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15. *Seismometrical Studies of Volcano Asama* *Part 1.*

Seismic and Volcanic Activities of Asama during 1934-1969.

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Contents

1. Introduction

It was in 1909, about sixty years ago, that F. Omori[1] started to study Volcano Asama seismometrically and geophysically and established a volcano observatory at Yunotaira, about 2.5 km south-west of the summit

1) F. OMORI, *Bull. Imp. Earthq. Invest. Comm.*, **6** (1914), 1-147; **6** (1912), 149-226; **6** (1914), 227-257; **7** (1914), 1-215; **7** (1917), 217-326; **7** (1917), 327-456.

crater.

During the period from 1909 to 1914, Volcano Asama was, in fact, extremely active and a lot of strong explosive eruptions, typical Vulcanian eruptions, took place in the summit crater. Of his various studies of Asama, the seismological investigations based on the observation at the Yunotaira Volcano Observatory include most important and interesting suggestions regarding earthquakes originating from the volcano, which are still highly appreciated.

In 1933, the Earthquake Research Institute newly established Asama Volcano Observatory at 4.2 km east of the summit crater and restarted volcanological observations including earthquakes of volcanic origin, deformations of the earth's surface, geomagnetic and gravity fields on and near the volcano.

The results of these observations and surveys of Mt. Asama, have already been partially reported in this Bulletin[2] and in Bulletin volcanologique of I.A.V.[3] etc.

The writers deal in this report with the seismometrical network, the activity of various types of earthquakes in the volcanically active and calm periods since 1934 and the nature of earthquakes originating from Asama.

2. Seismometrical net-work of Volcano Asama

During the period from 1933 to 1953, the seismographs of ordinary type for observing earthquakes originating from the volcano, were used at the Asama Volcano Observatory and at other sub-stations situated on and around the volcano.

Since earthquakes originating from Asama have been extremely small in amplitude, the writers made efforts mainly to increase the magnification of the instruments, without electric amplifier, and for the purpose, the mechano-optical recorders with an optical lever of 1 m long were applied for obtaining a higher magnification than 5000.

In 1954, the telemetering system with transmission wire was adopted not only for the continuous observations of earthquakes, but also for those of geothermal temperature in accordance with development of

2) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **13** (1935), 629-644; **13** (1935), 790-800; **13** (1935), 318-327; **15** (1937), 492-496; **20** (1942), 431(504; **38** (1960), 497-544; **16** (1938), 100-116; **18** (1940), 178-250; **20** (1942), 40-64. *Bull. Volcanologique*, **10** (1950), 59-87; **18** (1956), 39-76; **21** (1959), 127-151.

3) T. MINAKAMI and S. SAKUMA, *Bull. Volcanol.*, **14** (1953), 79-130.

T. MINAKAMI, *Bull. Volcanol. Soc. Japan*, **14** (1959), 104-114.

T. MINAKAMI, S HIRAGA, S. UTIBORI and T. MIYAZAKI, *Bull. Volcanol. Soc. Japan*, **14** (1959), 115-130.

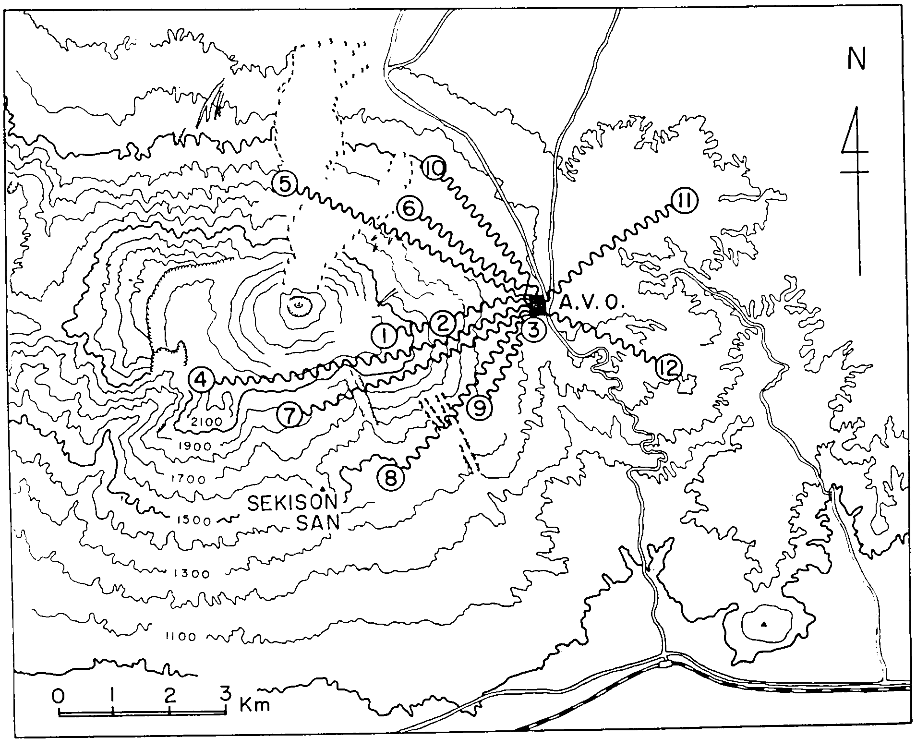


Fig. 1. Permanent seismometrical net-work of Asama Volcano Observatory.

Table 1. Geographical positions of the permanent stations equipped with transducers and seismographs as of 1966–1969.

Stn. No.	Place	Latitude (N)	Longitude (E)	Altitude
1	Huzimizaka	36°23′ 55″	138°32′ 22″	2160m
2	Sannotorii	〃 24′ 02″	〃 33′ 05″	1820 〃
3	Nakanosawa	〃 24′ 01″	〃 34′ 09″	1380 〃
4	Gippa-yama	〃 23′ 40″	〃 29′ 54″	2000 〃
5	Oniosidasi W.	〃 25′ 21″	〃 31′ 17″	1630 〃
6	Kuromamegawara U.	〃 25′ 12″	〃 32′ 40″	1560 〃
7	Sekison-san	〃 23′ 10″	〃 31′ 17″	1860 〃
8	Hotokeiwa	〃 22′ 39″	〃 32′ 26″	1470 〃
9	Okubozawa	〃 23′ 15″	〃 33′ 32″	1580 〃
10	Kuromamegawara D.	〃 25′ 40″	〃 32′ 55″	1460 〃
11	Tutuzigahara	〃 25′ 13″	〃 35′ 53″	1350 〃
12	Siraitonotaki I	〃 23′ 39″	〃 35′ 41″	1365 〃
30	Asama Observatory	〃 24′ 05″	〃 34′ 19″	1400 〃

electronic technics.

The ground noise on Asama caused by traffic on the roads passing its lower slopes is quite serious, and the instrumental magnification of continuous observation is adjusted indispensably in a range between 3500 and 5000. It will be certainly needless to describe that the temporary observations for special purposes have been made with higher sensitive recorders as well as the oscillographs with 24 or 12 elements and the tape recorders with seven channels equipped with an endless tape.

Tables 1, 2 and 3 show the geographical positions of the transducer stations and their altitudes, and Table 4 represents the characters of transducers and the kinds of recorder connected with the transducers.

Table 2. Geographical positions of the temporary stations in which seismometric observations were made for a longer period than one month with highly sensitive seismographs.

Stn. No.	Place	Latitude (N)	Longitude (E)	Altitude
13	Kurohu-yama	36°24′ 34″	138°30′ 21″	2120m
14	Hotokeiwa U.	〃 24′ 24″	〃 32′ 11″	1920 〃
15	Hotokeiwa D.	〃 22′ 29″	〃 32′ 47″	1380 〃
16	Tinotaki	〃 22′ 09″	〃 32′ 24″	1320 〃
17	Ko-Asama	〃 24′ 25″	〃 33′ 55″	1650 〃
18	Gyozyamodosi	〃 24′ 08″	〃 33′ 36″	1570 〃
19	Higasi-Maekake	〃 24′ 00″	〃 31′ 56″	2350 〃
20	Oniosidasi E.	〃 26′ 24″	〃 32′ 25″	1330 〃
21	Okubozawa D.	〃 22′ 29″	〃 33′ 46″	1280 〃
22	Sanzenton-iwa	〃 24′ 21″	〃 31′ 24″	2500 〃
23	Maekake-Kako	〃 24′ 16″	〃 31′ 02″	2440 〃
24	Maekake-yama	〃 24′ 00″	〃 30′ 56″	2490 〃
25	Ohinata	〃 21′ 09″	〃 33′ 45″	1060 〃
27	Sin-Nakanosawa	〃 24′ 00″	〃 34′ 08″	1390 〃
28	Siraitonotaki II.	〃 24′ 00″	〃 35′ 16″	1400 〃
31	A. V. Observatory W.	〃 24′ 05″	〃 34′ 15″	1420 〃

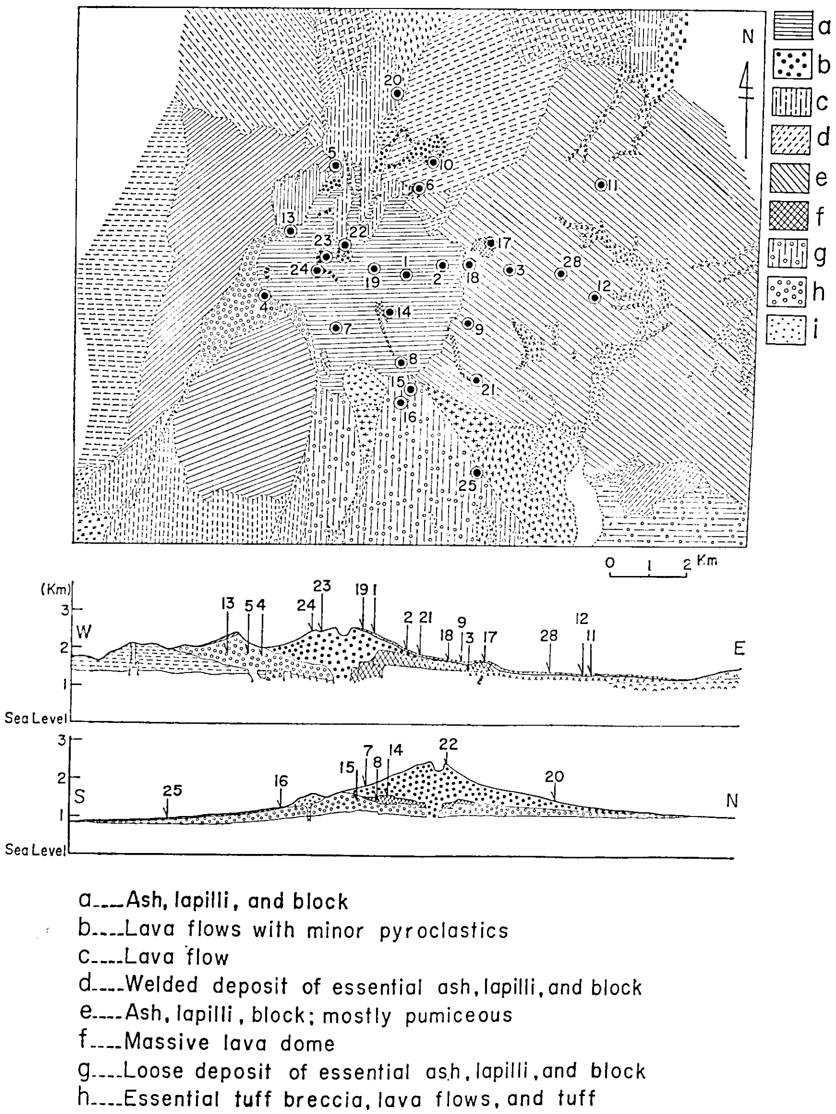
Fig. 3 shows the system of seismometric observation at Asama Volcano Observatory in the form of a block diagram. The response curves for the systems of the seismic observation which are indicated in the above block diagrams are illustrated in Fig. 4. Of the eight response curves, those (1), (2) and (5) are similar with the ones for the portable instruments which are shown in the previous paper of the Bulletin.[4]

4) T. MINAKAMI et al., *Bull. Earthq. Res. Inst.*, **47** (1969), 893-949.

Table 3. Horizontal distances from the center of the summit crater to the permanent and temporary stations and the geological formations on which these stations are built.

Stn. No.	Place	H. Distance	Geological formation[5]
1	Huzimizaka	1.7km	Recent pumice etc.
2	Sannotorii	2.6 〃	Recent pumice etc.
3	Nakanosawa	4.1 〃	Hotokeiwa lava
4	Gippa-yama	2.4 〃	Old Asama formation
5	Oniosidasi W.	2.3 〃	Old Asama formation
6	Kuromamegawara U.	2.6 〃	Historical lava flow
7	Sekison-san	2.0 〃	Maekake-yama formation
8	Hotokeiwa	3.3 〃	Old Asama formation
9	Okubosawa	3.7 〃	Recent pumice
10	Kuromamegawara D.	3.3 〃	Recent lava flow
11	Tutuzigahara	7.0 〃	Recent pumice etc.
12	Siraitonotaki I	6.7 〃	Recent pumice etc.
13	Kurohu-yama	1.6 〃	Old Asama formation
14	Hotokeiwa U.	2.0 〃	Old Asama formation
15	Hotokeiwa D.	4.0 〃	Old Asama formation
16	Tinotaki	4.2 〃	
17	Ko-Asama	3.8 〃	Recent pumice layer on the dacite dome
18	Gyozyamodosi	3.3 〃	Recent pumice and lapilli
19	Higasi-Maekake	0.9 〃	Recent lapilli, pumice and fine ejecta
20	Oniosidasi E.	4.4 〃	The 1783 lava flow
21	Okubo D.	4.8 〃	Thin recent pumice and ash on old Asama formation
22	Sanzenton-iwa	0.3 〃	Lava blocks and bombs
23	Maekake-Kako	0.5 〃	Lava blocks, bombs and ash etc.
24	Maekake-yama	0.8 〃	Bombs and ash on lava flows
25	Ohinata	6.8 〃	Pyroclastic products
27	Sin-Nakanosawa	4.0 〃	Recent pumice and ash on dacite lava
28	Siraitonotaki II.	5.8 〃	Recent pumice and ash
30	Asama V.O.	4.4 〃	Recent pumice and ash
31	Asama V.O.W.	4.3 〃	Recent pumice and ash
40	Naka-Karuizawa	8.7 〃	Recent pumice and ash on old pyroclastic products
41	Syoono	8.3 〃	Old pyroclastic products
42	Asamakan	4.7 〃	Old Asama formation and alluvium
43	Takamine	4.5 〃	Pre-Asama formation

5) S. ARAMAKI, *Jour. Fac. Sci. Univ. Tokyo*, Sec. II, **14** (1963), 229-443.



a---Ash, lapilli, and block
b---Lava flows with minor pyroclastics
c---Lava flow
d---Welded deposit of essential ash, lapilli, and block
e---Ash, lapilli, block; mostly pumiceous
f---Massive lava dome
g---Loose deposit of essential ash, lapilli, and block
h---Essential tuff breccia, lava flows, and tuff
i---Recent pumices and fine ejecta

Fig. 2. Localities of the permanent and temporary seismic stations on various geological formations. Numeral; Stn. No.
(Compiled from the geological map made by S. Aramaki).

According to the seismometrical observation at the Observatory, it is a remarkable feature in the earthquakes originating from Volcano Asama that their main part at least in their frequency, consists of the B type earthquakes located near the summit crater and a few classified into the A type quakes.

Since the present seismometrical net has completely covered the volcano since 1963, earthquakes originating from any part of Asama have been recorded by it.

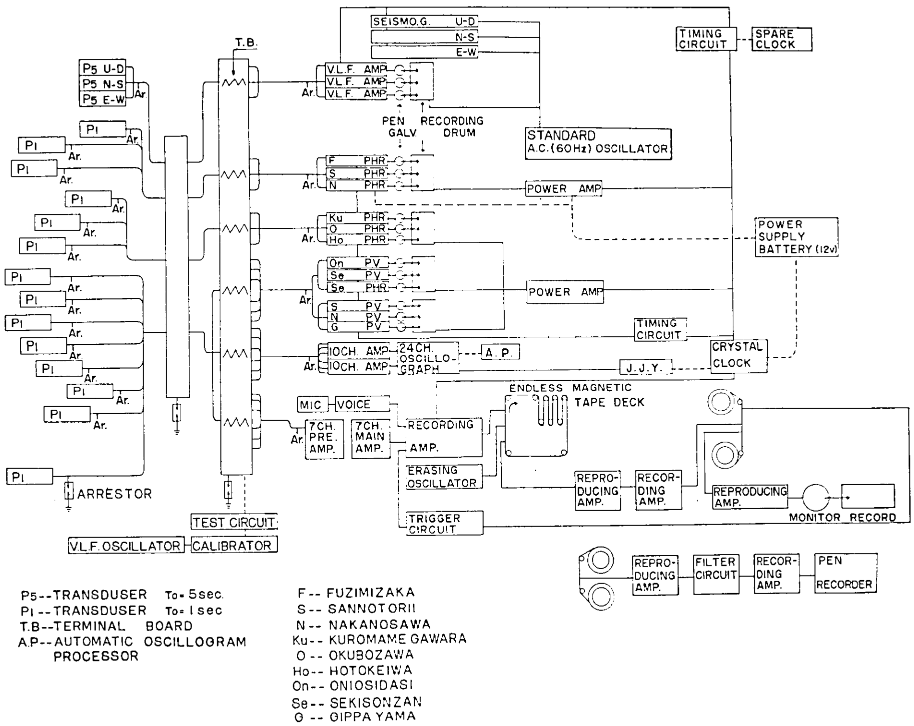


Fig. 3. The block diagram of the seismic observation at Asama Volcano Observatory.

The above tele-metering observation is outstandingly convenient on the volcano, because electric power is required at the recorder station only and even a dry-cell is unnecessary at any of the transducer stations. Therefore, the same apparatus for seismic observation was adopted not only for volcanoes in Japan, but also for Volcanoes Vesvius in Italy and Taal in the Philippines.

Table 4. The permanent seismometrical net.

Stn. No.	Place of transducer	Transducer	Recorder	Magnification
1	Huzimizaka	1.0 Hz Horizontal 1.0 Hz Vertical	Smoked paper Smoked paper Tape recorder Oscillograph	4000
2	Sannotorii	1.0 Hz Horizontal 1.0 Hz Vertical 1.0 Hz Vertical	Smoked paper Smoked paper Tape recorder Oscillograph	4000 4000
3	Nakanosawa	1.0 Hz Horizontal 1.0 Hz Vertical 0.2 Hz Horizontal 0.2 Hz Vertical	Smoked paper Oscillograph Smoked paper Oscillograph Smoked paper	4000 4000 500
4	Gippa-yama	1.0 Hz Horizontal 1.0 Hz Vertical	Smoked paper Oscillograph Smoked paper	4000 4000
5	Oniosidasi W.	1.0 Hz Horizontal 1.0 Hz Vertical	Smoked paper Oscillograph Smoked paper Oscillograph	4000 4000
6	Kuromamegawara U.	1.0 Hz Vertical	Tape recorder Oscillograph	
7	Sekison-san	1.0 Hz Horizontal 1.0 Hz Vertical	Smoked paper Tape recorder Oscillograph	4000
8	Hotokeiwa	1.0 Hz Horizontal 1.0 Hz Vertical	Smoked paper Oscillograph Tape recorder Oscillograph	4000
9	Okubosawa	1.0 Hz Horizontal	Smoked paper Tape recorder Oscillograph	4000
10	Kuromamegawara D.	1.0 Hz Horizontal	Smoked paper	4000
11	Tutuzigahara	1.0 Hz Vertical	Smoked paper Tape recorder Oscillograph	4000
12	Siraitonotaki I	1.0 Hz Vertical	Tape recorder Oscillograph	
30	Asama Observatory	Ishimoto's type Seism. 1.0 Hz Horizontal 2 1.0 Hz Vertical 1	Smoked paper	350

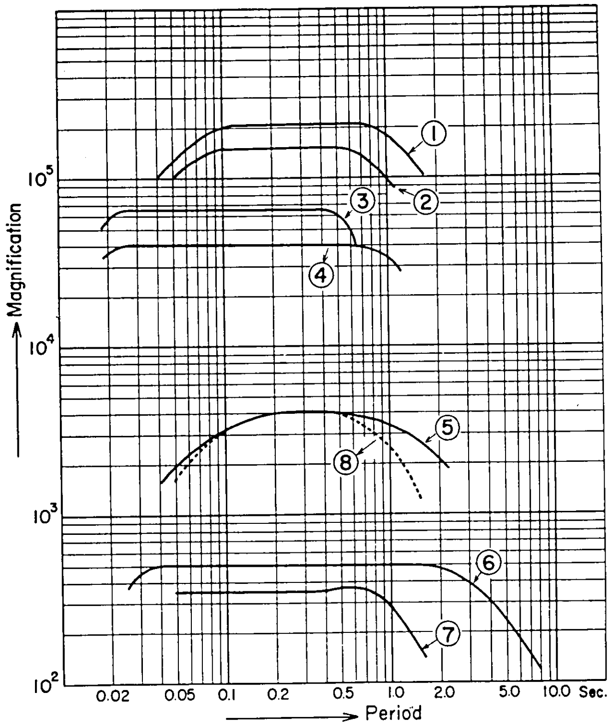


Fig. 4. The response curves of the seismographs at Asama Volcano Observatory.

