in the geometrical magnification.

However, after several days of observations, the seismograph set at Hukaba was replaced by an acceleration seismograph, seeing that earthquake-motions were too strong for the use of the former instrument.

On the basis of these seismometric observations, the distribution of seismicity on and around the volcano is illustrated in Fig. 1 by the daily frequencies of shocks recorded at the above mentioned five stations. The seismic activity shown in Fig. 1 includes the period from the end of June to August in 1944, when the paroxysmal eruptions were most fierce in the recent activity of Usu.

---

1) T. MINAKAMI, *Bull. Earthq. Res. Inst.* 25 (1947), 65, 71.

Although the acceleration seismograph records only such strong earthquakes as can be felt, the frequency at Hukaba was more than ten times of those of the other locations. According to investigations of perceptible area, most of earthquakes recorded at Hukaba were felt only at a limited area in the vicinity of that station, being less than 1 km in its diameter.

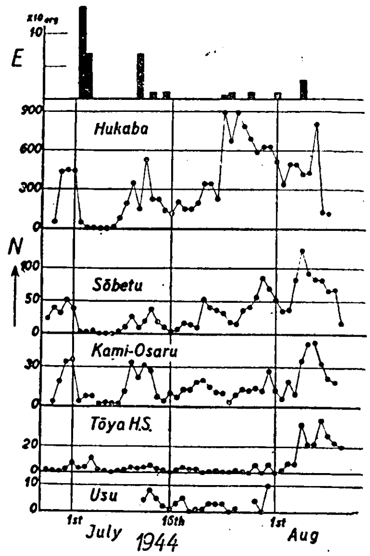



Fig. 1. Daily frequencies of earthquakes recorded at the five stations around Mt. Usu during the stage of paroxysmal eruption.
N; Daily frequencies.
E; Energies of main explosion (Unit; $10^{19}$ ergs.)

Table I. Depth of hypocentres and distance coefficients.

| Date | | Time | | Z | K |
|---|---|---|---|---|---|
| | | h | m | km. | km/sec |
| July | 13 | 0 | | 2.7 | 5.2 |
| | 13 | 4 | 28 | 3.6 | 4.8 |
| | 14 | 1 | 11 | 3.4 | 4.4 |
| | " | 3 | 50 | 4.1 | 4.8 |
| | 18 | 10 | 26 | 3.1 | 3.3 |
| | " | 14 | 06 | 1.0 | 2.5 |
| | " | 14 | 06 | 3.8 | 5.0 |
| | 24 | 21 | 17 | 3.5 | 5.2 |
| | 26 | 0 | 11 | 1.7 | 3.3 |
| | " | 2 | 50 | 4.1 | 4.0 |
| | 31 | 22 | 50 | 2.3 | 5.0 |
| | " | 22 | 50 | 3.0 | 3.6 |

Since the durations of preliminary tremors observed at Hukaba ranged mostly between 0.0 second and 0.4 second, or 0.3 second in the mean value, the hypocentres of these earthquakes are estimated at depth between the earth's surface and 1 km, if the distance coefficient is assumed to be 2.0 (Fig. 2). However, this assumption may be reasonable in view of the distance coefficient of deeper earthquakes originated from the southern side of this volcano, as will be seen in Table I. According to the seismometric study of the Oosima volcano made by R. Takahasi and T. Nagata[2], the dis-

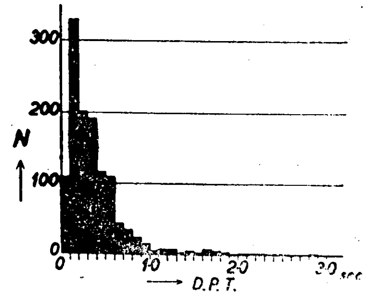



Fig. 2. Frequency distribution of duration of preliminary tremors observed at Hukaba.

2) R. TAKAHASI and T. NAGATA, *Zisin*, 11, No. 4 (1939), 161.

tance coefficient was found to be 2.2 and 2.4 for the earthquakes originated from the earth's surface and 0.5 km deep.

From these investigations, it is evident that a greater part of numerous earthquakes observed at Hukaba, occurred on and directly below the rising area including the village Hukaba, accompanied by the marked topographical deformations, tilting of the earth's surface, and cracks of various scales.

Of these earthquakes originated from the Hukaba area, only the few earthquakes of strong intensity were recorded by the seismographs of higher sensibility at the other stations.