(1): the electro-magnetic oscillographs of 12 and 24 elements for 1 Hz horizontal transducers,

(2): the electro-magnetic oscillographs of 12 and 24 elements for 1 Hz vertical transducers,

(3): the seven channelled tape-recorder for 1 Hz horizontal transducers,

(4): the seven channels tape-recorder for 1 Hz vertical transducers,

(5): the smoked paper recorders of continuous observation for 1 Hz horizontal and vertical transducers,

(6): the smoked paper recorders of continuous observation for 0.2 Hz horizontal and vertical transducers,

(7): Ishimoto's micro-seismographs,

(8): the seismographs of direct connection of 1 Hz transducers with galvanometer (used during 1955-1961).

However, on the occasion of lightnings, induced currents are produced in the circuit of transducer-transmission wire-amplifier-galvanometer which disturb the seismograms. The coils of transducer, galvanometer, and amplifiers were broken once or twice a year. Therefore, it may be said that this is the weakest point of the method in the region where thunderstorms often occur.

On the other hand, for preventing damage of the instruments by lightning, the writers have used arresters suitable for the purpose and made careful precaution by earthing.

Even though the telemetering observation with transmission wire suffers the above-mentioned defect from lightning, the said method for seismic observation is useful, especially at volcanoes for determining the locality of earthquakes and for obtaining precise observations of the arrival times of seismic waves.

3. The explosive eruptions of Asama during the period from 1934 to 1969

As described before, an explosive eruption is defined as follows:

An eruption means the phenomenon erupting solid materials from a crater to the earth's surface, such solid materials including lava stream, lava block, volcanic detritus, lapilli, gravel, ash and any other forms of solid material, usually together with gases.

In order to show an outline of the eruptive activity of Asama, it is represented in a form of the monthly frequency of eruption during the period from 1934 to 1969 in Table 5. It is necessary to remark here that the numbers of eruptions in Table 5 include not only these stronger than 10^{20} erg in kinetic energy, but also extremely small ones ejecting only a small amount of fine ash.

In the same Table, it will be noted that a number of eruptions in the periods from November 1940 to October 1942, and from September to November 1961 consist mainly of small eruptions.

Table 5. The monthly frequencies of the Asama explosive eruptions during the period from 1934 to 1969.

Year \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
1934	0	0	0	0	0	0	0	0	0	0	0	0	0
1935	0	1	0	8	34	6	4	23	12	3	1	2	94
1936	0	14	5	4	0	0	30	4	4	3	2	0	66
1937	0	3	13	6	1	8	0	0	0	0	0	0	31
1938	0	0	1	8	24	20	22	10	26	17	8	9	145
1939	1	17	7	11	6	6	13	5	3	2	0	0	71
1940	2	0	0	0	2	0	0	1	1	2	17	27	52
1941	95	109	21	12	18	5	11	12	13	19	21	55	391
1942	62	42	54	74	18	6	10	56	50	21	0	0	393
1943	0	0	0	0	0	0	0	0	0	0	0	0	0
1944	0	0	0	0	0	0	0	1	19	52	28	18	118
1945	22	42	19	14	3	3	6	2	0	2	3	0	116
1946	0	0	0	0	0	0	0	0	0	0	0	0	0
1947	0	0	0	0	0	0	1	1	0	0	0	0	2
1948	0	0	0	0	0	0	0	0	0	0	0	0	0

(to be continued)

Table 5. (continued)

Year \ Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
1949	0	0	20	1	0	1	4	56	41	5	0	0	128
1950	0	0	0	0	0	0	0	0	2	2	0	1	5
1951	0	1	0	1	1	0	1	0	0	0	0	0	4
1952	1	0	0	0	0	1	0	0	0	0	0	0	2
1953	0	0	0	0	0	0	0	0	0	0	0	13	13
1954	85	76	38	25	34	25	24	12	1	0	3	1	324
1955	1	2	2	24	10	45	1	0	0	0	0	0	85
1956	0	0	0	0	0	0	0	0	0	0	0	0	0
1957	0	0	0	0	0	0	0	0	0	0	0	0	0
1958	0	0	0	0	0	0	0	0	0	20	84	74	178
1959	0	0	1	3	8	5	18	9	0	0	0	0	44
1960	0	0	0	0	0	0	0	0	0	0	0	0	0
1961	0	0	0	0	0	0	0	8*	16*	8*	8*	0	40
1962	0	0	0	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0	0	0	0	0

* Excluding the frequencies of successive small eruptions.

The eruptions of the latter period took place every 30 seconds or 2 minutes as well as the Strombolian eruptions and their ejecta consisting of small bombs and ash which fell back into the crater floor and their small parts being scattered about the margin of the crater. Just before and during the September-November 1961 eruptions, fresh lava was extruded in an incandescent state through a narrow fissure on the crater floor and covered its surface. It seems that the lava extruded on the crater floor was not so viscous as is usual at Asama, judging from the behaviour of lava on the crater bottom.

It is reasonable to mention that the main and important factor for determining the types of eruption, Vulcanian, Strombolian or Hawaiian, is the value of viscosity of lava and not its chemical and petrological character.

4. Earthquakes originating from Volcano Asama

In the previous paper[6], one of the writers classified the earthquakes of volcanic origin according to the hypocentral position of respective volcanoes, the depth of hypocenter, the nature of seismic wave, es-

6) T. MINAKAMI, *loc. cit.*, 2).

pecially P and S phases, and the relation to eruption.

In the review of the results of seismic observations for quite a long period, all types of volcanic earthquakes were observed in Volcano Asama, the relationship between eruption and seismic frequency also being elucidated to some extent.

However, the most remarkable characteristic of Volcano Asama is that earthquakes originating from it consist mainly of the B-type located near the summit crater, very few of them being classified into the A type. Since the Asama eruption is usually explosive, the so-called Vulcanian type, an earthquake there corresponds to an explosive eruption. On the other hand, harmonic tremors of continuous train originate also from the volcano at its eruptive stage, though this is extremely rare.

It must be added here that F. Omori[7] classified the Asama earthquakes into two types, types A and B, but they do not agree with those defined by the present writers. Omori's A type quake corresponds to the writer's explosion earthquake or an earthquake followed by an explosive eruption, and his B type quake coincides with the writer's A and B types earthquakes.

As already described the Asama B type earthquakes have a close relationship with occurrences of explosive eruption, and on the basis of frequency of the B type earthquakes an empirical formula for predicting volcanic eruption of Mt. Asama was conducted in 1958.

During about thirty five years from 1934 to 1969, no remarkable seismic activity of the A type appeared, though a few A type quakes took place before and during the eruptive activities.

According to Omori's report[8] concerning the Asama earthquakes, however, strong earthquakes now and then took place in and near Volcano Asama causing slight damage to mountain roads and houses at the foot, as in the cases of the Yunotaira earthquake on July 16, 1912, and the strong Ozasa one on February 22, 1916. The former earthquake was followed by 48 felt quakes for 12 hours at Yunotaira, the latter one causing slight damage to dwelling houses at the village of Ozasa and its vicinity at the north base of Mt. Asama.

Besides the above-mentioned two earthquakes, the following strong earthquakes originating at Asama and its neighbourhood were reported by F. Omori[9]. Therefore, it will be remarked that a lot of the A type earthquakes including severe ones took place in the period of the 1908–1914 explosive activity of Asama, no strong Asama earthquake or no remarkable earthquake swarm of the A type occuring after 1934, notwithstanding the fact that a lot of strong explosive eruptions took place in

7) F. OMORI, *loc. cit.*, 1).

8), 9) F. OMORI, *loc. cit.*, 1).

the volcano in the periods 1935–1942, 1944–1945, 1954–1956 and 1958.

Other strong Asama earthquakes are as follows:

May 26, 1908, 9h 18m a.m.,	Asama origin,
July 16, 1912, 7h 45m a.m.,	〃 ,
Jan. 22, 1910, 3h 03m p.m.,	Near Asama,
Aug. 17, 1912, 11h 21m a.m.,	〃 ,
April 2, 1911, 10h 30m p.m.,	〃 .

However, it was in extremely rare cases in the period from 1934 to 1969 that the A type earthquakes observed with low sensitive seismographs took place before and during explosive activities.

As is shown in Fig. 36, the earthquake motions of the A type earthquakes from Asama consisting of rapid shocks, judging from their apparent features on the seismogram, do not differ from those of the tectonic origin of extremely shallow depth recorded near the epicenter.

5. Explosion earthquakes or earthquakes followed by explosive eruptions

It has been usual for the Asama eruptions in the past hundred years to be outstandingly explosive, a lot of volcanic bombs and ash being ejected from the summit crater with furious detonations. However, a single explosive eruption of Asama finishes generally within a few minutes and the ejection of lava blocks and bombs of large size usually coming to an end within 30 or 60 seconds from the commencement of outburst. Another strong eruption takes place usually after several days and at least several hours even in the active period of the volcano.

On the other hand, an earthquake is recorded on the seismogram corresponding to an explosive eruption of Asama and has the following characteristics in its earthquake motions, which are very different from the A type earthquake.

The maximum amplitude or the magnitude of the explosion earthquake has a close relation with the intensity of explosive eruption and is approximately proportional to the kinetic energy[10] of its ejecta. Therefore, the magnitude or the intensity of the Asama explosive eruption is given by the empirical formula based on the maximum amplitude of respective explosion quake, as reported before in the same Bulletin.[11]

As is shown in Figs. 37 and 38, the earthquake motions of explosion earthquake are predominant in longer vibration periods as compared with those of the A type and tectonic ones. On account of this, such earthquake-motions at the Asama Volcano Observatory, located 4.3 km east

10) T. MINAKAMI, *Bull. Earthq. Res. Inst.*, **20** (1942), 65–92.
11) T. MINAKAMI, *loc. cit.*, 2).

of the crater, have never been felt though its amplitudes of vibrations are fairly large. However, the detonation or air vibration of explosive eruption is outstandingly strong causing houses to vibrate violently. In some cases[12], a lot of glass-panes of houses and buildings situated nearer than ten—fifteen km, were seriously damaged, the detonations being heared at Nagoya and Osaka, 200 km and 350 km distant from Asama.

It is one of the most remarkable features that the initial motion of the explosion earthquake is usually clearly recorded on the seismograms, its direction indicating "push" and "upward" motion without exception in all directions from the crater. In other words, the explosion earthquake originates from a positive single source in the production of seismic wave. On the other hand, the S phase of the explosion earthquake is not clear, and the surface waves are extremely predominant on account of shallow origin.

On the seismograms of the explosion earthquakes, we often find special phase of rapid vibrations evidently caused by air shocks, as is shown in Figs. 37 and 38.

Since the Asama Volcano Observatory was established in August 1933, the volcano was remarkably active during the period from April 1935 to 1942 and minor explosive activities took place in 1958-59 and 1961 etc.

During the 1935-1950 activity of Asama, seismic observations at the Volcano Observatory were made with a low sensitive seismograph, of which the magnification was nearly 100 for earthquake-motions of 5.0 sec – 2.0 sec in their vibration periods, the period of the pendulum being nearly 5.0 sec. Besides the above seismograph, seismographs, of which the period of the pendulum and the magnification were 1.0 sec and 350 respectively, were set at the Observatory in 1937.

With these two kinds of seismographs, the Asama explosion earthquakes which occurred in the period from 1935 to 1950 were observed, though seismic observations of the volcano have been made with highly sensitive seismographs in the mechano-optical method since 1951, and by the telemetering one since 1954. However, since the B type earthquakes from the volcano are on quite a small scale, it is useful and necessary for precise observations of them to use the highly sensitive seismographs. But, the Asama explosion earthquakes include amplitudes of earthquake motions as large as 500 micron in the maximum amplitude at the Observatory and, therefore, it is necessary to operate not only the highly sensitive seismographs as large as 5000 in magnification but also the lower sensitive ones as small as 200 in magnification.

In Tables 6 (a), (b) and 7, are shown the amplitudes of the initial

12) S. SAKUMA, *Bull. Earthq. Res. Inst.*, **29** (1951), 605-615.

Table 6(a). The explosion earthquakes observed with the low magnification seismographs ($V=100$, $T_0=5.0$ sec) at Asama Volcano Observatory (1935 through 1939).

2A: Maximum amplitude,
T: Vibration period of the maximum amplitude.

Date and time				Component N 45° E–S 45° W Initial motion		2A	T	Component S 45° E–N 45° W Initial motion		2A	T
				Azimuth	Amp.			Azimuth	Amp.		
1935		h	m		μ	μ	sec		μ	μ	sec
Apr.	20	16	20	N 45° E	8.0	370	—	S 45° E	3.0	245	—
May	5	08	47	〃	2.0	135	0.42	〃	0.5	80	—
	11	02	58	〃	1.0	65	0.84	〃	1.0	75	—
	11	04	05	〃	3.0	130	—	〃	2.0	110	0.32
	11	14	37	—	—	16	—	—	—	14	—
	16	21	15	N 45° E	3.0	195	—	S 45° E	1.0	117	0.21
	20	04	02	〃	2.0	117	—	〃	1.0	90	—
	28	18	14	〃	5.0	150	1.02	〃	2.0	150	1.02
Jul.	2	11	42	—	—	24	—	—	—	34	—
Aug.	4	07	29	N 45° E	2.0	90	—	S 45° E	1.0	115	—
	17	16	50	—	—	65	—	—	—	49	—
	28	08	10	N 45° E	2.0	105	—	S 45° E	1.0	90	—
Sept.	19	15	59	〃	5.0	215	—	〃	4.0	128	—
Oct.	20	—	—	—	—	25	—	—	—	30	—
Nov.	7	12	08	N 45° E	1.5	100	0.63	S 45° E	0.5	109	0.63
1936											
Feb.	7	14	27	N 45° E	6.0	163	0.93	S 45° E	3.0	216	1.60
	10	10	—	〃	2.5	86	0.76	〃	0.8	63	0.61
	12	13	—	〃	1.0	46	1.16	〃	0.7	32	0.82
	12	14	—	—	—	34	0.98	—	—	42	0.88
	15	15	54	N 45° E	4.0	100	—	S 45° E	1.0	89	0.78
Mar.	5	16	09	〃	3.0	85	0.98	〃	1.0	85	0.78
	7	10	30	〃	6.0	165	0.87	〃	3.0	130	0.87
Apr.	20	01	20	N 45° E	2.0	120	—	S 45° E	1.0	120	—
	23	08	15	〃	1.0	65	1.12	N 45° W	1.0	72	0.98
Jul.	22	22	00	〃	3.0	81	—	S 45° E	2.0	74	—
	24	13	37	〃	2.0	225	—	N 45° W	1.0	145	—
	26	09	49	〃	9.0	410	—	S 45° E	5.0	390	—
	26	16	49	〃	3.0	225	—	〃	1.0	230	—
	27	01	45	〃	7.0	130	—	〃	3.0	125	—
	29	09	11	〃	21.0	300	1.82	〃	11.0	320	0.96
Aug.	4	04	23	—	—	65	0.61	—	—	75	0.93
Sept.	19	18	15	N 45° E	3.0	160	0.78	S 45° E	1.0	250	1.62
Oct.	1	10	29	—	—	74	1.32	—	—	56	0.88
	15	07	24	N 45° E	2.0	200	0.86	S 45° E	1.0	235	0.91
	17	09	34	〃	6.0	180	0.93	〃	2.0	120	0.93

(to be continued)

Table 6(a). (continued)

Date and time				Component N 45° E–S 45° W Initial motion		2A	T	Component S 45° E–N 45° W Initial motion		2A	T
				Azimuth	Amp.			Azimuth	Amp.		
1937 Mar.	1	22h	—m	N 45° E	2.5μ	374μ	1.38sec	S 45° E	1.0μ	215μ	0.91sec
	12	12	—	—	—	109	—	〃	0.5	109	—
	18	05	—	N 45° E	6.0	401	—	〃	2.5	258	—
	25	16	—	〃	4.5	200	—	〃	2.0	144	—
Apr.	6	—	—	—	—	106	1.23	—	—	85	0.79
	16	00	01	N 45° E	5.0	957	0.93	S 45° E	2.0	789	0.88
Jun.	7	—	—	S 45° W	0.5	152	1.84	〃	1.5	144	1.02
	28	—	—	N 45° E	6.5	132	—	〃	2.5	108	—
	30	—	—	〃	2.5	86	—	〃	1.0	68	—
1938 Mar.	25	10	15	N 45° E	—	370	—	S 45° E	4.0	245	—
Apr.	20	03	47	〃	5.0	655	1.80	〃	4.0	415	0.93
	23	02	21	〃	0.5	257	1.93	〃	1.0	176	1.11
May	1	10	07	—	—	160	—	—	—	165	—
	21	—	—	—	—	182	—	—	—	136	—
Jun.	7	06	24	—	—	474	—	—	—	646	—
	30	13	36	—	—	18	0.72	—	—	27	1.27
Jul.	3	11	28	—	—	62	—	—	—	54	—
	4	02	17	—	—	—	—	S 45° E	2.5	154	—
	16	13	01	N 45° E	3.0	132	—	〃	2.0	194	—
	18	17	47	〃	2.0	100	—	〃	2.0	102	—
	21	18	40	〃	3.5	57	—	〃	1.5	76	—
Aug.	19	07	17	—	—	65	—	—	—	73	—
Sept.	3	07	41	N 45° E	7.0	197	1.46	S 45° E	5.0	134	0.68
	3	12	11	〃	3.0	84	0.69	〃	2.0	125	1.67
	3	15	50	〃	1.0	67	—	〃	1.0	80	—
	3	17	—	〃	0.8	24	—	〃	0.5	24	—
	4	10	20	〃	5.0	127	1.20	〃	2.0	123	1.05
	10	12	44	—	—	55	—	—	—	50	—
	20	03	32	N 45° E	1.0	141	—	S 45° E	1.0	259	—
	20	07	25	—	—	298	—	—	—	160	—
	26	13	43	N 45° E	3.0	175	—	—	—	245	—
Oct.	4	20	21	〃	6.0	250	0.88	S 45° E	4.0	205	0.83
	6	00	26	〃	2.0	185	0.83	〃	2.0	200	1.27
	10	07	57	〃	3.0	120	0.83	〃	2.0	160	1.13
	19	23	36	—	—	74	—	—	—	—	—
	30	16	43	N 45° E	2.0	55	—	S 45° E	1.2	163	—
Nov.	5	21	43	—	—	56	—	—	—	40	—
	6	00	34	—	—	98	—	—	—	96	—
	15	17	14	N 45° E	3.0	228	—	S 45° E	4.0	203	—
	28	20	51	〃	3.0	175	—	〃	3.0	140	—
Dec.	1	02	54	N 45° E	1.5	58	1.53	S 45° E	1.5	52	1.20

(to be continued)

Table 6(a). (continued)

Date and time				Component N 45° E-S 45° W Initial motion		2A	T	Component S 45° E-N 45° W Initial motion		2A	T
				Azimuth	Amp.			Azimuth	Amp.		
1938 Dec.	4	22	48	N 45° E	0.5	91	—	S 45° E	0.5	67	—
	11	18	19	—	—	—	—	〃	2.0	165	—
	15	17	11	N 45° E	0.5	62	1.50	〃	1.5	69	1.37
	28	23	16	〃	0.5	170	—	〃	2.0	120	—
1939 Jan.	2	01	—	—	—	70	—	〃	0.5	100	—
Feb.	2	21	48	N 45° E	3.0	385	—	〃	3.0	325	—
	15	09	14	〃	4.0	429	—	〃	3.0	190	—
Jun.	25	00	47	〃	3.0	138	—	〃	2.0	156	—
Jul.	14	21	06	—	—	160	—	—	—	86	—
	30	18	50	—	—	102	—	—	—	79	—
Aug.	26	03	22	N 45° E	1.0	79	—	S 45° E	1.0	107	—

Table 6(b). The explosion earthquakes observed with the low magnification seismographs ($V=350$, $T_0=1.0$ sec.) at Asama Volcano Observatory (1950 through 1961).

T: Vibration period of the maximum amplitude.

S.O.*: Scale out.

Date and time				Component	Initial motion		max. amp.	T
					Azimuth	Amp.		
		h	m			μ	μ	sec
1950 Sept.	23	04	37	E-W	E	1.3	—	—
				N-S	N	0.1	—	—
				U-D	D	0.7	—	—
Oct.	4	15	14	E-W	E	0.7	109	0.55
				N-S	—	—	—	—
				U-D	U	0.3	29	0.43
1954 Sept.	6	18	00	E-W	E	0.3	—	—
				N-S	—	—	128	0.46
				U-D	—	—	79	—
1955 Jun.	11	19	45	E-W	E	1.7	—	—
				N-S	N	0.6	161	0.89
				U-D	—	—	73	—
1958 Nov.	10	22	50	E-W	E	2.9	S.O.	—
				N-S	—	—	S.O.	—
				U-D	U	1.1	S.O.	—

(to be continued)

Table 6(b). (continued)

Date and time	Component	Initial motion		Max. amp.	T
		Azimuth	Amp.		
1959 Dec. 4 07h 02m	E-W	E	0.3μ	48μ	sec —
	N-S	—	—	60	0.63
	U-D	—	—	47	—
Dec. 4 11 46	E-W	E	1.1	S.O.	—
	N-S	S	0.9	S.O.	—
	U-D	—	—	90	—
Dec. 5 13 08	E-W	E	1.1	'S.O.	—
	N-S	S	1.1	S.O.	—
	U-D	—	—	91	—
1959 Mar. 10 19 00	E-W	E	0.9	37	0.29
	N-S	S	0.3	41	0.48
	U-D	—	—	18	0.29
Apr. 14 20 29	E-W	E	2.3	46	—
	N-S	N	0.3	60	0.78
	U-D	U	0.6	21	0.47
Jun. 25 12 37	E-W	—	—	53	—
	N-S	—	—	69	0.48
	U-D	—	—	46	0.47
Jul. 16 15 31	E-W	E	0.6	22	0.59
	N-S	S	0.6	31	0.59
	U-D	—	—	13	—
Jul. 21 08 29	E-W	E	0.9	33	—
	N-S	S	0.9	35	0.49
	U-D	—	—	26	0.40
Aug. 9 01 14	E-W	E	0.3	38	0.67
	N-S	—	—	57	0.77
	U-D	—	—	14	0.48
1961 Aug. 8 14 41	E-W	E	5.4	100	0.87
	N-S	—	—	117	0.88
	U-D	U	2.6	79	—
Sept. 15 20 16	E-W	E	0.9	49	—
	N-S	N	1.1	59	0.48
	U-D	U	2.0	53	—
Oct. 3 21 15	E-W	—	—	27	—
	N-S	—	—	47	0.69
	U-D	—	—	30	0.49
Oct. 6 00 11	E-W	E	0.9	23	0.68
	N-S	S	0.6	35	0.77
	U-D	—	—	10	—
Oct. 7 17 05	E-W	—	—	65	—
	N-S	—	—	58	—
	U-D	—	—	38	—
Nov. 5 07 52	E-W	E	2.9	75	0.74
	N-S	N	0.9	82	0.67
	U-D	U	0.9	—	—
Nov. 7 21 52	E-W	—	—	73	0.65
	N-S	—	—	99	0.86
	U-D	U	0.9	32	—

motion, the maximum amplitude of explosion earthquakes and the time differences between the arrival times of the initial motions or the P wave, and that of the air vibration.

If an explosion earthquake took place below the crater floor and the air vibration started at the first movement of the crater floor, the time lag of occurrences of the above two phenomena and the travel times of the P wave and the air wave will be expressed by the following relations in reference of Fig. 5.

$$\delta t = T_z - T_p \ ,$$

$$t_p = (R-a)/V_p \ ,$$

$$R = \{\Delta^2 + (H_1 - h_1 - h_2 - H_2)^2\}^{1/2} \ ,$$

$$S = S_1 + S_2 \ ,$$

$$S_1 = (r^2 + h_1^2)^{1/2} \ ,$$

$$S_2 = \{(\Delta - r)^2 + (H_1 - H_2)^2\}^{1/2} \ ,$$

$$t_z = S/V(\theta) \ ,$$

$$V_z(\theta) = 331.5 + 0.61\theta \ \text{(m/sec)} \ ,$$

$$t_{p-z} = t_z - t_p + \delta t \ \text{ or } \ T_z - T_p = t_{p-z} + t_p - t_z \ ,$$

where T_p: occurrence time of the P wave at the hypocenter,
T_z: occurrence time of the air shock on the crater floor,
δt: time difference between the above two phenomena,
R: distance from the center of the sphere of the hypocentral domain,
Δ: epicentral distance or the horizontal distance from the center of the hypocentral domain,

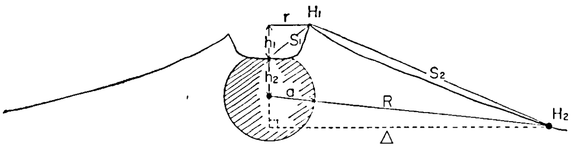


Fig. 5. A model of the origins of the explosion earthquake and the detonation or air shock.

S: distance along the earth's surface to Observatory,
S_1: distance from explosion spot on the crater floor to the margin of the crater,
S_2: distance from the crater margin to Observatory along the earth's surface,

h_1: depth of the crater,
h_2: hypocentral depth measured from the crater floor,
V_p: propagating velocity of P wave,
$V_z(\theta)$: propagating velocity of air wave at temperature θ°C,
t_p: travel time of P wave,
t_z: travel time of air wave,
θ: average air temperature at H_1 and H_2,
H_1: altitude at the crater margin,
H_2: altitude at Observatory,
a: radius of the spherical hypocentral domain,
r: horizontal distance from the crater margin to explosion spot.

Since the propagating velocity of air wave vitally depends on the air temperature from the summit to the Observatory, the travel times of the air wave were calculated by the mean air temperature of those at Observatory and the summit.

Although the propagating velocity of air wave depends also on the moisture of air and wind velocity at the time of its propagation, they are not so remarkable as the air temperature, their effects being negligibly small in the present case. Although the depth measurement of the crater was carried out just before some of the eruptions, we have no information about the exact depth at the time of eruption for the other most part of the above explosive eruptions. However, the topographical surveys of the summit crater including the crater depth were often made during the period from 1934 to 1940, and according to the result, it was in a range from 50 m to 180 m. Therefore, it will be reasonable to assume the crater depth through the period as 180 m, deepest value, for the present calculation, judging from the purpose of the present study about the occurrence times of the phenomena. On account of the above reason, the writers deal here with the problem by taking 180 m as the constant depth of the crater for calculating the travel time of air shock of respective eruptions. It is also important to make sure on which side of the crater floor the explosions took place. In the present calculation, it is assumed that all the explosions during 1935–1942 took place at the west side of the crater floor, in accordance with the present purpose. On account of these two reasonable assumptions, it will be said that the above delayed time (δt) or the delays of the commencement of eruption on the crater-floor as compared with that of explosion quake at the hypocenter, shows the minimum values in the following three cases.

On the other hand, it will be quite reasonable to suppose that the hypocenter of explosion earthquake is located just below the crater floor, based on the arrival times of the initial wave (P), the geographical

Table 7. The difference (t_{p-z}) between the arrival times of the P wave and the air shock, travel time of the air shock ($t_{z,c}$) and mean air temperature (θ) at the summit and the Observatory at the time of explosive eruptions.

No.	θ (Observed)	t_{p-z} (Observed)	$t_{z,c}$ (case 2) (Calculated)	$t_{p-z}-t_{z,c}+t_{p,c}=\delta t$
1	−12.0°C	13.56 sec	13.13 sec	−0.43 sec
2	−10.0	13.21	13.04	0.17
3	− 8.0	13.36	12.99	0.37
4	− 8.0	13.45	12.99	0.46
5	− 6.5	13.16	12.95	0.21
6	− 6.0	13.09	12.93	0.16
7	− 5.8	14.04	12.95	1.09
8	− 5.0	13.15	12.91	0.16
9	− 4.0	14.25	12.88	1.37
10	− 3.0	12.85	12.86	−0.01
11	0	13.09	12.78	0.31
12	1.0	12.61	12.75	−0.17
13	2.0	13.44	12.73	0.71
14	4.0	13.43	12.69	0.74
15	4.0	13.03	12.69	0.34
16	4.0	12.82	12.69	0.13
17	5.0	13.46	12.65	0.81
18	5.0	12.54	12.65	−0.11
19	6.0	12.82	12.63	0.19
20	6.5	12.93	12.61	0.32
21	7.0	13.91	12.60	1.31
22	7.0	13.10	12.60	0.59
23	7.0	12.90	12.60	0.30
24	7.0	12.66	12.60	0.06
25	8.0	12.95	12.58	0.37
26	8.0	12.77	12.58	0.19
27	8.0	12.71	12.58	0.13
28	9.0	13.33	12.56	0.77
29	9.0	12.90	12.56	0.34
30	9.0	12.75	12.56	0.19
31	10.0	13.16	12.52	0.64
32	10.5	13.01	12.52	0.49
33	11.0	13.00	12.52	0.48
34	12.0	13.05	12.48	0.57
35	12.5	13.18	12.47	0.71
36	14.5	13.44	12.42	1.04
37	15.0	12.90	12.40	0.50
38	15.0	12.80	12.40	0.40
39	16.0	13.16	12.38	0.78
40	17.0	12.02	12.36	−0.34
41	17.7	12.53	12.33	0.20
42	18.0	12.70	12.32	0.38
43	18.0	12.51	12.32	0.19
44	19.0	12.41	12.30	0.11
45	20.0	12.58	12.28	0.30
46	22.0	12.88	12.24	0.64
47	22.2	12.41	12.24	0.17
48	24.0	12.50	12.19	0.31
49	25.0	12.60	12.16	0.44

distribution of their amplitudes on and around the volcano and the nature of the phenomenon.

It is also natural to assume that the source of explosion quake has its volume for simplicity as a sphere and that the initial wave of an explosion quake propagates from a spherical surface.

The time difference (δt) between the occurrence time (T_p) of an explosion earthquake in which the initial wave starts to propagate from the spherical surface of the source and the commencement time (T_z) of outburst on the crater floor, is expressed in the formulae, in which t_{p-z}, V_2, V_p, Δ, r, h_1, H_1, h_2, H_2 and θ are given by seismometrical observation and by other measurements. The hypocentral depth (h_2) or the depth of the center of the hypocentral domain will not be very different from the value of the radius (a) of the hypocentral sphere, and their values will be in all probability in a range of 0.1 km–0.5 km. On the other hand, the propagating velocity of the P wave which passes from the hypocenter to the Observatory, will likely be in a range from 2.5 km/sec to 3.5 km/sec. Therefore, the travel time of the P wave or $(R-a)/V_p$ in the formula is in a range from 1.1 sec to 1.6 sec, for the case 1.

On the basis of the following results of the observations and measurements necessary for the present purpose, the travel times of the P wave of explosion earthquake and the air wave originated from the crater floor are calculated for the following three cases.

$$H_1=2560\text{ m},$$

$$H_2=1406\text{ m},$$

$$h_1=180\text{ m},$$

$$r=220\text{ m},$$

$$\Delta=4.45\text{ km},$$

$$V_p=3.0\text{ km/sec},$$

$$a=500\text{ m},\quad h_2=500\text{ m},\quad \text{(case 1)},$$

$$a=300\text{ m},\quad h_2=300\text{ m},\quad \text{(case 2)},$$

$$a=0\text{ m},\quad h_2=0\text{ m},\quad \text{(case 3)}.$$

In order to show the travel times, especially, the time difference of occurrence of the two phenomena are represented in Fig. 6 and Table 7 in relation with the average air temperature on the occasion of respective explosive eruptions. In the same figure, the lines (1–3) indicate the calculated differences of the travel times of the two phenomena for the above three cases, in order to make clear the difference of occurrence

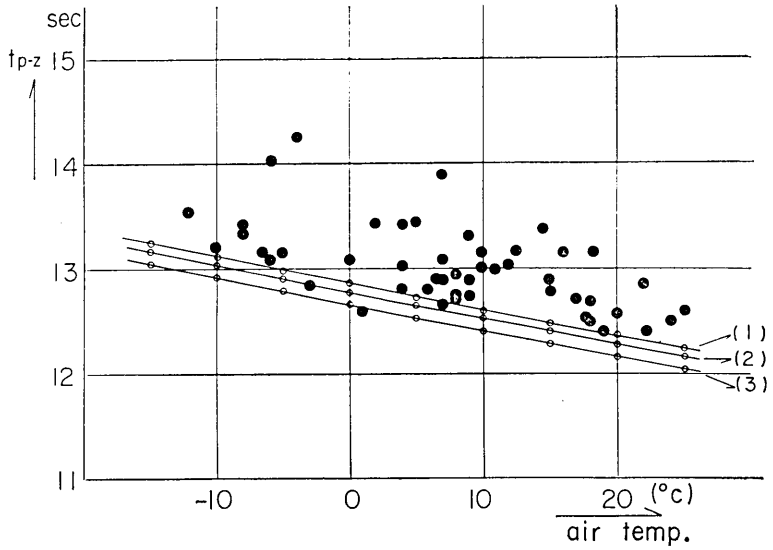


Fig. 6. Time differences in the arrival times of the P wave and the air shocks of a series of explosion earthquakes of Asama, (1), (2) and (3) indicating the calculated values based on the three cases of assumption.

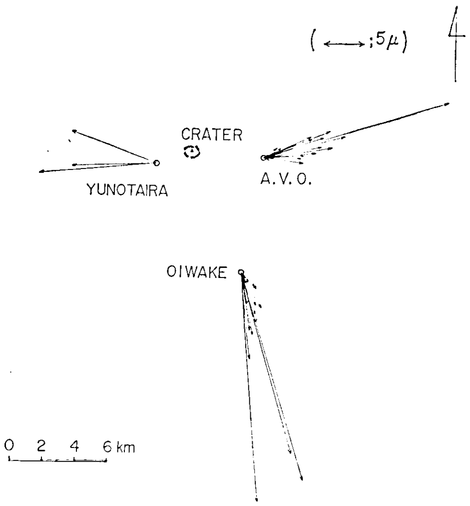


Fig. 7. The geographical distribution of the initial motion of explosion earthquakes in different periods.
(Observations at Yunotaira and Oiwake were made by F. Omori and Karuizawa Weather Station respectively).

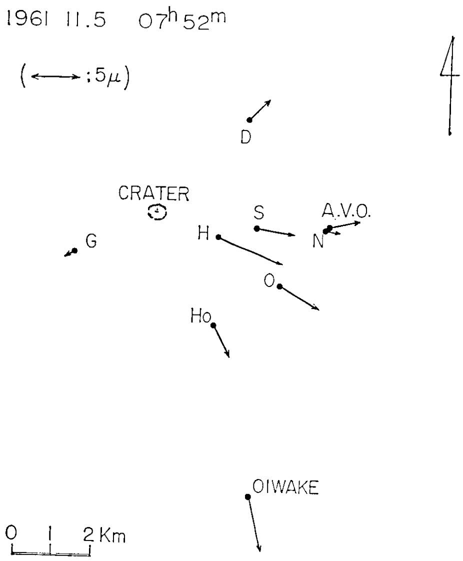


Fig. 8. The geographical distribution of the initial motion of the explosion earthquake at 07h 52m on November 5, 1961, amplitude indicating horizontal component except at G.
(Observation at Oiwake was made by Karuizawa Weather Station).

times of the two phenomena.

As described above, the dalayed time (δt) of outburst on the crater floor, in other words, the time difference between the commencement of the initial movement of ejecta on the crater bottom and that of the seismic wave at the above-mentioned source was obtained mostly in a range between 0.4 sec and 0.6 sec.

On the other hand, the problem regarding the geographical distribution of the initial motion of explosion earthquake is an interesting and important factor not only for studying the mechanism of explosion earthquake, but also for making clear that of the volcanic eruption. According to the results of seismic observations at Volcano Asama made by F. Omori[13] at Yunotaira, SW, 2.5 km of the summit crater, by the writers in the seismometrical net of Asama Volcano Observatory and by the Oiwake Weather Station (now Karuizawa Weather Station), the initial motions of explosion quakes showed always "push" or "upward" at any place on and around the summit crater of Asama, and no "pull" or "downward" motion being observed.

It will be clear that the above geographical distribution of the initial motion shows nothing but that the explosion earthquake originates from a single positive source which suggests an increase of vapour pressure just below the crater floor.

Judging from the two observed phenomena mentioned above, the delayed time (0.4 sec − 0.6 sec) and the mechanism of a positive single source, it will be natural to make the following interpretation about the explosive eruption of Volcano Asama: the vapour pressure of lava in the vent near the crater floor increases rapidly and as a result the initial seismic wave propagates as "push" wave from the positive single source and, at the same time, the rapid increase of vapour pressure will cause destruction of highly viscous or almost solidified lava below the crater bottom and a lot of destroyed lava blocks including bombs of large sizes and fine ejecta, will have quite a high velocity of flight of 150 m/sec − 200 m/sec in strong eruptions. However, it will take time to erupt these ejecta with a initial velocity from the crater bottom after the rapid increase of vapour pressure. On the other hand, the air shocks including low frequency pressure waves will propagate simultaneously with the start of ejecta from the crater floor.

It must be added here that the initial air wave or air shock has always indicated a marked increase of air pressure according to the records on the aneroid barometers set on and around the crater.

Although the present seismometrical net work shown in Fig. 1 was almost completed in 1963, Asama has been very calm during the last

13) F. OMORI, *loc. cit.*, 1).

nine years and no eruption occurring after the 1961 Aug.~Nov. eruptions. Therefore, an explosion earthquake including air shock has not yet completely been caught by the present net work. However, the explosive activity of Asama is expected to occur before long, judging from the historical activity of the volcano, and a lot of more precise data concerning explosion earthquakes will be obtained for a study of the dynamical mechanism of Asama explosive eruption.

It must be necessary to add here that the explosion earthquake-motions consist mainly of those of vibration periods longer than those of the A and B earthquakes originating from the volcano, and especially the initial motions of explosion earthquake is generally longer than 0.5~1.0 sec in its vibration-period, even though it was observed near the crater as like 2.0 km-4.0 km in its epicentral distance.

With respect to the nature of explosion earthquake-motions, the writers will deal later again with a comparison with those of the A and B earthquakes.

6. The B type earthquakes of Volcano Asama

Since the Asama Volcano Observatory was established in August 1933, the strong explosive eruption on April 20, 1935 was the first experience of eruption for the Observatory, when the seismograph of two horizontal components whose vibration period and magnification were adjusted to 5.0 sec and 100 times on the smoked paper was operated. After examining the seismograms recorded with the above instrument, the writers found a series of tremors on the seismograms, of which the amplitudes were extremely small, their forms being very different from the usual quakes. At that time we classified such tremors as volcanic tremors. Moreover, it was found that frequency of the volcanic tremors had increased remarkably since December 1934, four months before the first eruption of the 1935-1942 major volcanic activity of Asama. Since it was clear that the mode of appearance of volcanic tremor had a close relation with the occurrences of explosive eruptions of Volcano Asama, the writers have continued to investigate their locality and the natures of their earthquake-motions etc. It is needless to mention that such volcanic tremors were later called as the B type earthquakes of volcanic origin.

In order to make clear the origin of the above tremors or the B quakes, the writers set seismographs at various parts of Asama, including Yunotaira, Sannotorii, Oniosidasi E., Naka-Karuizawa, Onuma-mura and Komoro etc, located at distances of 2.0 km, 2.6 km, 4.4 km, 8.5 km, 7.0 km and 12.0 km respectively from the summit crater, as is shown in Fig. 9.