Bisides the earthquakes which occurred near Hukaba, other earthquakes were recorded by all the seismographs located around this volcano, though their frequency was not so notable as that of the Hukaba earthquakes.

With respect to the earthquakes recorded at the four stations, positions of their hypocentres and the distance coefficients of the respective earthquakes were studied on the basis of preliminary tremors, and the distribution of hypocentres was illustrated in the previous report[3].

A glance at the seismograms of two kinds of earthquakes (Fig. 6 and Fig. 7) of which one took place at the depth between two and five km of the southern side of the mountain, and the other was originated from the Hukaba area near the earth's surface, will show the conspicuous differences in their characters of earthquake-motions, that is, amplitudes and periods of the seismic waves. For convenience of description, the former and latter earthquakes will be called A and B types of earthquakes respectively.

In order to throw a light on the nature of the A and B types of earthquakes, period analyses of earthquake-motions were carried out for those of the two types recorded at the four or five stations.

As an example, the frequency distribution of periods of an A type earthquake-motions recorded at Kami-Osaru, Sōbetu, Tōya H. S. and the village Usu are represented in

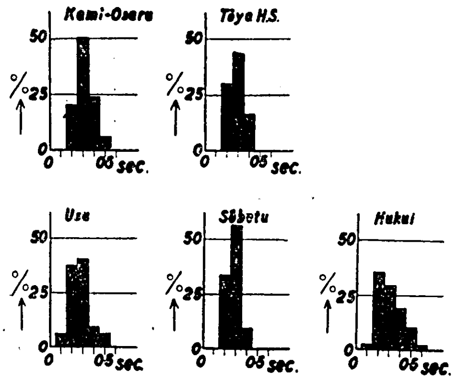


Fig. 3. Frequency distribution of periods of the A type earthquake-motions, and that of an after-shock observed at Hukui.

3) T. MINAKAMI, *loc. cit.*

Fig. 3, together with that of an after-shock of tectonic origin, while those of a B type earthquake recorded at the four stations just mentioned and the Hukaba station are shown in Fig. 4. In addition to that, the mean periods of earthquake-motions were obtained for seven A type earthquakes and six B type ones both recorded at the four or five stations respectively, of which the results are represented in Table II. As being shown clearly in these diagrams and the table, the mean periods of earthquake-motions of the A type except that of Hukaba are always shorter than those of the B type, being almost 0.3 second for the former, and from 0.2 to 0.7 second for the latter. Judging from the result of the period analyses and the form of the seismo-

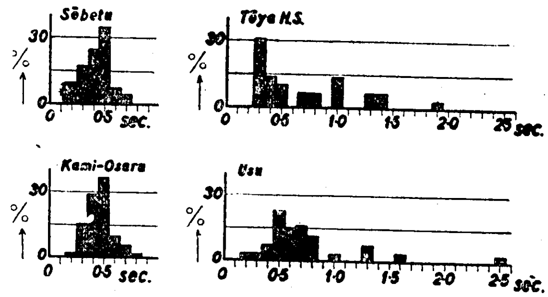


Fig. 4. Frequency distribution of periods of the B type earthquake-motions.

Table II, (a). Mean periods of earthquake-motions of the A type.

| Date of earthquakes. | Mean periods | | | |
|---|---|---|---|---|
| | Usu | Tōya H. S. | Sōbetu | Kami-Osaru |
| | Sec. | Sec. | Sec. | Sec. |
| July 13, 0 h | 0.24 | 0.22 | 0.22 | 0.26 |
| „ 4 „ | 0.27 | 0.29 | 0.27 | 0.30 |
| „ 22 „ | — | 0.19 | 0.19 | 0.19 |
| 14, 0 „ | — | 0.25 | — | 0.22 |
| „ 1 „ | 0.36 | 0.35 | 0.26 | — |
| „ 8 „ | 0.32 | 0.33 | 0.30 | 0.31 |
| 26, 3 „ | 0.33 | 0.33 | 0.23 | 0.28 |

Table II, (b). Mean periods of earthquake-motions of the B type.

| Date of earthquakes | Mean periods | | | | |
|---|---|---|---|---|---|
| | Usu | Tōya H. S. | Sōbetu | Kami-Osaru | Hukaba |
| | Sec. | Sec. | Sec. | Sec. | Sec. |
| July 9, 19 h | — | 0.68 | 0.33 | 0.49 | 0.28 |
| 12, 9 „ | 0.69 | — | — | 0.51 | 0.24 |
| „ 17 „ | 0.69 | 0.65 | 0.32 | 0.50 | 0.20 |
| 13, 0 „ | — | 0.63 | 0.37 | 0.50 | 0.20 |
| 20, 19 „ | 0.70 | — | — | 0.49 | 0.18 |
| 22, 1 „ | 0.76 | 0.69 | 0.40 | 0.46 | 0.21 |

grams, we can not find any different character in earthquake-motions between the A type earthquake and the so-called tectonic one.