Secondary, they tried to adjust such seismographs to a higher

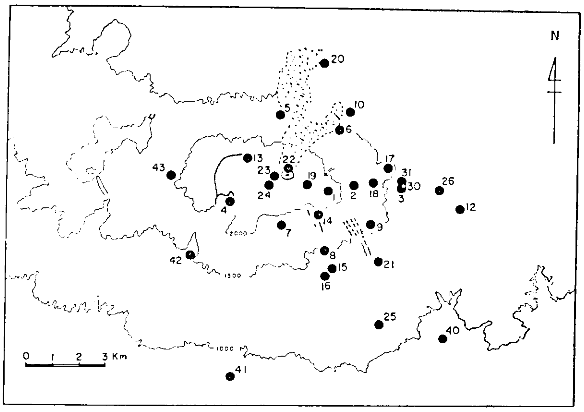


Fig. 9. Localities of the permanent and temporary seismic stations where the seismic observations were made with the highly sensitive seismographs in the period from 1941 to 1969. Numerals indicate station No. in Table 3.

magnification and sensitivity by applying the mechano-optical method without electronic amplification.

In 1954, the writers applied the tele-metering system for seismometrical observation and in 1963 completed the present seismometrical net of the volcano, as already described.

1) *Hypocentral locality of the B type quakes at Asama*

Through permanent seismometrical observations and temporary seismometric surveys during the last 35 years, the following knowledge concerning the origin and the nature of the B type earthquakes of Asama was made clear.

The hypocentral localities of the B type quakes concentrate near the summit crater according to their amplitude distribution and seismic frequency one on the volcano observed with the same kind of seismograph. More precisely speaking, it can be said that the hypocentral positions of this kind concentrated mostly nearer than 1 km from the center of the crater in their epicenters and less than 0.5 km and 1.0 km even at the deepest of their hypocenters. Since the hypocenters are extremely shallow and concentrate in and near the summit crater as mentioned above, it is natural that the amplitudes of quakes attenuate remarkably according to the epicentral distance or the distance from the crater, as will be seen in the series of seismograms recorded at distances on the volcano (Fig. 41 and Fig. 44).

For the reason that the hypocentral depths of the Asama B quakes are extremely shallow and the surface part of the volcano consists of various kinds of ejecta including a series of pumice layers, lava flows and pyroclastic layers, the attenuation and decay of seismic waves which propagate through these loose and complex ejecta, are most remarkable, especially, on the eastern side of the volcano. It is another feature of the B quakes that their magnitude or their maximum amplitude did not exceed 30 micron at the distance of 2.6 km and 10 micron at the distance of 4.1 km, from the center of the crater. As the above problem is discussed later in the detail, we need only state that the B type earthquakes originating not only from Asama, but also from other volcanoes are of markedly small scale in amplitude as compared with those of the A type quake and the explosion quake.

On the other hand, the B quakes originating from the active center such as the active craters of Volcano Asama, Volcano Sakura-zima and Volcano Kilauea such active volcanoes being covered with pumices, scoria and other loose ejecta which were erupted in recent years. On account of the loose ejecta, the noise level on these volcanoes is generally very high and prevents us from applying sensitive seismographs higher than 4000 or 5000 times in displacement magnification for continuous observation at the earth-surface. Therefore, we have no precise knowledge about the distribution of the initial motion of the B type earthquakes, in other words, the initial motions of the B quakes are in most cases disturbed by ground noise.

2) *Frequencies of the Asama B type quakes observed with seismographs of low magnification.*

In order to sketch an outline of the relationship between the frequency of the B quakes and the explosive activity, the problem is dealt with from the annual seismic frequency and the annual sum of the kinetic energy of explosive eruption. For the purpose, the writers adopt here the seismic frequency for the period from 1934 to 1950, observed with seismographs of low magnification installed at the Observatory. Strictly speaking, for the above seismometrical observation, the following two kinds of seismographs were used depending on the period of observations;

Period	Magnification	Vibration period of pendulum	Components
1934-1948	100	5.0 sec	Horizontal 2
1938-1970	350	1.0 sec	Horizontal 2 Vertical 1

From the comparison of observation made by the above two seismographs, it was made clear that the seismic frequencies made by both seismographs were not so different from each other, as far as the B

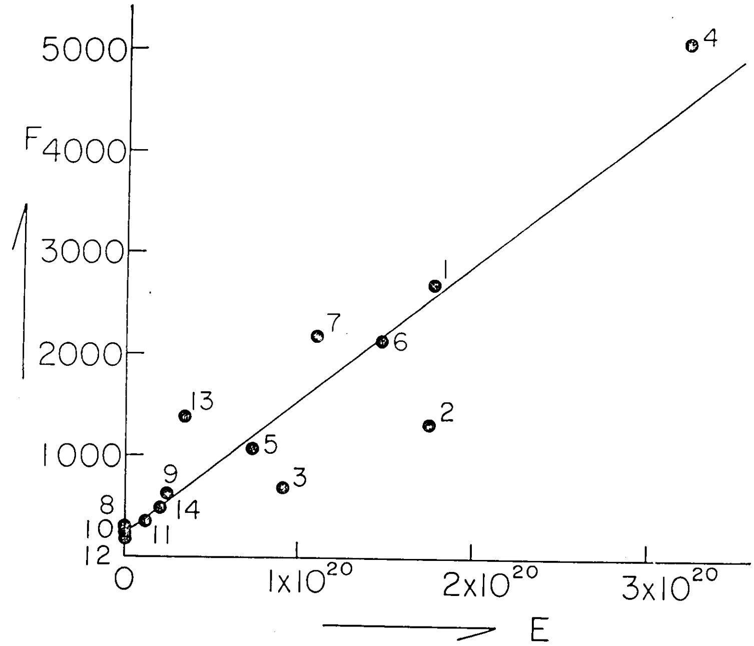


Fig. 10. The annual sum of the kinetic energy of explosive eruptions and the annual seismic frequency observed at Asama Volcano Observatory with the low sensitive seismographs.

1; 1935,	2; 1936,	3; 1937,	4; 1938,
5; 1939,	6; 1941,	7; 1942,	8; 1943,
9; 1944,	10; 1946,	11; 1947,	12; 1948,
13; 1949,	14; 1950.		

type quakes are concerned.

As will be seen in Fig. 10, that the annual seismic frequencies during 1934–1950 are closely related with the annual sum of the kinetic energy of explosive eruptions for the same period. It may be said that annual seismic frequencies are to some extent proportional to the annual energy of eruptive activity, the annual seismic frequency observed with the above-mentioned seismograph at the place during the inactive period being in a range from 200 to 300. The above relation is approximately expressed by the following empirical formula;

$$F = 223 + 1318E\ ,$$

where F: annual seismic frequency,

E: annual energy of eruption (10^{20} erg).

It will be interesting to investigate or to compare the above relation with that given by the recent observation with the higher sensitive seismographs. The annual frequencies of the B quakes at Nakanosawa are indicated in Table 8.

Table 8. Annual frequencies of the Asama B quakes at Huzimizaka, Sannotorii and Nakanosawa.

	Huzimizaka	Sannotorii	Nakanosawa
1959	—	5003	2268
1960	—	4216	2153
1961	17846	16446	5597
1962	16207	13807	3831
1963	8242	7709	2960
1964	8376	7241	1930
1965	10856	9518	3113
1966	9855	9204	4108
1967	17808	16659	7009
1968	15970	14373	5180

On the other hand, it has been certified by a number of researchers that the relationship between the magnitude and the seismic frequency, or the Ishimoto-Iida's empirical formula, is also applicable to the B type quakes. According to the result of the investigations, the average value, 2.3, of the coefficient (m) for the B quakes at Stn. Nakanosawa is adopted for the present calculation. It is necessary to add here that the attenuation of the maximum amplitudes of the B quakes depends on their magnitude, because the smaller the maximum amplitude is, the shorter the vibration-period is at least statistically. Therefore, the coefficient (m) at Nakanosawa shows a bigger value for the comparatively large B quakes than 3.0 and for small ones less than 2.0. The above value 2.3 for the present case is the average value including all the B quakes observed at Nakanosawa.

On the basis of the empirical formula concerning the kinetic energy and seismic frequency given by the low sensitive one, and the Ishimoto-Iida's empirical formula, it will be possible to conduct a formula which represents the relation between the annual seismic frequency and volcanic eruption suitable for the higher sensitive seismograph mentioned above.

The recorders of the above both low and higher seismographs were used in the smoked paper with 1.0 mm/sec, the response curves being almost of similar character, though their magnifications were 350 and 4000 respectively for the earthquake-motions, of which the vibrations-periods were in a range from 0.3 sec to 1.0 sec. The relation of the total seismic frequencies expected from the observations with the above two seismographs are given approximately by the following expression;

$$N_1 = c\int_{\infty}^{a} A^{-m} dA \ , \quad \text{for the lower magnification seismograph}$$

$$N_2 = c\int_{\infty}^{b} A^{-m} dA \ , \quad \text{for the higher magnification seismograph}$$

$$\frac{b}{a} = \frac{350}{4000} \ , \quad \frac{N_2}{N_1} \doteqdot 22 \ ,$$

where N_1: frequency of B quakes obtained by the lower magnification seismograph,
N_2: expected frequency of B quakes expected by the higher magnification seismograph,
a: lower limit of the maximum amplitudes measured by the lower magnification seismographs,
b: lower limit of the maximum amplitudes measured by the higher magnification seismographs,
$m = 2.3$
c: constant

As described above, the ratio (N_2/N_1) of the two seismic frequencies of the B quakes is expected to be nearly 22. Therefore, the empirical formula concerning the seismic frequency will be applicable to the higher sensitive seismograph at Nakanosawa station located near the Observatory as follows:

$$N_2 = 4906 + 28996E \ ,$$

where N_2: expected annual seismic frequency,
E: annual kinetic energy of explosive eruption (10^{20} erg).

However, the total kinetic energy of the August-November, 1961 eruptions was estimated at nearly 10^{19} erg and therefore the annual seismic frequency of the same year is expected to be 7800 from the above empirical formula. The result of the seismic observation, however, shows 5597 as the 1961 annual frequency at Nakanosawa as is seen in Table 8.

With respect to the above slight discrepancy of the two values, several reasons can be given. First of all, it must be considered that Volcano Asama had been quite active during the period from 1935 to 1950, in which the seismometrical observation was based on the relation between the seismic frequency and volcanic activity. Of the above period, the volcano did not erupt in 1934, 1943, 1946 and 1948, and, therefore, we assumed the annual seismic frequencies of these four years as the seismic level of the B quakes in the calm or inactive state of Asama.

As has been made clear, earthquakes originating from volcanoes nicreased before, during and just after their eruptive activities not only in Asama but also in a number of other volcanoes. Although no eruption took place at all in the above four years, we recorded a number of the B quakes before and after such years. Therefore, it may be required to determine more precisely whether the Asama's seismicity in the above four years was normal as the value of the calm period or not.

On the other hand, Volcano Asama during the period from 1962 to 1969 has not erupted after the minor eruptive activity from August to November, 1961. It is quite a long time of quiescence of the volcano in the history of the Asama eruptions. As is seen in Table 8, the annual seismic frequencies since 1959, which were observed with the higher sensitive instruments, undulate with a fairly large range between 1930 quakes in 1964 and 7009 ones in 1967, notwithstanding the fact that no eruption took place during the period. Therefore, the mean annual seismic frequency, 223, in the inactive period, which was given by the observation of the low sensitive seismographs, corresponds to 5000 for the high sensitive one, as described above. However, it will be worthy of note that the average annual seismic frequency observed with the high sensitive instruments was 4018 at Nakanosawa in the inactive period during 1962–1968, and harmonizes fairely well with the expected value, 4906.

As a result of the comparison of the seismic observations made with the low and highly sensitive seismographs, the frequency observed at Nakanosawa with the highly sensitive one was 20–30% less than that expected from the empirical formula concerning the seismic frequency and the kinetic energy of eruption, which was given with the seismic observation with the low sensitive seismographs at the Observatory. Although the Station Nakanosawa is located near the Observatory, the geological formations of the above two places on which the seismographs were set, are very different. The Observatory is built on thick layers of pumices and fine ashes. On the contrary, Stn. Nakanosawa is built on hard rock formation consisting of dacite massive lava. As will be described precisely later, the seismic frequency is closely related with the ground formations on which the observations are made.

Thus, the seismic observation made with the low magnification seismograph since 1934 was connected continuously through the Ishimoto-Iida's empirical formula with that which has been made with the above-mentioned highly sensitive one.

7. The monthly and daily frequencies of the B earthquakes

In order to obtain an outline of the development of the Asama B quakes, the writers represent it in a form of monthly and daily frequencies observed with the highly sensitive seismographs in the period from 1957 to 1968. At a glance of the diagram in Fig. 11, the frequency of B quakes at these stations is closely related with their distances from the summit crater, that is, the nearer the station is to the crater, the more the B quakes are observed with the seismographs of the same sensitivity. It is also shown that the hypocenters of these earthquakes concentrate near the summit crater, though the problem con-

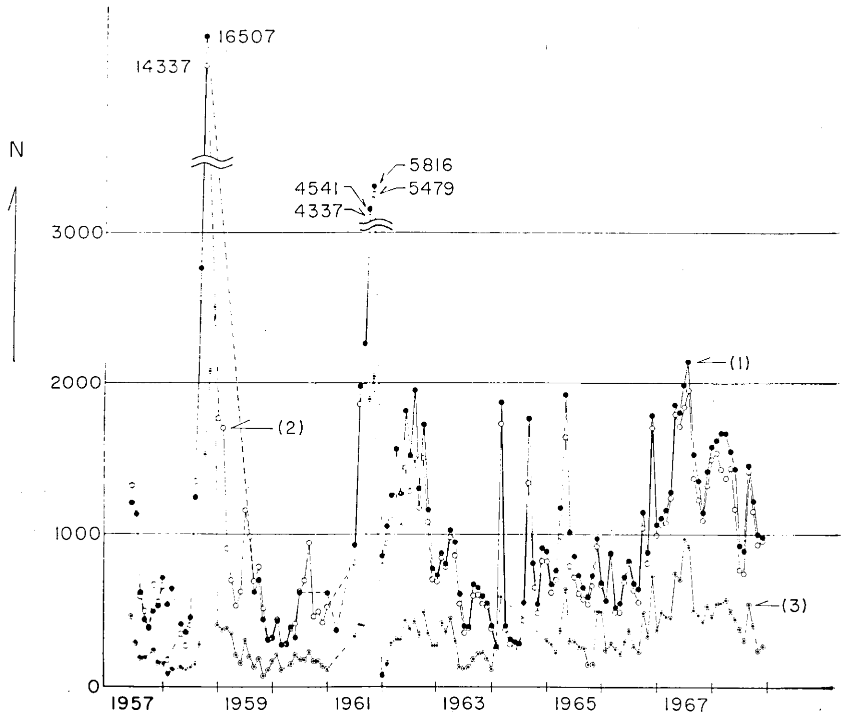


Fig. 11. The monthly seismic frequencies of the B earthquakes at Stns. Huzimizaka (solid circle), Sannotorii (open circle) and Nakanosawa (double circle), during 1957-1968.

cerning the hypocentral position will be studied more precisely later.

In the same figure, it is also evident that the B quakes occurred markedly just before, during and just after the explosive eruptions, as compared with those in the calm period of the volcano. The relationship between the seismic and eruptive activities is, however, more evident in their daily frequencies, because the B quakes in some cases predominated rapidly one or two days before an explosive eruption.

Reviewing the activities of Asama over the last 40 years, it is noted that the volcano during the last 8 years or, precisely speaking, from 1962 to 1969 has been in the quiescent state of longest period. Therefore,

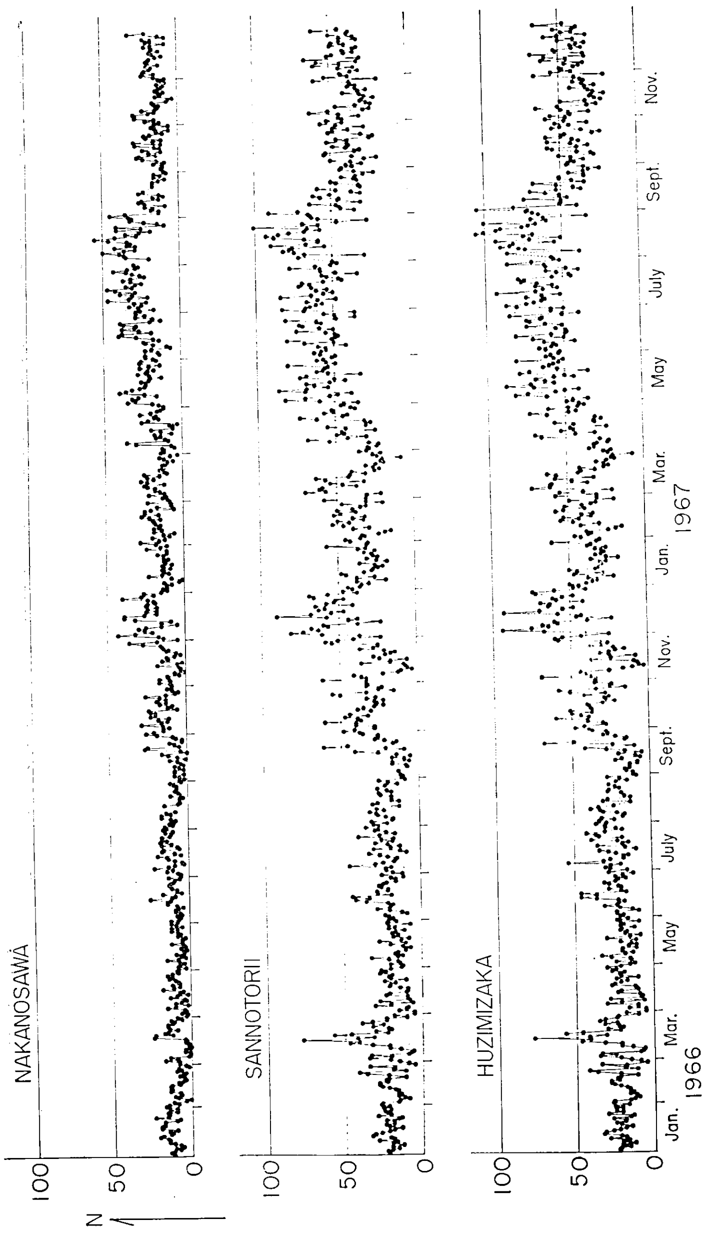


Fig. 12(a). Daily seismic frequencies at Stns. Huzimizaka, Sannotorii and Nakanosawa during the period from January 1, 1966, to December 31, 1967.

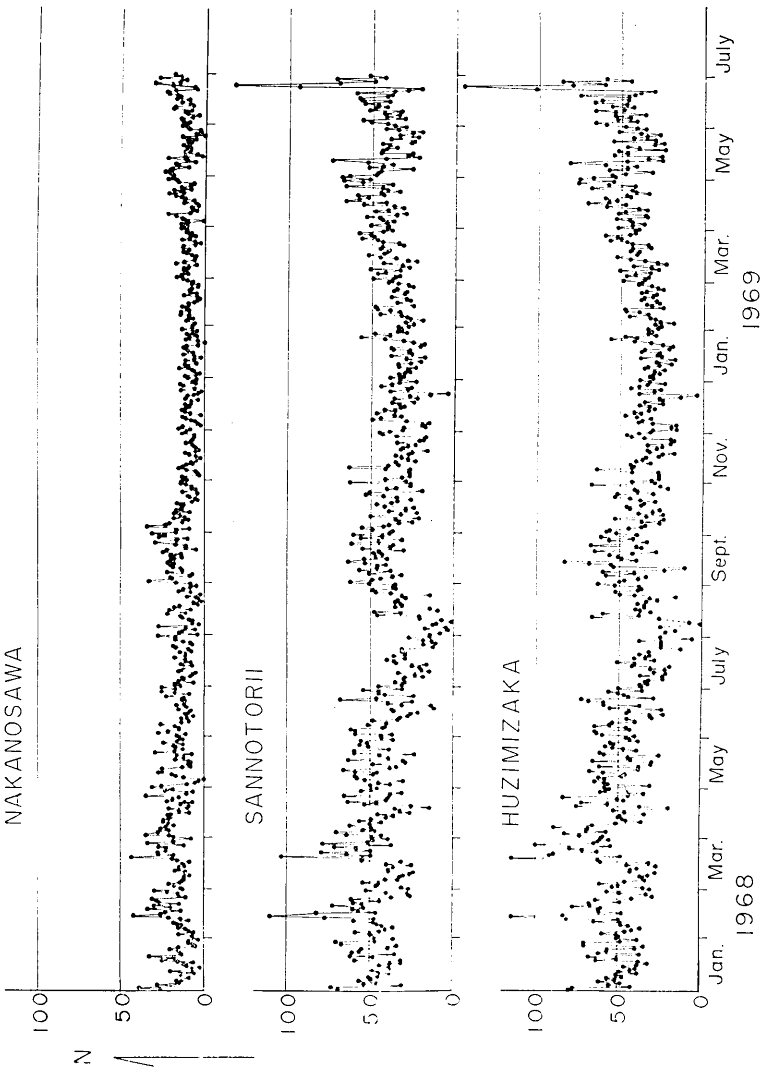


Fig. 12(b). Daily seismic frequencies at Stns. Huzimizaka, Sannotorii and Nakanosawa during the period from January 1, 1968, to July 31, 1969.

an opportunity has been available to study the seismic level in the volcanic quiescent state, which is important for making clear the seismic activity at the pre-eruptive and eruptive stages of the volcano.

For the purpose, the monthly seismic frequencies at the three stations, Huzimizaka, Sannotorii and Observatory (Nakanosawa) are illustrated in Fig. 11, for the period from 1959 to 1968, in which no eruption took place in the years from 1962 to 1969 and a minor volcanic activity in 1958, 1959 and 1961 as is seen in Table 5.

As is shown clearly in Fig. 11, the monthly seismic frequencies at the three places are in the ranges from 275 to 2143, from 175 to 1953 and from 74 to 914 respectively at the calm period of the volcano. Accordingly, it may be said that the frequency of the B quake undulates a great deal even at the non-eruptive period of the volcano. However, it is also absolutely evident that the monthly frequency in the eruptive period as in August-November, 1961, shows outstandingly a great number as compared with that at the non-eruptive one.

In order to clarify the problem further, the seismic daily frequency at the above three stations in the period from 1966 to July 1969 is illustrated in Fig. 12 (a) and (b).

Although the frequencies at the above three places decrease according to the distance from the summit crater, that at Nakanosawa shows a markedly small value as compared with that expected from those at the other two places. It means that the frequency of the B quakes depends not only on the distance from the summit crater in which their hypocenters concentrate, but also on the nature of geological formations on which the transducers are placed. More precisely speaking, the transducers at Huzimizaka and Sannotorii are set on a thick layer of pumice and those at Nakanosawa are set on a rock bed in a cave dug in the Hotokeiwa lava formation, an older formation of Asama. It is necessary to add that the same phenomenon is found also at other stations of Asama, for example, the transducers at Gippa-yama are set in a cave on the rocky formation of Gipp-yama, an older formation of Asama.

8. The monthly frequency of the Asama B earthquakes at the nine permanent stations on the volcano

As already mentioned, a continuous seismic observation has been made with the tele-metering net-work consisting of nine permanent stations. The above seismographs are all adjusted to the same magnification and the same response to earthquake-motions, more precisely speaking, 4000 times in the displacement amplitudes for the earthquake-motions of which the vibration periods are in a range from 0.3 sec to

Table 9(a). The monthly frequencies of the B quakes at each station in 1965.

Month	F_{Hu}	F_{Sa}	F_{Na}	F_{Ho}	F_{Ku}	F_{Ok}	F_{Se}	F_{Gi}	F_{On}
Jan.	887	819	298	313	384	388	823	569	647
Feb.	669	615	278	256	—	344	615	529	—
Mar.	761	702	223	241	—	330	671	539	—
Apr.	1169	984	365	320	—	491	1067	765	—
May	1921	1640	633	625	753	818	1701	1273	—
June	1012	789	298	446	511	539	821	553	547
July	856	716	296	336	420	370	758	524	556
Aug.	727	610	266	238	318	313	641	546	524
Sept.	651	575	253	213	359	327	603	513	521
Oct.	593	540	147	261	415	392	566	513	475
Nov.	724	659	150	347	451	397	673	621	554
Dec.	969	920	492	508	601	520	897	819	807

Station F_{Hu}: Huzimizaka F_{Sa}: Sannotorii F_{Na}: Nakanosawa
F_{Ho}: Hotokeiwa F_{Ku}: Kuromamegawara F_{Ok}: Okubozawa
F_{Se}: Sekison-san F_{Gi}: Gippa-yama F_{On}: Oniosidasi W.

Table 9(b). Ratios of the monthly frequency at each station to that at Stn. Huzimizaka (from Table 9(a)).

	$\frac{F_{Hu}}{F_{Hu}}$	$\frac{F_{Sa}}{F_{Hu}}$	$\frac{F_{Na}}{F_{Hu}}$	$\frac{F_{Ho}}{F_{Hu}}$	$\frac{F_{Ku}}{F_{Hu}}$	$\frac{F_{Ok}}{F_{Hu}}$	$\frac{F_{Se}}{F_{Hu}}$	$\frac{F_{Gi}}{F_{Hu}}$	$\frac{F_{On}}{F_{Hu}}$
Freq. ratio to Huzimizaka	1.00	0.88	0.34	0.38	0.53	0.49	0.91	0.73	0.73
Mean deviation	±0.00	±0.05	±0.08	±0.07	±0.10	±0.07	±0.02	±0.10	±0.09

1.0 sec.

For an example of the seismic frequencies of the Asama B quake, the monthly frequencies at the nine permanent stations of Asama are shown in the period of 1965 in Table 9(a). Although Volcano Asama was in a calm state throughout the year of 1965, the seismic frequency undulated in quite a wide range. As will be seen in Table 9 (a), the frequencies of May 1965, showed about three times as many as in October of the same year.

However, the seismic frequencies at the nine stations undulate in parallel, though they depend on the distance from the summit crater to each station and on the geological formations on which the stations are built. In order to further clarify the above problem, the seismic frequencies at the nine stations are shown in a form of ratios to that at Station

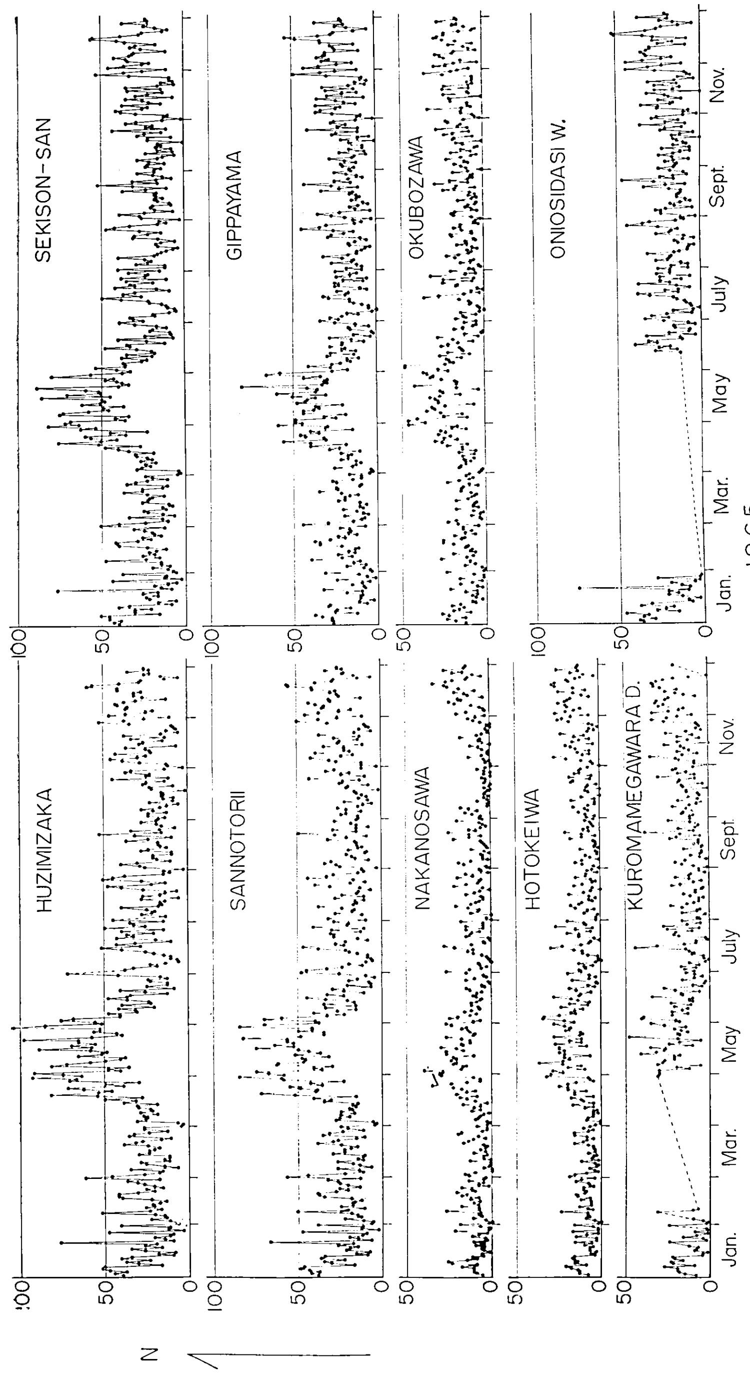


Fig. 13. Daily frequencies of the B quakes at nine stations on Asama during January 1-December 31, 1965.

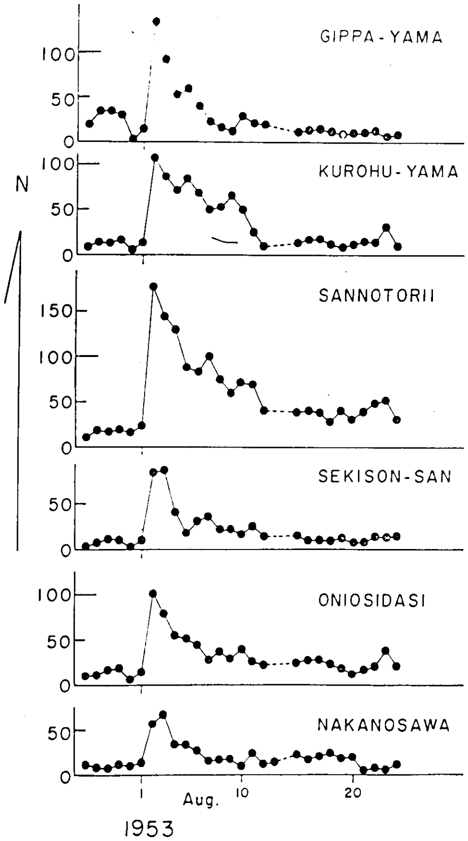


Fig. 14. Daily frequencies of the B quakes observed at six seismic stations during July 27-August 24, 1953.

Huzimizaka.

As another example, the frequencies of the Asama B quakes in different period are illustrated in Fig. 14 in a form of daily frequency observed during July and August 1953 with the mechano-optical seismographs without any electronic amplifier. The above seismographs were 1.0 sec in the period of their pendulum and 5000 times in their magnification on the seismogram, and almost similar in the response curve to the present seismograph shown in Fig. 4.

9. The seismic frequency according to different lower limits of trace-amplitude

The seismic frequency of the Asama B quakes observed on various parts of the volcano with the same kind of seismographs, depends not only on the distance from the summit crater but also on the nature of geological formations on which the seismometrical observations were placed.

In order to make clearer the meaning of the seismic frequency at a number of positions on the volcano, the writers made three kinds of monthly seismic frequency classified according to the trace amplitude;

1) Frequency read as carefully as possible from the seismograms (F_1)
2) Frequency picked up larger than 1.0 mm in trace-amplitude (F_2)
3) Frequency picked up larger than 3.0 mm in trace-amplitude (F_3)

Table 10. The monthly seismic frequencies at each station during July 1965.

F_1: frequency read from the seismograms as many as possible.
F_2: frequency of 1.0 mm and larger than 1.0 mm in the trace-amplitude.
F_3: frequency of 3.0 mm and larger than 3.0 mm in the trace-amplitude.

	Huzimi.	Sanno.	Nakano.	Hotok.	Kuroma.	Okubo.	Seki.	Gippa.	Oniosi. W
F_1	856	716	180	175	219	216	758	524	556
F_2	656	558	59	77	161	177	535	235	363
F_3	262	196	29	22	37	36	186	58	95

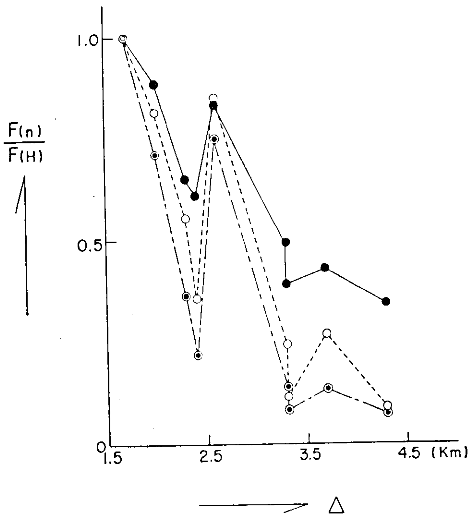


Fig. 15. The seismic frequency ratios at the nine parmanent stations to that at Stn. Huzimizaka, and the distance from the summit crater.
solid circle; total seismic frequency.
open circle; seismic frequency larger than 1.0 mm in trace amplitude.
double circle; seismic frequency larger than 3.0 mm in trace-amplitude.

The frequencies of the above three kinds, F_1, F_2 and F_3 are shown in Table 10, for nine stations, Huzimizaka, Sannotorii, Nakanosawa, Hotokeiwa, Kuromame-gawara, Okubosawa, Sekison-san, Gippa-yama and Oniosidasi W. Although the relationship among the three frequencies are evident in Table 10, it will be further clarified in Fig. 15, in which the ratios of seismic frequencies at each station to those at Huzimizaka are illustrated for the above-mentioned three kinds of frequency in relation with the distances from the summit crater to each station. As made clear in Fig. 15, according to the distance, the ratios decrease more rapidly in F_3 and F_2 than in F_1, this decrease in ratio being especially remarkable on the hard rock formations as at Stn. Gippa-yama and Nakanosawa etc.

It will be necessary to know the contents of the seismic frequency F_1 read from the seismograms as much as possible without considering the trace amplitudes. For the purpose, the writers re-examined the contents of the seismic frequency F_1 by means of making clear its amplitude distribution. As an example, the B earthquakes observed at the following nine stations during the period of July 1965, were classified into every 0.1 mm in their maximum trace amplitude, the result being shown in Table 11.

As can be seen in Table 11, the maximum trace amplitude in which the maximum seismic frequency appears, is markedly different at the respective stations. On the other hand, these maximum frequencies at each station provided by the present seismic observation, do not indicate the lower limit of the B earthquakes, judging from the magnification of the seismographs applied at Asama. This shows the limitation of reading from the seismograms. Besides the above reason, the disturbances caused by noise prevented us from picking up completely the earthquakes of small size from the records. It is also evident that the noise level depends remarkably not only on the distances from various sources of noise but also on the geological formation on which the

Table 11. Frequencies classified into every 0.1 mm in the maximum trace-amplitudes (July 1-31, 1965).

A	Huzimi.	Sanno.	Nakano.	Hotok.	Kuroma.	Okubo.	Sekison.	Oniosi.	Gippa.
0.1 mm	0	0	0	0	0	0	0	0	0
0.2	3	0	0	0	0	0	0	0	0
0.3	3	0	2	0	1	0	0	0	4
0.4	2	1	6	1	0	1	9	4	21
0.5	6	4	21	13	4	6	15	13	54
0.6	18	9	22*	18	4	4	45	33	77*
0.7	24	18	22	23*	9	6	54*	39	42
0.8	32	35	16	13	13	12	42	49	41
0.9	49	47	16	14	15	8	45	50*	37
1.0	61*	63*	13	8	17*	16*	40	44	28
1.1	45	34	6	10	15	11	34	30	22
1.2	46	47	4	6	17	15	31	28	22
1.3	43	35	4	9	13	16	24	19	18
1.4	40	32	6	7	12	8	26	22	14
1.5	29	29	8	7	8	11	28	15	16
1.6	24	23	2	3	9	13	16	16	9
1.7	25	18	3	3	10	6	16	15	2
1.8	24	19	3	5	3	4	15	9	5
1.9	17	12	2	3	6	8	19	8	11
2.0	16	20	1	2	6	7	16	10	6
2.1	14	6	1	2	1	5	11	6	3
2.2	6	13	1	0	2	2	12	8	6

* Maximum frequency at each station.

stations are established. The seismic observations on the hard rock formation are usually in an extremely low-noise level and cover up the small trace amplitude like 0.2–0.5 mm as in the stations, Gippa-yama, Hotoke-iwa and Nakanosawa in Table 11. However, at the same time, the amplitudes observed on these hard rock formations are remarkably reduced on the seismograms as compared with those on the soft or loose formation such as the pumice layers on which Stations Sannotorii and Huzimizaka are built.

Therefore, it is reasonable to say that the seismic frequency of the kind of F_1 indicates a compensated result to some extent on account of the above two reasons which act in an opposite sense.

10. Temporary seismometric surveys of Asama

Besides the continuous seismometric observations since 1934, the writers made a series of temporary seismic surveys at various places on the volcano. Since 1949, the writers applied to their purpose the highly sensitive seismographs adjusted to 4000–5000 times in instrumental magnification, these being almost similar in response character with the present seismographs. In the period from 1949 to 1955, the mechano-optical seismographs were used for getting the high magnification, the vibration-period of the pendulum being 1.0 sec. In the period from 1956 to 1957, seismometric observations were carried out with the transducers of 1.0 sec in vibration-period connected directly with the sensitive galvanometers of 0.3 sec in period. In 1958, temporary observations were transferred to permanent ones and the present net-work was partly established, though temporary observations have been still made for special purposes.

In order to obtain useful information about the hypocentral depth of the B quakes, transducers were set inside the ancient crater, on the central cone of Maekake-yama and on the margin of the summit crater in summer in 1954–1957. According to the result of the seismic observations, the seismic frequencies on the central cone and inside the old crater were not so very different from those of Stations Higasimaekake-

Table 12. Results of the temporary observations.

(1) The temporary seismic observation during July 24–Aug. 24, 1952.

F: The seismic frequency during the period.

Station	Gippa.	Sanno.	Nakano.	Oniosi. E.	Ohina.
F	387	482	161	202	6

(2) The temporary seismic observation during July 27–Aug. 24, 1953.

Station	Gippa.	Sanno.	Nakano.	Oniosi. E.	Kurohu.	Tinotaki
F	1123	1532	494	808	887	557

(3) The temporary seismic observation during July 24–Aug. 25, 1954.

Station	Gippa.	Sanno.	Nakano.	Oniosi. E.	Kurohu.	Huzimi.	Maeka.
F	2598	3023	243	1512	2840	3607	3260

(4) The temporary seismic observation during July 28–Sept. 2, 1955.

Station	Sanno.	Nakano.	Oniosi. E.	Kurohu.	Hotok.	Higasi.
F	912	408	411	757	581	1645

(5) The temporary seismic observation during July 31–Aug. 31, 1956.

Station	Sanno.	Nakano.	Higasi.	Maek. kako	Gyozya.
F	186	60	272	245	112

(6) The temporary seismic observation during July 31–Aug. 30, 1957.

Station	Sanno.	Nakano.	Higasi.	Sanzen.	Maek.
F	392	114	417	(378)	(350)

yama and Huzimizaka. In other words, almost the same frequency of the B earthquakes of Asama were observed on places within 1.0 km from the center of the crater, with the same seismographs.

In Table 12, the results of temporary seismometrical surveys in the period 1952–57, are shown in the total frequency of the B quakes at each station.

11. The frequency of the B quakes in the active and inactive periods of Asama

It will be important to investigate precisely variations of the seismic frequency at the same station in the calm period of the volcano, in order to make clear the anomalous feature of the seismic frequency, if any, in its active period. We have a lot of questions about the B quakes;

whether their hypocentral area stands still through the calm and active states of Asama or becomes enlarged according to volcanic activity or not, whether their hypocentral depths move upward and downward or not and whether the seismic magnitude and frequency are always in a constant relation at their origin or change in accordance with volcanic activity or not.

The relationship between the 1958–59 and 1961 eruptive activities and the respective annual seismic frequencies was not so evident for the reason that these activities including very small eruptions lasted for only a few months. However, it must be remarked that the above relation is remarkably clear in the form of the monthly frequency of the B quakes, which is represented in Fig. 11 for the three stations.