In contrast to that, that of the B type shows distinguished characters as if it were a distant earthquake of tectonic origin, and as will be seen in Fig. 7, the amplitudes of the B type earthquake decrease more rapidly with the epicentral distance than those of the other type.

It may be noted that, though the mean period of earthquake-motions of the A type is almost constant in spite of the various epicentral distances, that of the B type depends remarkably on the epicentral distance, as seen in the diagram of Fig. 5 clearly.

It is, however, believed that the notable characters mentioned with respect to the B type earthquakes show nothing but the fact that the depths of their hypocentres were extremely shallow and, as a result, the seismic waves were considerably disturbed and dissipated by the complex formations near the earth's surface. In addition to that, the shorter the period of the seismic wave is, the more seriously the dissipation affects on it. Therefore, the characteristics of the B type earthquake-motions are mainly caused by the comlex structures of the volcano, in other words, by remarkable dissipations in loose materials such as pumice, ash and other fragmental ejecta, and frequent reflexions and refractions of the seismic waves at the various boundaries between volcanic ejecta and older formations.

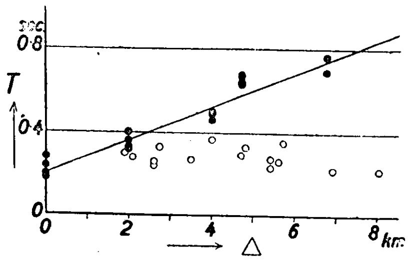
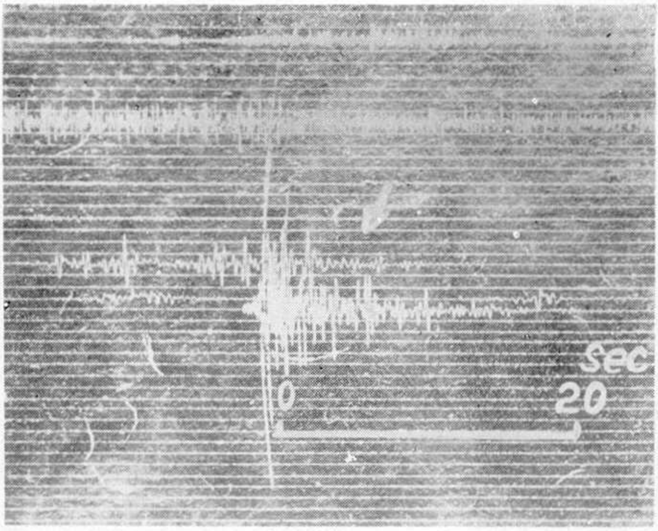



Fig. 5. Relationship between mean period of earthquake-motions and epicentral distances.
black circle; that of the B type earthquake.
open circle; that of the A type earthquake.

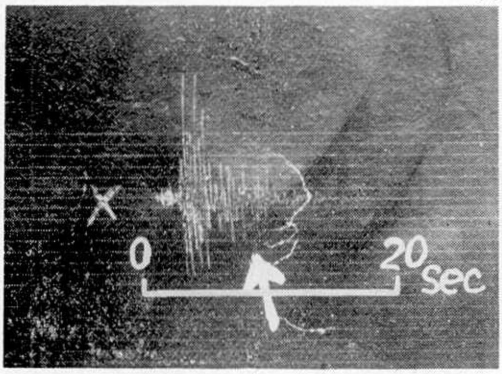
On the other hand, we must take into consideration that the surface waves of the B type earthquake are more conspicuous than those of the A type one, owing to the fact that the former was originated from extremely shallow hypocentre accompanied by the marked rise of the epicentral area. But, doubtless the above mentioned discussion will be not seriously affected by the problem with respect to production of the surface wave.

From the fact that whether the earthquake assumes the characters of A type or B type depends on whether its hypocentre is deeper than nearly 1 km or not, we conclude that there may exist a discontinuous boundary in the formations of this volcano at the depth between 1.3 and 0.5 km below the earth's surface.