As mentioned in the previous paragraphs, the B quakes increased their frequency not only in the midst of eruptive activity but also in a few months before and just after explosive activity. In order to make clear statistically the above phenomenon, the histogram about the monthly seismic frequencies are represented in Fig. 16 in the calm and active periods of the volcano, though the above relation is more evident in the comparisons of the daily seismic frequency.

In order to obtain information useful for making clear the shift of the hypocentral area, the ratios of the seismic frequencies at Sannotorii (F_S) and Nakanosawa (F_N) to those at Huzimizaka (F_H) and the ratio of those at Nakanosawa to Sannotorii are made for every year and for every month on the basis of the comparison of seismic frequencies at

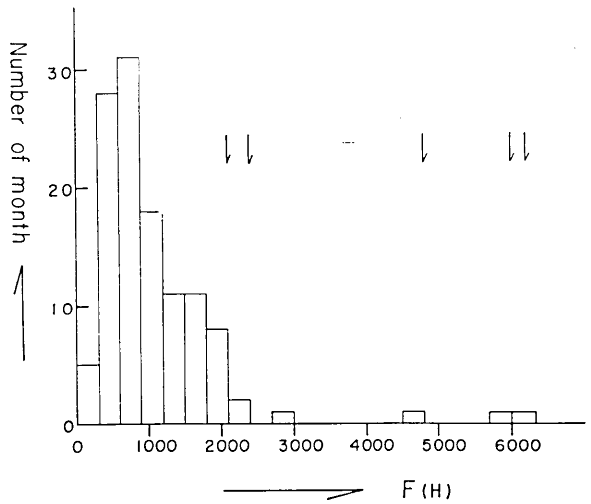


Fig. 16. The histogram of the monthly seismic frequency at Stn. Huzimizaka.
arrow; volcanically active month.

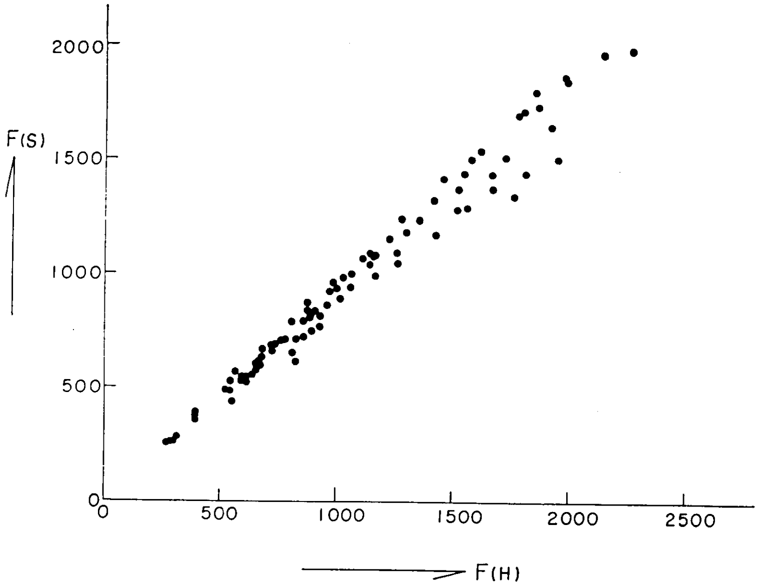


Fig. 17. Comparison of the monthly seismic frequencies at Stns. Huzimizaka and Sannotorii during the period from July 1961 to December 1968.

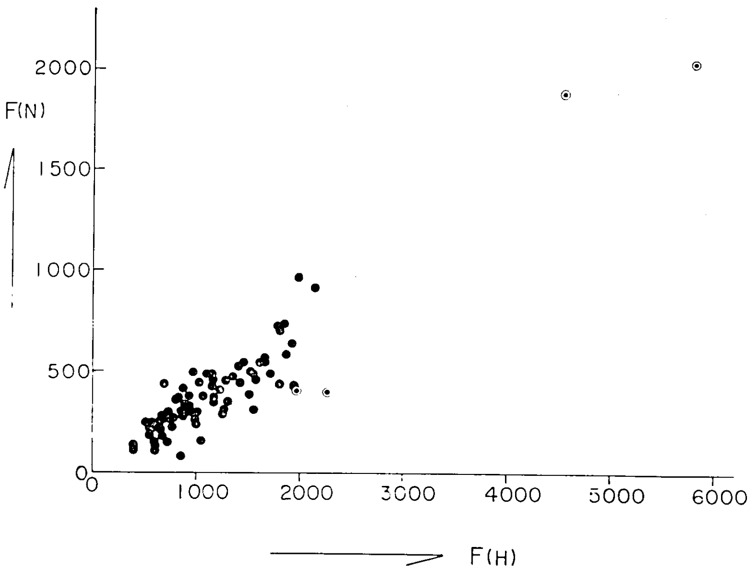


Fig. 18. Comparison of the monthly seismic frequencies at Stns. Huzimizaka and Nakanosawa.
double circle; eruptive state of Asama.

the three stations (H, S and N). The ratios of the annual frequency, F_S/F_H and F_N/F_H are in a range from 0.86 to 0.94 and from 0.28 to 0.42 respectively. On the other hand, the monthly frequency ratios

F_S/F_H and F_N/F_H distribute mainly from 0.85 to 0.95 and from 0.25 to 0.45 respectively.

As mentioned above, the frequency ratios between Huzimizaka and Nakanosawa change remarkably in the active period, though those between Huzimizaka and Sannotorii do not change much throughout the calm and active periods of the volcano. It is especially worthy of note that the seismic frequency at Nakanosawa does not always change proportionally with those at the other two stations in the active period of the volcano, notwithstanding the fact that the B quakes increase remarkably at the other two stations. According to careful examinations of the seismograms at the above three stations, the comparatively small B quakes at the active period increase markedly in the earlier stage of their active period much more than in the calm period of the volcano, and in addition their hypocenters moved toward the crater floor and become shallower in the statistical average than in the calm period, judging from the attenuation of the amplitude of the B quakes.

Therefore, not only the frequency of the B quakes of Asama increase remarkably in its active period, but also the center of hypocentral domain

Table 13. Monthly frequencies (F_1) of the Asama B quakes. (1957–1968)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1957 F_{Hi}	—	—	—	—	—	1208	1121	616	540	390	495	533
F_{Sa}	—	—	—	—	—	1320	1167	592	496	382	667	562
F_{Na}	—	—	—	—	—	460	290	190	188	—	239	154
1958 F_{Hi}	712	537	643	—	407	358	453	1227	2760	16507	—	—
F_{Sa}	659	175	—	—	344	266	400	1345	2561	14337	—	—
F_{Na}	149	84	109	—	125	110	127	144	275	1621	2075	2502
1959 F_{Hi}	—	—	—	—	—	—	—	—	618	697	440	306
F_{Sa}	1759	1700	902	696	532	619	1150	982	687	785	511	306
F_{Na}	405	374	379	344	208	157	300	194	133	183	73	108
1960 F_{Hi}	320	429	275	278	393	323	614	—	—	—	—	—
F_{Sa}	320	442	274	282	379	414	624	694	942	461	491	418
F_{Na}	165	206	113	—	149	210	180	173	224	166	165	135
1961 F_{Hu}	612	—	370	—	—	—	929	1974	2262	4541	5816	—
F_{Sa}	523	—	—	—	—	—	813	1854	1979	4133	5479	—
F_{Na}	116	—	—	—	—	—	331	406	398	1888	2043	—

(to be continued)

Table 13. (continued)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1962												
F_{Hu}	856	1052	1253	1557	1265	1807	1516	1950	1294	1720	1163	774
F_{Sa}	790	939	1088	1283	1043	1432	1278	1499	1172	1502	1078	703
F_{Na}	74	153	291	308	310	435	383	429	341	488	352	267
1963												
F_{Hu}	731	874	805	1026	952	608	394	393	670	651	593	545
F_{Sa}	689	846	784	980	860	546	354	382	598	602	545	523
F_{Na}	269	414	359	444	298	129	121	131	179	213	219	184
1964												
F_{Hu}	397	263	1867	395	310	295	281	552	1760	807	541	908
F_{Sa}	377	250	1728	371	278	259	255	435	1334	648	481	825
F_{Na}	116	—	587	—	—	—	—	—	256	157	118	156
1965												
F_{Hn}	887	669	761	1169	1921	1012	856	727	651	593	724	969
F_{Sa}	819	615	702	984	1640	789	716	610	575	540	659	920
F_{Na}	298	278	221	365	633	298	296	266	253	147	150	492
1966												
F_{Hu}	682	565	875	520	545	721	824	677	639	1144	882	1781
F_{Sa}	666	564	870	487	487	686	709	631	556	1040	809	1699
F_{Na}	439	243	280	247	218	298	366	266	232	486	336	722
1967												
F_{Hu}	1062	1104	1157	1275	1856	1801	1985	2143	1522	1350	1141	1412
F_{Sa}	994	1060	1073	1238	1792	1710	1841	1953	1364	1227	1089	1318
F_{Na}	374	486	460	450	739	706	967	914	499	472	425	528
1968												
F_{Hu}	1574	1616	1666	1665	1542	1426	928	896	1453	1220	1000	984
F_{Sa}	1490	1531	1426	1368	1432	1166	767	745	1409	1149	933	957
F_{Na}	454	544	549	569	494	444	377	308	543	402	239	278

Station F_{Hi}: Higasi-maekake F_{Hu}: Huzimizaka
F_{Sa}: Sannotorii F_{Na}: Nakanosawa

shifts near the earth's surface, though only slightly.

The seismic monthly frequencies at Stn. Huzimizaka (Higasi-maekake, 1957–1960), Sannotorii and Nakanosawa are represented in Tables 13 ~ 15, during the period from 1957 to 1968. These three Tables are for the three kinds of seismic frequency, F_1, F_2 and F_3 respectively as defined in Paragraph 9.

It is necessary to add that a series of shock type earthquakes took place just before and during the eruptive period, the epicentral area of the B quakes enlarging in the active stage of the volcano to some extent. As an example of the shock type quakes, the seismograms are

Table 14. Monthly frequencies (F_2) of the Asama B quakes whose maximum amplitudes are larger than 1.0 mm. (1957–1968)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1957												
F_{Hi}	—	—	—	—	—	1178	1012	564	539	390	495	532
F_{Sa}	—	—	—	—	—	809	555	421	264	225	370	406
F_{Na}	—	—	—	—	—	45	24	47	33	—	107	55
1958												
F_{Hi}	664	391	342	—	269	245	395	1196	2475	15584	—	—
F_{Sa}	445	142	—	—	211	137	302	1100	2226	—	—	—
F_{Na}	31	25	28	—	33	38	54	44	54	1240	—	—
1959												
F_{Hi}	—	—	—	—	—	—	—	—	549	633	398	299
F_{Sa}	1439	1477	844	682	495	560	1019	845	537	619	402	263
F_{Na}	128	119	88	124	62	39	92	66	31	37	21	20
1960												
F_{Hi}	309	421	266	270	287	316	575	—	—	—	—	—
F_{Sa}	258	373	196	219	297	353	480	440	586	389	407	353
F_{Na}	31	22	8	—	19	13	34	39	36	29	22	25
1961												
F_{Hu}	600	—	286	—	—	—	880	1937	2220	4507	5803	—
F_{Sa}	429	—	—	—	—	—	686	1471	1482	3923	5373	—
F_{Na}	46	—	—	—	—	—	171	176	179	1765	1982	—
1962												
F_{Hu}	773	976	1124	1273	1026	1538	1309	1851	1213	1461	1045	717
F_{Sa}	719	795	821	845	657	877	748	897	922	1174	897	573
F_{Na}	60	88	107	89	104	164	145	125	96	119	59	27
1963												
F_{Hu}	639	784	719	890	858	561	358	349	611	622	576	525
F_{Sa}	498	619	586	724	636	371	279	316	489	517	462	417
F_{Na}	17	33	41	63	35	7	15	13	10	16	8	10
1964												
F_{Hu}	366	245	1780	378	278	275	238	459	1581	693	436	813
F_{Sa}	300	219	1581	331	221	219	217	385	1273	565	417	759
F_{Na}	10	—	245	—	—	—	—	—	79	60	49	58
1965												
F_{Hu}	773	614	681	1015	1788	854	700	711	624	591	719	961
F_{Sa}	681	492	596	849	1479	695	557	539	421	489	625	890
F_{Na}	128	105	78	149	151	54	64	174	129	52	78	217
1966												
F_{Hu}	674	545	856	520	543	709	819	673	636	1131	842	1657
F_{Sa}	631	446	722	476	483	668	675	611	549	1010	750	1630
F_{Na}	217	48	103	108	48	93	111	74	65	170	100	249

(to be continued)

Table 14. (continued)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1967												
F_{Hu}	960	979	1011	1174	1768	1695	1859	1979	1392	1265	1114	1356
F_{Sa}	908	919	961	1075	1582	1529	1684	1777	1231	1148	1025	1138
F_{Na}	131	139	144	97	204	141	396	328	147	228	241	321
1968												
F_{Hu}	1479	1507	1278	1327	1450	1360	853	877	1308	1123	952	947
F_{Sa}	1311	1330	960	725	1246	896	660	593	1161	1030	883	914
F_{Na}	210	175	62	97	141	125	69	84	313	270	57	72

Station F_{Hi}: Higasi-maekake F_{Hu}: Huzimizaka
F_{Sa}: Sannotorii F_{Na}: Nakanosawa

Table 15. Monthly frequencies (F_3) of the Asama B quakes whose maximum amplitudes are larger than 3.0 mm. (1957–1968)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1957												
F_{Hi}	—	—	—	—	—	660	434	320	338	251	311	266
F_{Sa}	—	—	—	—	—	163	114	170	93	79	78	79
F_{Na}	—	—	—	—	—	20	12	14	4	—	25	14
1958												
F_{Hi}	517	235	200	—	131	132	337	701	1372	11602	—	—
F_{Sa}	191	64	—	—	75	54	138	394	770	8000	—	—
F_{Na}	14	6	14	—	11	7	12	21	14	1175	—	—
1959												
F_{Hi}	—	—	—	—	—	—	—	—	175	197	117	113
F_{Sa}	445	506	235	284	193	196	400	276	118	128	65	37
F_{Na}	27	41	9	41	22	12	31	19	9	1	9	6
1960												
F_{Hi}	153	182	106	101	82	157	193	—	—	—	—	—
F_{Sa}	31	41	18	28	74	64	126	115	149	57	70	70
F_{Na}	3	2	0	—	6	5	7	19	12	13	10	6
1961												
F_{Hu}	284	—	120	—	—	—	590	1092	1061	3831	5340	—
F_{Sa}	152	—	—	—	—	—	391	669	577	3761	4987	—
F_{Na}	12	—	—	—	—	—	33	59	19	1680	1938	—
1962												
F_{Hu}	219	337	401	375	363	641	551	1443	433	451	321	158
F_{Sa}	175	182	183	153	158	288	140	274	210	304	237	129
F_{Na}	32	25	22	16	45	88	86	47	28	45	14	12

(to be continued)

Table 15. (continued)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1963 F_{Hu}	170	253	186	241	238	195	162	118	223	257	236	97
F_{Sa}	68	115	89	136	106	73	69	81	107	134	110	39
F_{Na}	6	9	8	16	10	4	8	11	3	5	1	2
1964 F_{Hu}	57	61	946	258	123	145	136	152	426	158	131	182
F_{Sa}	33	49	652	125	46	78	66	132	408	120	111	121
F_{Na}	0	—	62	—	—	—	—	—	11	7	2	6
1965 F_{Hu}	319	241	244	387	547	221	243	393	329	398	437	629
F_{Sa}	226	149	180	251	359	180	151	248	124	147	267	456
F_{Na}	25	11	6	9	47	3	9	39	17	2	0	29
1966 F_{Hu}	400	175	281	298	260	403	437	429	274	537	256	480
F_{Sa}	274	89	135	138	101	295	214	227	196	364	133	474
F_{Na}	54	3	25	10	3	47	21	4	12	27	37	14
1967 F_{Hu}	267	240	292	338	640	665	854	754	447	458	381	318
F_{Sa}	271	148	259	191	419	466	578	435	289	306	291	173
F_{Na}	7	4	17	1	2	5	119	19	1	22	8	10
1968 F_{Hu}	359	412	272	349	440	671	326	477	488	387	385	582
F_{Sa}	189	262	235	66	451	279	378	202	305	349	417	222
F_{Na}	7	8	1	17	29	27	1	15	81	46	9	1

Station F_{Hi}: Higasi-maekake F_{Hu}: Huzimizaka
F_{Sa}: Sannotorii F_{Na}: Nakanosawa

illustrated in Fig. 41.

Since the B quakes of the shock type consist of rapid vibrations, the attenuation acting on the earthquake-motions is most remarkable in propagation through the extremely heterogeneous hard formations of the volcano. For the above reason, these earthquakes were not recorded with the seismographs located at places further than 3.0 km from the summit crater. Therefore, the seismic frequency observed at these distant stations in the earlier stage of the eruptive periods did not always harmonize with that expected from the results of seismic observations made at the nearer stations.

12. The A type earthquakes of Asama

As already mentioned, the A type quakes have not often taken place since 1934. Therefore, it may be said that the seismic features of Asama for the last thirty five years were very different from those in period 1908–1913. However, a few A quakes were observed with the low sensitive seismograph in the 1935–1942 and 1958 activities.

Two quakes of A type were successively recorded with a low sensitive seismograph at Asama and Komoro Observatories and at the Oiwake Weather Station, on November 10, 1958, at about 20h 10m. After nearly one hour of the above earthquakes, a furious explosive eruption occurred causing serious damage to glass-panes and doors of houses at the base of the volcano on account of strong air shocks.[14]

According to the result of observations, the values of S–P for one of the above A quakes were 1.2 sec at Asama Volcano Observatory, 1.2 sec at Oiwake Weather Station and 2.3 sec at Komoro Geochemical Laboratory respectively.

If the distance coefficient is assumed as 5.0, the hypocentral position can be placed at 2 km south of the summit crater and about 4 km in its depth.

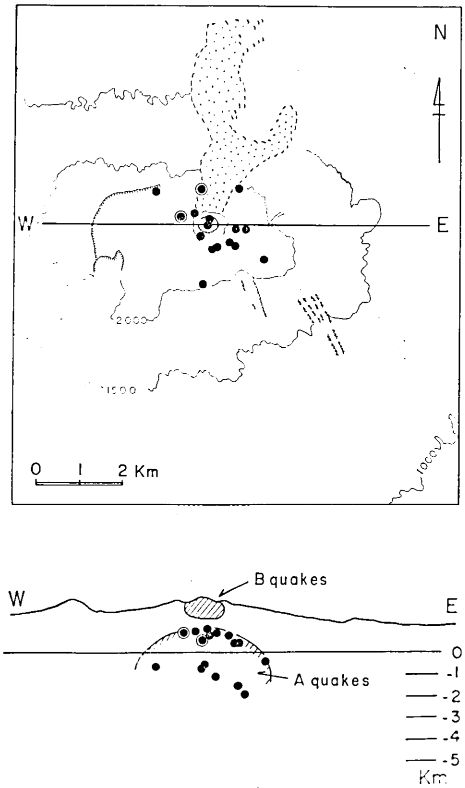


Fig. 19. The hypocentral distribution of the Asama A earthquakes in Nov.~Dec. 1961 and July 6, 1965.

According to seismic observation with the present highly sensitive seismographs, a few percent of the Asama earthquakes even at the inactive period can be classified as the A type.

As an example, the geographical distribution of the Asama A earthquakes is illustrated in Fig. 19, for the earthquakes which took place mainly in Nov.~Dec. 1961, a minor eruptive period and on July 6, 1965, the calm period, of the volcano. P and S phases in the seismograms of these earthquakes were observable. As a result, their hypocentral positions were given on the basis of S–P observed with the present seismic net. As illustrated in Fig. 19, the epicentral area occupies within 1.6 km of the radius from the center of the crater,

14) S. SAKUMA, *loc. cit.*, 11).

Table 16(1). The Asama A earthquakes on November 7, 1961.

Time	S-P				Hypo. depth	Dist. coeff.
	Stn. 2	Stn. 8	Stn. 10	Stn. 4		
14h 55m 50s	3.5 sec	3.8 sec	4.2 sec	3.2 sec	2.8 km	2.2
15 55 35	1.9	2.2	2.8	2.9	2.5	3.0
18 53 50	2.3	2.8	2.6	1.8	1.0	2.7
19 14 30	1.9	2.4	2.3	1.7	1.2	3.0
20 06 25	2.6	2.3	3.6	2.3	2.6	2.9
21 56 20	2.5	2.6	3.0	2.5	3.2	3.2
21 57 40	2.7	3.1	3.1	3.1	3.5	3.0
21 58 35	3.2	3.5	3.2	2.3	2.7	3.0
22 15 30	2.9	3.3	3.3	3.4	4.0	3.0
22 16 20	1.8	2.0	2.6	1.8	1.1	2.9
22 22 50	1.9	2.3	2.3	1.7	0.9	3.0
22 50 20	1.8	2.2	2.7	2.4	1.6	2.7
22 54 10	1.6	2.0	2.4	2.0	1.3	2.9

Table 16(2). The Asama A earthquakes on December 5, 1961.

Time	S-P				Hypo. depth	Dist. coeff.
	Stn. 1	Stn. 3	Stn. 8	Stn. 10		
05h 44m 20	1.5 sec	2.6 sec	2.6 sec	1.7 sec	1·6 km	3.2

Table 16(3). The Asama A earthquakes on July 6, 1965.

Time	S-P						Hypo. depth	Dist. coeff.
	Stn. 7	Stn. 5	Stn. 1	Stn. 2	Stn. 10	Stn. 4		
05h 44m	2.5 sec	1.6 sec	— sec	2.6 sec	2.6 sec	1.4 sec	1.4 km	2.5
06 42	2.0	1.9	2.1	—	—	1.1	1.1	2.5

and their hypocentral depths are in a range from 0.9 km to 4.0 km.

In Table 16 (1)-(3), date and time, S-P, hypocentral depth etc. are represented for the mentioned A earthquakes.

The above earthquakes, especially, in the calm period of the volcano were on a small scale, their maximum amplitude being in a range from 30 micron to 5 micron near the epicenter.

Although the Asama earthquakes observed during the last thirty five years consisted mainly of the B type, a few percents of the A quakes originating from the volcano. It is necessary to remark that a series of the A quakes took place just before strong explosive eruptions. Since the present seismometrical net work does not yet completely cover an eruptive period, it will be reasonably expected to have a lot of new informations with respect to the development of seismic activity at the deep part of the volcano in a new volcanic activity.

13. The geographical distribution of the seismic frequency of the B quakes on Volcano Asama

Besides the seismic observation with the present net-work, the writers made temporary seismic observations at a number of places on Volcano Asama with various methods. However, as mentioned already, the seismographs used for the purpose were almost similar in instrumental response and magnification. Throughout the periods of seismic observation since 1950, the writers made observations at Stations Sannotorii and Nakanosawa. On the other hand, the Asama earthquakes consist mainly of the B type which concentrate at the summit crater and originate from extremely shallow places. Therefore, the seismic frequency at each station depends remarkably on the distance from the summit crater or the center of the epicentral area which is within 0.5-1.0 km from the center of the crater floor.

It is needless to mention that besides the epicentral distance the seismic frequency at each station is seriously affected by the geological formation and the noise-level of respective places on which the seismometrical stations are built.

If the hypocentral positions and the nature of earthquake motions of the B quake have not changed markedly during the permanent and temporary seismic observations, the ratio of the seismic frequency observed at each station to the total frequency at the summit crater must be nearly constant throughout the period mentioned above.

According to the seismometrical surveys on the central cone and near the summit crater during July-August, 1954-1957, the seismic frequencies of the B quake observed nearer than 1.0 km from the center of the crater floor, showed almost similar values, though the seismic frequency at the place of more than 2 km distant depends remarkably on the distance from the summit crater.

1) *The seismic frequencies at nine stations on Asama during January-December 1965*

The seismic frequencies of the Asama B quakes observed at the nine permanent stations are given in a form of the monthly sum in Table 9 (a), their ratios to the frequency at Huzimizaka also being given in the same Table 9 (b).

As will be seen in the above Table, the monthly seismic frequencies observed at the nine stations change in parallel with one another though their absolute frequencies are very different at the respective stations, depending remarkably on the distance from the summit crater and on the nature of the geological formations under the stations.

In order to show the problem, more precisely the seismic frequencies of the nine permanent stations are illustrated in Fig. 13 in a form of the daily frequency.

In order to examine a shift of the hypocentral position of the B quakes during the year 1965, if any, the monthly seismic frequencies at the nine stations were compared with those at Stn. Huzimizaka. For that purpose, the frequency ratios of monthly frequencies at the nine stations to those at Stn. Huzimizaka were made every month in 1965. As a result of the comparisons of these frequency ratios, the values of the ratios at respective stations did not change markedly throughout the year, as will be seen in Table 9 (a), (b), in which the fluctuation of the seismic frequency ratio are shown by means of the average deviation of the ratio at each station.

Judging from the above investigations, the B earthquakes of Asama did not shift their hypocentral positions statistically in the period of 1965, when Volcano Asama was in a quiescent state.

According to the results of the same investigations since 1954, the B earthquakes took place on and near the summit crater, more precisely within 1 km from the center of the crater, their depths being in a range from the earth's surface to $0.7\sim0.8$ km at their deepest.

From a comparison of the seismic frequency ratios in the active and inactive stages of the volcano, it can be said that the B quakes in the earlier stage of the eruptive period of the volcano increased in frequency, moreover, their hypocentral positions shifted slightly toward the surface of the summit crater.

2) *The geographical distribution of the seismic frequency ratio*

Since the hypocentral positions of the B quakes have stood still in average throughout the years, it is possible to study the problem by means of the seismic frequency ratio, based not only on the result of the present seismometrical observation, but also on those observations made in different periods already mentioned.

In a series of seismometrical surveys made on various parts of the volcano during the period from 1954 to 1960 and in the present seismometrical net also, the seismic observations have always been made at Stn. Sannotorii, Stn. Huzimizaka and Stn. Nakanosawa as the standard stations for comparison.

Therefore, it is reasonable that the seismic frequencies observed at a number of places in different periods are evaluated by taking the ratios of the seismic frequencies at these stations to those at the standard stations, in order to study the geographical distribution of the seismic level of the B quakes. In Table 17, the above-mentioned frequency ratios of 20 places on Asama are shown with the distances from the summit crater or the average epicentral distances.

As a first step to the study of the geographical distribution of the seismic level of B quake, the writers investigated the relationship of a series of frequency ratios with the distances of observed places from the summit crater, and as a result, the following relation was given:

$$R_c(F)=1.24\times e^{-0.270\Delta}\cdots(1).$$

Table 17. The B seismic frequencies observed on various geological formations and their relation to the distance from the summit crater.

F_H: seismic frequency at Stn. 1 (Huzimizaka),
F_n: seismic frequency at each station,
$R_n(F)=F_n/F_H$,
$R_c(F)$: estimated value given from the empirical formula (1),
$\delta R_n(F)$: anomalous value in the seismic frequency.

Stn. No.	Place	Distance	$F_n/F_H(R_n)$	$R_c(F)$	$\delta R_n(F)=R_n-R_c$
1	Huzimizaka	1.7 km	1.00	0.78	+0.32
2	Sannotorii	2.6	0.86	0.61	+0.25
3	Nakanosawa	4.1	0.32	0.41	−0.09
4	Gippa-yama	2.4	0.66	0.66	0.00
5	Oniosidasi W.	2.3	0.73	0.68	+0.05
7	Sekison-san	2.0	0.91	0.72	+0.19
8	Hotokeiwa	3.3	0.38	0.51	−0.13
9	Okubosawa	3.7	0.49	0.46	+0.03
10	Kuromame. D.	3.3	0.53	0.51	+0.02
11	Tutuzigahara	7.0	0.27	0.19	+0.08
13	Kurohu-yama	1.6	0.67	0.80	−0.13
14	Hotokeiwa U.	2.0	0.54	0.72	−0.18
16	Tinotaki	4.2	0.31	0.40	−0.09
18	Gyozyamodosi	3.3	0.52	0.51	+0.01
19	Higasi-maekake	0.9	1.29	0.97	+0.32
20	Oniosidasi E.	4.4	0.40	0.38	+0.02
22	Sanzenton-iwa	0.2	0.98	—	—
23	Maekake-Kako	0.5	1.14	—	—
24	Maekake-yama	0.8	1.90	—	—
28	Siraitonotaki II	5.8	1.19	0.26	−0.07

The anomaly of the seismic frequency which is defined with the difference between the observed frequency ratio ($R_n(F)$) and the one ($R_c(F)$) estimated from the above empirical formula (1) is given in Table 17.

Since it is clear that the anomaly of the seismic frequency is closely related with the nature of the geological formations under the stations, the above relation according to the epicentral distance is separately

Table 18. The anomalies of seismic frequency at stations on the loose ejecta located mainly at the eastern side of Asama.

R_cF: estimated value given from the empirical formula (2).

Stn. No.	Place	$R_n(F)$	$R_c(F)$	$\delta R_n(F)$
1	Huzimizaka	1.29	1.23	+0.06
2	Sannotorii	0.86	0.73	+0.13
7	Sekison-san	0.91	0.87	+0.04
9	Okubosawa	0.40	0.42	−0.02
10	Kuromame. D.	0.53	0.58	−0.06
11	Tutuzigahara	0.27	0.19	+0.08
18	Gyozyamodosi	0.52	0.59	−0.07
19	Higasi-Maekake	1.29	1.23	+0.06
20	Oniosidasi E.	0.40	0.42	−0.02
28	Siraitonotaki II	0.19	0.27	−0.08

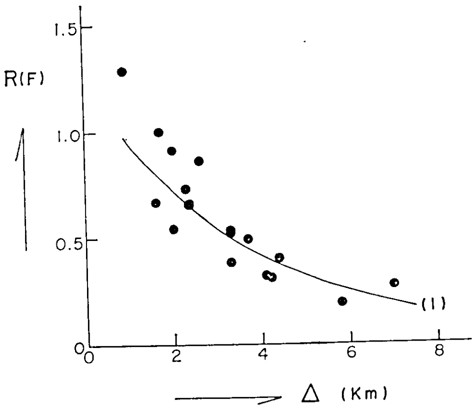


Fig. 20. Relation between the seismic frequency ratios and the distance from the summit crater.

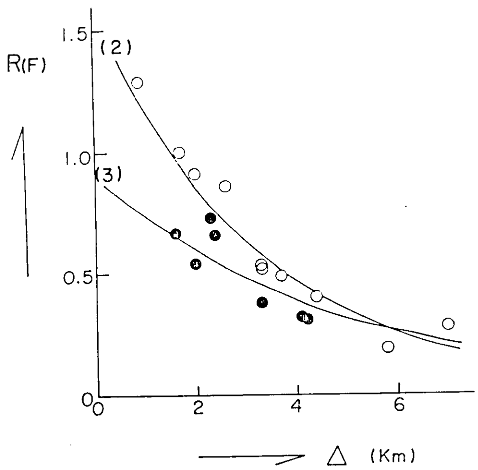


Fig. 21. Relations between the seismic frequency ratios on different geological formations and the distance from the summit crater.

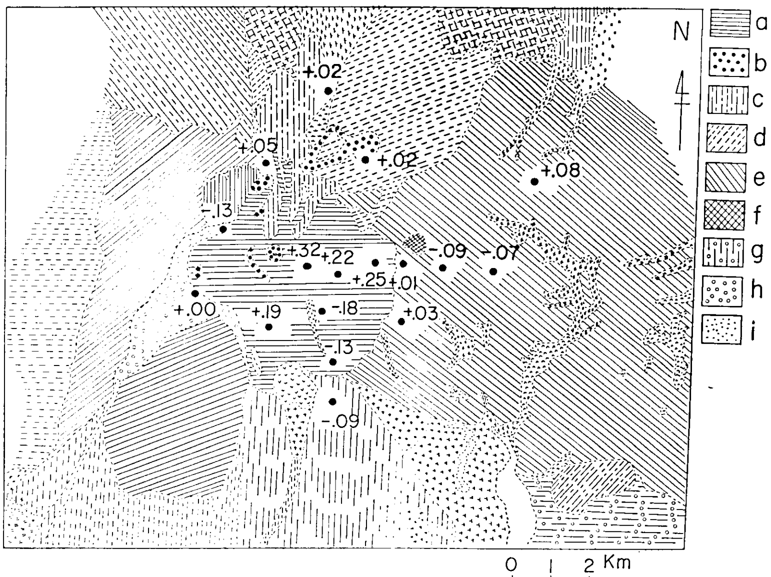
open circle; loose formation,

solid circle; hard formation.

Table 19. The anomalies of seismic frequency at stations on hard formations located mainly on the western side and the southern flank of the volcano.

$R_c(F)$: estimated value given from the empirical formula (3)

Stn. No.	Place	$R_n(F)$	$R_c(F)$	$\delta R_n(F)$
3	Nakanosawa	0.32	0.38	−0.06
4	Gippa-yama	0.69	0.55	+0.14
5	Oniosidasi W.	0.73	0.56	+0.17
8	Hotokeiwa	0.38	0.45	−0.07
13	Kurohu-yama	0.67	0.65	+0.02
14	Hotokeiwa U.	0.54	0.60	−0.06
16	Tinotaki	0.31	0.37	−0.06
22	Sanzenton-iwa	0.98	0.87	+0.11



a----Ash, lapilli, and block
b---Lava flows with minor pyroclastics
c----Lava flow
d----Welded deposit of essential ash, lapilli, and block
e----Ash, lapilli, block; mostly pumiceous
f----Massive lava dome
g----Loose deposit of essential ash, lapilli, and block
h----Essential tuff breccia, lava flows, and tuff
i----Recent pumices and fine ejecta

Fig. 22. Anomalies of the seismic frequencies of the B quakes observed on different geological formations of Volcano Asama.
(Compiled from the geological map made by S. Aramaki).

studied for two groups of the stations. The one group consists of stations built on loose ejecta including a series of historical pumices and ashes located mainly on the eastern side of the volcano, and the other those which are situated mainly on hard rock formations of the old Asama, including Kurohu and Hotokeiwa volcanoes located at the west side and south flank of the volcano, according to the geological map made by S. Aramaki[15].

For the first group, the following relation was obtained.

$$R_c(F)=1.61\times e^{-0.370\Delta} \cdots (2),$$

for the second, the following relation was conducted,

$$R_c(F)=0.91\times e^{-0.212\Delta} \cdots (3).$$

In Tables 18 and 19, the anomalies of the seismic frequency are represented for the respective stations of the two groups.

As will be seen in Tables 18, 19 and Fig. 21, of the stations belonging to the first group, the seismic frequencies on the thin loose ejecta upon the hard formation as well as those of Stn. Okubosawa, Kuromame D and Gyozyamodosi show an intermediate value.

It is worthy of note that the geographical distribution of the above frequency ratio reflects clearly the nature of the geological formations near the earth's surface.

14. The geographical distribution of the maximum amplitudes of the B quakes on Volcano Asama

The writers described in the previous paragraphs the remarkable attenuation of seismic frequency of the Asama B quakes in the relation with the distance from the summit crater.

It is beyond doubt that the reduction of seismic frequencies in the above case is caused by the notable attenuation of amplitude according to the distance from the summit crater to each seismic station.

In order to elucidate directly the attenuation of amplitude, the relationship between the maximum amplitudes of the B quakes and the distance from the summit crater were studied at the 11 stations. For the purpose, the maximum amplitudes of the B quakes which took place during 1st–31st July 1965, and during November 1969–January 1970, were precisely investigated on the basis of the seismograms at nine stations for the former period and eleven stations for the latter.

For convenience, the above relation was studied by the ratios of the maximum amplitudes at each station to that at Station Huzimizaka as well as in the case of the distribution of the seismic frequency.

15) S. Aramaki, *loc. cit.*, 5).

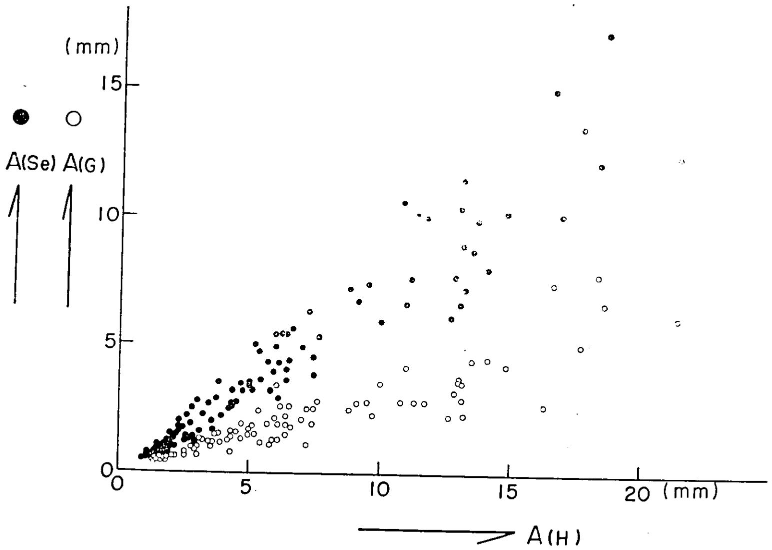


Fig. 23. Comparison of the maximum trace-amplitudes at Stns. Sekison-san and Gippa-yama with those at Stn. Huzimizaka.

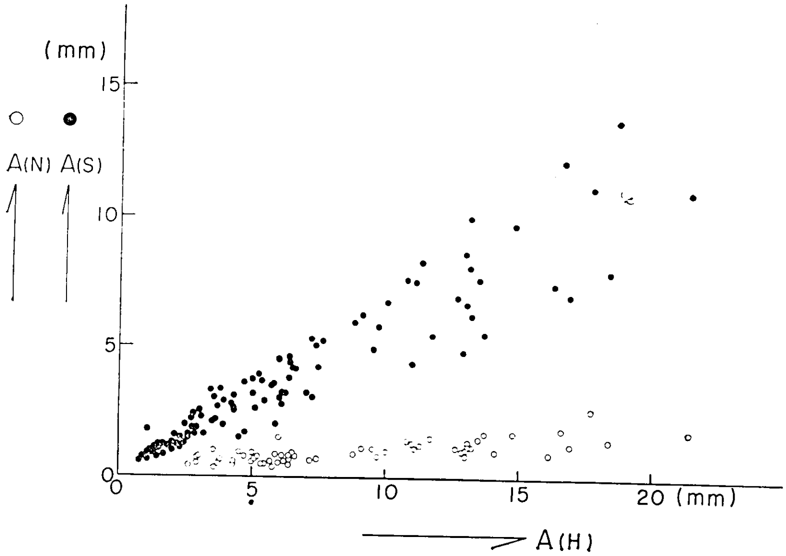


Fig. 24. Comparison of the maximum trace-amplitudes at Stns. Sannotorii and Nakanosawa with those at Stn. Huzimizaka.

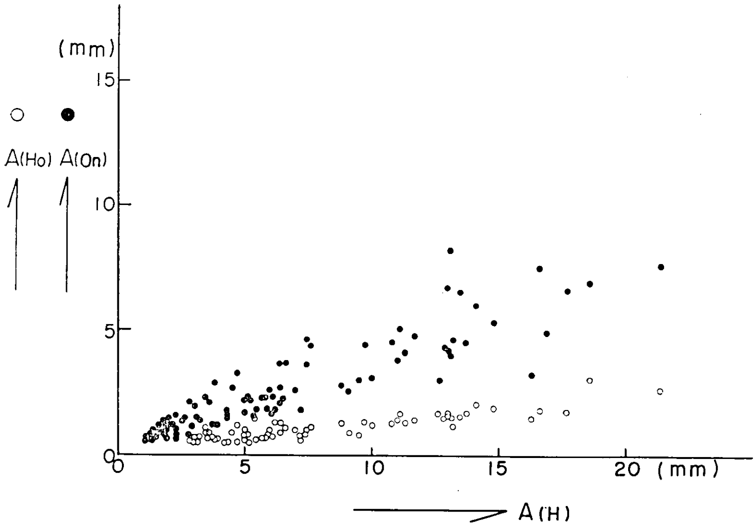


Fig. 25. Comparison of the maximum trace-amplitudes at Stns. Oniosidasi W. and Hotoke-iwa with those at Stn. Huzimizaka.

1) *The distribution of the maximum amplitudes for the B quakes during July 1965, and from November 1969–January 1970*

The maximum amplitudes at the nine places on the volcano were read for the B earthquakes, and the ratios of the maximum amplitudes at the respective stations to those at Stn. Huzimizaka were made for a great number of the B quakes.