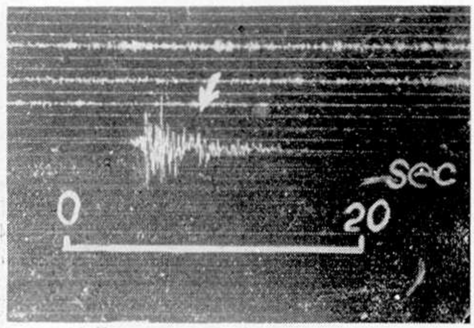
We must briefly touch upon the time relationship between frequency of earthquake and the paroxysmal eruptions, which both occurred during the period from June to August 1944. For this purpose, every marked explosion was expressed by its kinetic energy at the moment of outburst, and the seismic activity during the period was indicated by daily frequencies of earthquakes observed at the five stations. The diagram of Fig. 1 shows distinctly that the predominant earthquakes lasted several days prior to every marked eruption, which is as if the former half of a finite amount of energy took the form of seismic activity and the latter half of it the form of paroxysmal eruption, from two to five days after the outburst, the seismic activity grew remarkably weak.



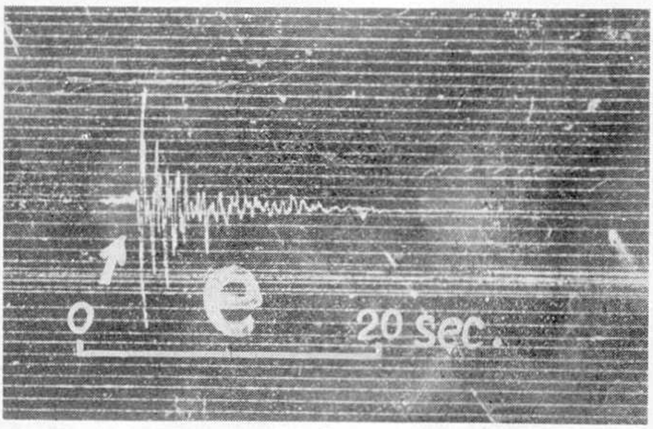

(a)




(b)




(c)




(d)

Fig. 6. Seismorams of the A type earthquake.

(a) Recorded at Kami-Osaru (Δ=1.9 km) (Seismograph magn.=350).
(b) „ „ Village Usu (Δ=3.5 km) ( „ =350).
(c) „ „ Tōya H. S. (Δ=4.7 km) ( „ =200).
(d) An after-shock recorded at Hukui. ( „ =350).

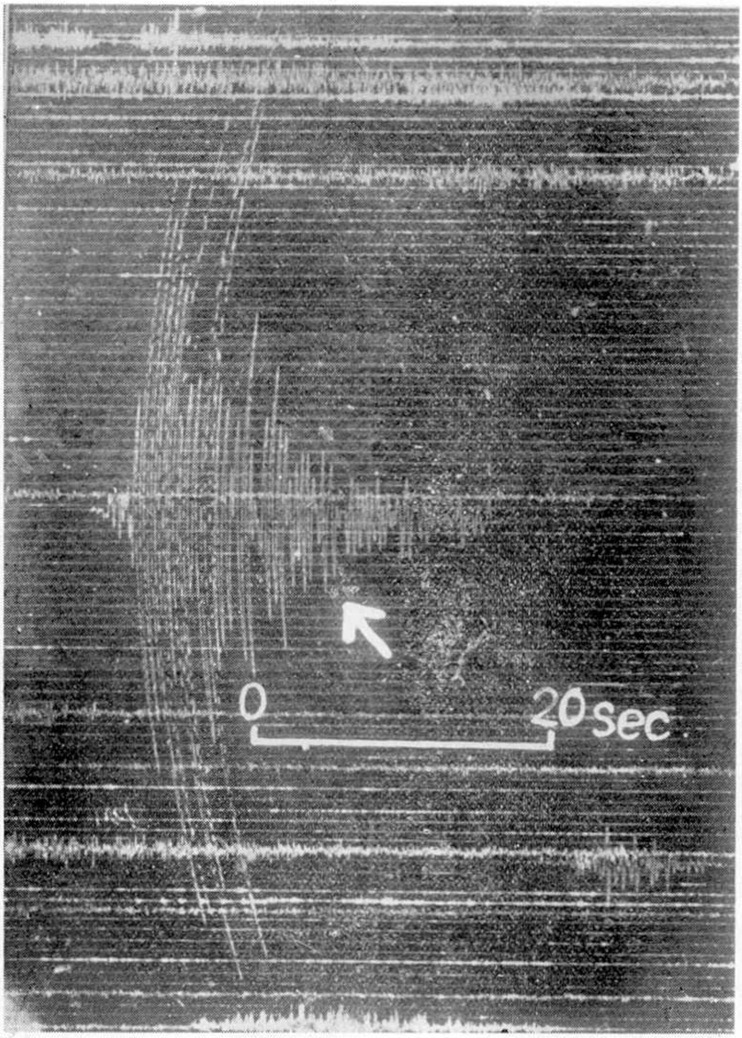



Fig. 7. (a) Seismogram obtained at Kami-Osaru
($\Delta$=4.0 km, Seismograph magn. ×350).

Fig. 7. (a), (b), (c), (d).
Seismograms of the B type earthquake on July 22, 1944.

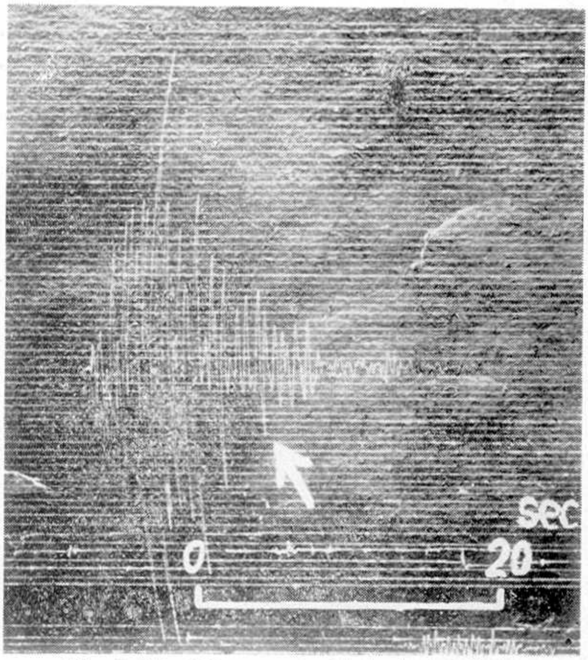



Fig. 7. (b) Seismogram obtained at Sobetu
(Δ=2.0 km, Seismograph magn. × 200).

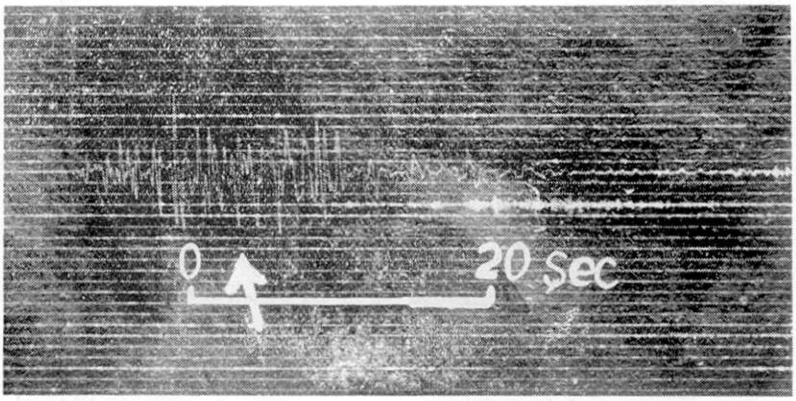



Fig. 7. (c) Seismogram obtained at Toya H. S.
(Δ=4.7 km, Seismograph magn. × 350).

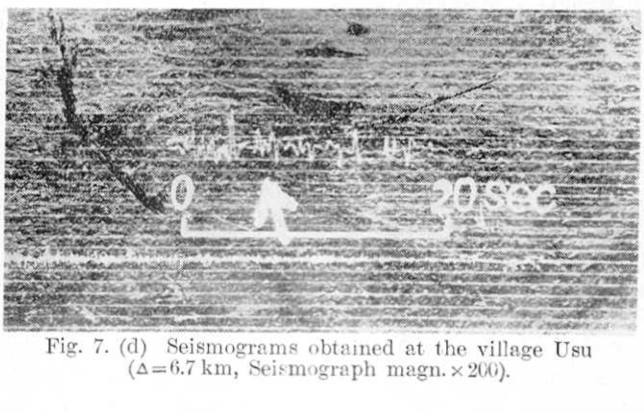



Fig. 7. (d) Seismograms obtained at the village Usu
(Δ=6.7 km, Seismograph magn. × 200).

〔震研彙報 第二十七號 圖版 水上〕