The mean values of the amplitude ratios for the nine stations are shown in Table 20 in the periods from 1st to 31st July, 1965, and for the eleven stations in the period from November 29, 1969 to January 8, 1970.

In order to investigate the geographical distribution of the amplitude of the B quakes and the pattern of attenuation according to the distance from the summit crater, the relation with respect to the distance was given as the following empirical formula which is the same form as in the case of the seismic frequency:

$$R_c(A)=0.59\times e^{-0.151\Delta} . \quad (4)$$

As can be seen in Fig. 26, the amplitude of the B quakes is much more vitally related with the nature of the geological for-

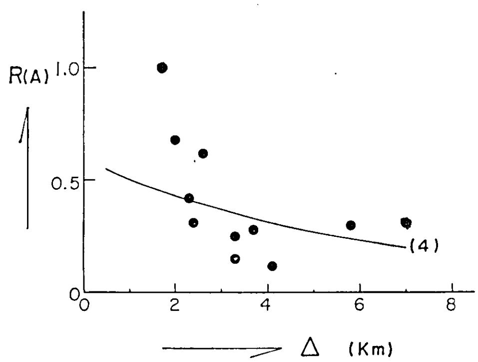


Fig. 26. Relation between the amplitude ratios and the distance from the summit crater.

Table 20. The ratios of the maximum amplitudes of the B quakes observed at various distances to that at Stn. Huzimizaka.

$R_n(A)$: The amplitude ratio given by the observations,
$R_c(A)$: The amplitude ratio expected from the empirical formula (4),
Δ: Distance from the center of the summit crater.

Stn. No.	Place	Δ	$R_c(A)$	$R_n(A)$	$\delta R(A) \equiv R_n(A) - R_c(A)$
1	Huzimizaka	1.7 km	0.45	1.00	+0.55
2	Sannotorii	2.6	0.39	0.62	+0.23
3	Nakanosawa	4.1	0.31	0.12	−0.19
4	Gippa-yama	2.4	0.40	0.31	−0.09
5	Oniosidasi W.	2.3	0.41	0.42	+0.01
7	Sekison-san	2.0	0.43	0.68	+0.25
8	Hotokeiwa	3.3	0.35	0.15	−0.20
9	Okubozawa	3.7	0.33	0.28	−0.05
10	Kuromame. D.	3.3	0.35	0.25	−0.10
11	Tutuzigahara	7.0	0.20	0.31	+0.11
26	Siraitonotaki II	5.8	0.24	0.30	+0.06

mation than in the case of the seismic frequency distribution.

It is required to subtract the attenuation according to the propagating distance, in order to make clearer the effect from the nature of the geological formation on which observations were made, though the amplitude distribution is not so simple as can be expressed by the above-mentioned simple relation.

The stations which show a remarkable positive anomaly of amplitude are all situated on pumice and loose ejecta. On the contrary, the stations which indicate a large negative anomaly are located on hard rocks of the old Asama formations.

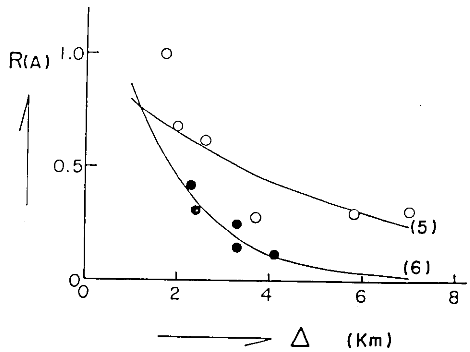
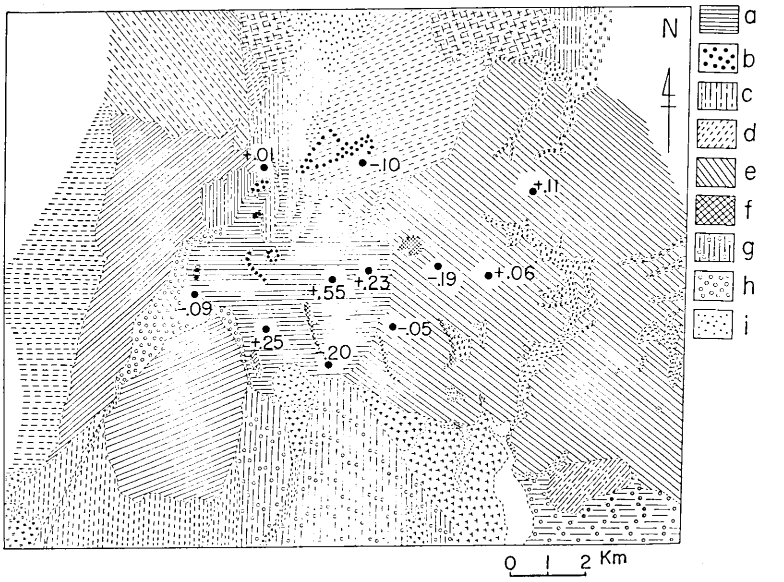


Fig. 27. Relations between the amplitude ratio at each station and the distance from the summit crater.
open circle; pumice and lapilli layer,
solid circle; old Asama formations consisting mainly of lavas.

Since the geographical distribution of amplitude ratio is considerably affected by the nature of the geological formation of the volcano, the relation between the amplitude and the epicentral distance is given for the two groups of stations, in which the one situated on the loose ejecta and the other on the hard rock formations as in the case of the geographical distribution of the seismic frequency.



a---- Ash, lapilli, and block
b---- Lava flows with minor pyroclastics
c---- Lava flow
d---- Welded deposit of essential ash, lapilli, and block
e---- Ash, lapilli, block; mostly pumiceous
f---- Massive lava dome
g---- Loose deposit of essential ash, lapilli, and block
h---- Essential tuff breccia, lava flows, and tuff
i---- Recent pumices and fine ejecta

Fig. 28. Anomalies of the amplitude of the B quakes on different geological formations of Volcano Asama.
(Compiled from the geological map made by S. Aramaki).

Table 21(1). The anomalies of the amplitude ratios on the loose formations on Asama.

$R_c(A)$: estimated value given from the empirical formula (5).

Stn. No.	Place	$R_n(A)$	$R_c(A)$	$\delta R(A)$
1	Huzimizaka	1.00	0.70	+0.30
2	Sannotorii	0.62	0.58	+0.04
7	Sekison-san	0.68	0.66	+0.02
9	Okubosawa	0.28	0.47	−0.19
11	Tutuzigahara	0.31	0.25	+0.06
28	Siraitonotaki II	0.30	0.31	−0.01

The relations of the amplitude and epicentral distance are given separately for the loose and hard geological formations of Asama as follows:

$$R_c(A)=0.98\times e^{-0.200\Delta}\cdots(5)\ ,$$

for the loose formation on the eastern side of the volcano,

$$R_c(A)=1.63\times e^{-0.641\Delta}\cdots(6)\ ,$$

for the hard formation of the old Asama.

In Tables 21(1) and (2), the values of the anomalous amplitude ratios on the volcano are given for both the loose and hard formations respectively.

Table 21(2). The anomalies of the amplitude ratios on the hard formations on Asama.

$R_c(A)$: estimated value given from the empirical formula (6).

Stn. No.	Place	$R_n(A)$	$R_c(A)$	$\delta R(A)$
3	Nakanosawa	0.12	0.12	0.00
4	Gippa-yama	0.31	0.35	−0.04
5	Oniosidasi W.	0.42	0.37	+0.05
8	Hotokeiwa	0.15	0.20	−0.05
10	Kuromame. D.	0.25	0.20	+0.05

Since the relation between the amplitude and distance from the origin was made clear and the instrumental responses of seismographs of the Asama net are almost similar with that of Wood-Anderson's seismograph, it is possible to estimate the magnitude of the B quakes from Asama, in accordance with Richter's definition.

According to seismometrical observations made for quite a long time at Huzimizaka and Sannotorii, the double trace amplitudes of B quakes, recorded with the seismographs of 4000 magnification and 1.0 sec in vibration-period of pendulums, were smaller than 150 mm or 1.5×10^5 micron and mostly smaller than 50 mm or 5×10^4 micron.

If the empirical relation (4) between the amplitude and distance is extended to 100 km distant, the magnitude of the Asama B quakes can be given as about -3.0 for the largest one and mostly in a range from -4.0 to -6.0.

However, the B quakes from volcanoes vary much in magnitude and hypocentral depth from those of other earthquakes. Therefore, it may be reasonable to establish another magnitude and another energy scale for the B quakes, independent of the ready made magnitude scales.

15. The anomalous distributions of seismic frequency and amplitude on different geological formations

As outlined in the previous paragraphs, the seismic frequencies of the B quakes and their maximum amplitudes depend not only on the distance from the summit crater, but also remarkably on the nature of the geological formations on which the seismic observations were made.

It is also natural that these two anomalies originating from the nature of the formations are closely connected with each other, at least qualitatively.

On the other hand, the seismic frequencies as many as possible of which were picked up from the seismograms independently of their amplitudes, is remarkably dependent of the noise-level at each station. On the hard rocky formations like the old Asama formations, including those at Kurohu-yama and Hotokeiwa, the seismic amplitudes are remarkably reduced as compared with those on the loose formations consisting of pumice layers, ash and other pyroclastic ejecta located mainly at the eastern side of the volcano.

However, the seismic frequency on the hard formations is reduced on account of the attenuation of amplitude for micro-earthquakes, but is increased on account of the lower noise-level, as compared with that on the loose formations. As a result, the seismic frequencies on the different geological formations are compensated to some extent but not perfectly on account of the above contrary reasons.

In order to show the relation between the two anomalies of fre-

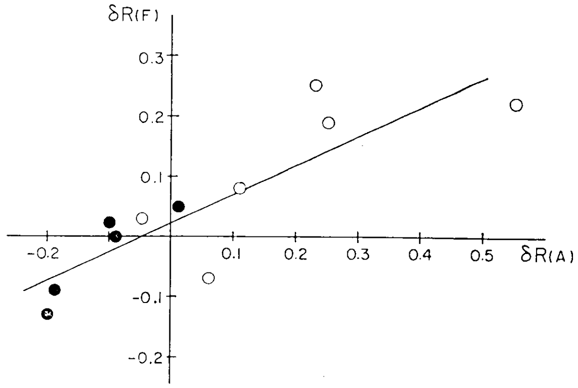


Fig. 29. Relations between the anomalies of the amplitude and seismic frequency.

$\delta R(F)$; anomaly of frequency ratio,
$\delta R(A)$; anomaly of amplitude ratio,
solid circle: anomalous value on the hard formations,
open circle: anomalous value on the loose formations.

quency and amplitude, the anomalous values of the seismic frequency given from the empirical formula (1) and those of the amplitude given from that at (4) are compared in Fig. 29.

The two kinds of anomalies are closely related and approximately connected in the linear relation, as being expressed in the following formula:

$$\delta R(F)=0.024+0.48\cdot\delta R(A)\cdots(7),$$

where $\delta R(F)$: anomaly of seismic frequency ratio,
$\delta R(A)$: anomaly of amplitude ratio.

It is also worthy of note that both the seismic frequency and amplitude ratio indicate a positive anomaly on the loose geological formations.

The anomalous distributions of seismic frequency and amplitude ratio of the B quakes are illustrated in Figs. 22 and 28, together with the geological map made by S. Aramaki[16]. From these figures, it will be noted that the anomalies described above show an evident contrast on the western and eastern sides of the volcano, of which the former side consists of the old Asama formation and the other the newly erupted pumice and fine ejecta.

16. Resumé

The report on the result of seismic observations of Volcano Asama which have been made since 1934 is described in a condensed form. In addition, the writers refer in the report to a number of problems concerning earthquakes of volcano origin and the dynamical mechanism of volcanic eruptions, which are required to be studied more precisely in future.

In concluding the report, the writers wish to express their hearty thanks to a number of persons who cooperated in the seismometrical observations and researches of Volcano Asama over a long period of thirty six years.

Especially, the writers wish to thank Mr. Teiiti Utibori, Mr. K. Iwama, Mr. S. Sakuma and Mr. K. Mogi who cooperated not only in the improvements of seismic observations but also in laborious works for operating and executing practical observations. The writers' thanks are also extended to Miss T. Takahashi, Miss K. Ito, Miss K. Fujii, Miss H. Terao, Miss K. Kurosaki, Miss F. Kobayashi, Mr. T. Kawamura, Mr. E. Koyama and Mr. F. Masutani, for their hard work in examining a great number of seismograms.

It is needless to say that the present report could not have been completed without their cooperative help.

16) S. ARAMAKI, *loc. cit.*, 15).

15. 浅間火山の地震計測学的研究

その1　1934～1969年の浅間火山の地震及び噴火活動

地震研究所
水上　武
内堀貞雄
平賀士郎
宮崎　務
行田紀也
宇都宮時子

本報告は，1934年浅間火山観測所が地震研究所の所属として設立されて以来1970年に至る約36年間に行なつた同火山に発生した地震の観測結果を基礎として，同火山の地震及び噴火活動の概略を記述したものである．

1. 先ず現在行なつている有線による遠隔記録の方法による地震観測及びそれに至るまでの観測の概略を記録した．

2. 浅間火山に発生した地震の震源位置及び噴火現象との関係から浅間火山の地震を次の4種類に分けて報告してある．

1. 火山のA型地震
2. 火山のB型地震
3. 爆発地震
4. 火山性脈動

かつて大森房吉博士は湯の平の地震観測の結果から浅間山の地震をA. Bに分類したが，博士は筆者等の爆発地震をA型地震と呼び，筆者等のA. B型地震を併せたものをB型地震と呼んだ．この点，筆者等の分類と異なることを念のため記載する．

3. A型地震

火山の地表下1～10kmの深さに起こる地震であるが，1934～1969年に亘る期間においてこの種の地震活動は著しくなかつた．特に有感地震は殆んど発生しなかつたといえる．この点，1909～1914年に亘る大森房吉博士が湯の平において観測した当時の浅間火山の地震活動とは大いに異なることが注目される．当時大筐地震をはじめ浅間火山に，しばしば強震が発生したことは同博士の報告に明らかにされている．

しかし，近年の35年間に稀ではあつたが，山頂の火口を中心として山体の1～5kmの深さにA型地震が発生した．A型地震は，噴火活動の発端となつて現われたこともあつたが，当時の地震観測を以ては充分に震源の位置の追跡ができなかつた．この事は次の活動期には現在の地震観測網を以て充分解明さるべき問題のひとつである．

4. B型地震

山頂火口底及びその周辺に密集して発生する極めて浅い地震である．この種の地震は，その発生回数が極めて多く，火口より2km以内で4000倍程度の地震計で少なくとも1日に30～80回は発生し，噴火前や活動期には1日に150回以上1000回程度の地震が記録される．その大きさは小さく，震央においても有感のものは経験されていない．震央域つまり火口の周辺で最大振幅が1μから50μ程度のものが主体を占める．

5. 爆発地震

1963年に現在の地震観測網が完成したが，それ以来1回の爆発もなく，詳細な観測結果は今後に残されている．

1935～1942年に亘つて著しい噴火の際の観測結果を基礎として次の事がいえる．

1) 爆発地震の初動は方位に無関係に“押し波”である．初動の周期は概して大きく，0.5～1.0秒程度のものが大部分を占める．S波の位相は明瞭ではない．

2) 爆発地震の大きさは爆発によつて噴出する溶岩片の器械的エネルギーにほぼ，比例している．

3) 爆発エネルギーが10^{19} ergを越える爆発地震の最大振幅は火口より約4kmの距離で，500μをこえるものがあるが，振動周期が大きく，加速度は小さいので地震動としては有感地震とならない．

4) 爆発に伴う空気波は著しく，約10^{17} erg 以上の爆発では火口より遠く離れた地域でも有感の場合が多い．従つて気圧計にはいうに及ばず地震計にも空気波を記録することが多い．空気波の発振時と爆発地震の発振時と両者のそれぞれの源からの走時を考えて，その源における発生時刻を比較すると常に爆発地震の方が約1秒早く発生している．つまり地震が起こつて火口底から噴出物が飛行するまでに若干の時間の遅れがあることを示す．この問題は，爆発的噴火の力学的機巧を考究する上で爆発地震の初動分布の特性と共に重要な手掛りを与えるものと考えられる．本問題の解明も，現在の観測網によつて爆発地震動及び空気波を高い精度でしかも多くの観測点で観測が可能であるので，今後の問題究明に期待される．

6. 火山性脈動

浅間火山は他のヴルカノ式噴火をする火山，例えば桜島火山と同様に，火山性脈動の発生は一般に著しくない．この点三原山，阿蘇火山のストロンボリ式噴火を常とする火山と相異する．

しかし浅間火山でも，比較的流動性の溶岩が火口底に噴出してくる時には連続的な火山性脈動が現われることがある．

7. B型地震の頻度と火口よりの距離

B型地震は火口底付近に集中して発生するので同じ種類，同じ倍率の地震計を用いて観測された頻度が火口よりの距離と密接な関係を持つことは当然である．

現在の観測網による観測結果と，かつて実施した火山の多数の場所での観測結果とを用いて，B型地震頻度の火口よりの距離により減衰を調べた．時期を異にして行なつた火山上の多数の場所における観測を可能な限り取り入れるため，各点での地震頻度を火口に近い観測点（富士見坂観測点）の頻度との比を以て距離に対する関係を求めた．各点の頻度比を$R(F)$として距離に対する減衰係数を次のように表わされる．

$$R_c(F)=1.24\,e^{-0.270\Delta}$$

8. B型地震の最大振幅と火口よりの距離

B型地震頻度の場合と同様に各点で観測された多くのB型地震について富士見坂のそれとの比を採つて，統計的にこの問題を取り扱つて次のような結果を得た．

$$R_c(A)=0.59\,e^{-0.154\Delta}$$

9. 観測点の地質構造とB型地震頻度及び振幅の関係

地表で観測される地震動は地震計設置場所の地質構造，地盤の性状によつて著しく相違することはすでによく知られた事実である．浅間山のB型地震の頻度及び振幅の減衰は一次的には火口より観測点までの距離の伝播途中における減衰及び波動の幾何学的な拡がりに由る．しかし，それと同じ程度に観測点の地質構造，地盤の性状に関係する．結論だけを述べれば，浅間山の東側の最も新しい軽石等の降下堆積層上に存在する，東前掛，富士見坂，三の鳥居，大窪沢，行者戻し等の観測点においては，B型地震頻度，振幅共に相対的に著しく大きい値を示し，正の異常を示す．これに反し，浅間山の古い山体，つまり黒斑山，牙山，仏岩火山体上に設置した観測点では頻度，振幅共に相対的に著しい負の異常を示す．その中間的の前掛山の南側中腹，鬼押出溶岩流東側等の如く，新しい軽石降下物が存在しないか，または薄い堆積上にある測点では頻度，振幅共に上記両地域の値の中間を示し，異常は小さい．

10. 記録振幅と地震頻度

B型地震の頻度を地震記録紙上より数える際に，振幅のいかんに関係なく，読み残しなく注意深く読んだ頻度（F_1），記録紙上で最大振幅が1 mm 以上の頻度（F_2），3 mm 以上の頻度（F_3）について調べてみた．先ず頻度F_1の内容を知るため，最大振幅を 0.1 mm 毎に分類した頻度をみると，その観測点で頻度，振幅が正の異常を示す所では最大振幅 1.0 mm の地震が最大頻度を示し，大きい負の異常を示す所では，0.4～0.5 mm の振幅で最大頻度を示した．つまり各観測点の noise level，地質構造に密接な関係を持つ．その意味で頻度F_1は noise level 及び地質構造の相違からくる相対的な異常をある程度相殺している．

11. 低倍率及び高倍率地震計で観測されたB型地震頻度の比較

1秒周期．倍率350倍の微動地震計による観測とその後使用した高倍率地震計とは特性が殆んど同じであり，倍率だけを異にする．低倍率地震計で行なつた約15年間の観測結果を現在の地震計によるものと比較検討するために，石本・飯田の頻度と最大振幅との関係を用いて両者の関係をつないだ．B型地震に対する石本・飯田の係数mの値は2.5～3.5の値を示すが，本文に述べた理由でここでは$m=2.3$として上記の頻度関係を求めた．ある期間は両種の地震計で観測されていたので，実際

の両種の地震計による観測結果とも比較して，上記の関係から与えられるものと一致することを確かめた.

12. B型地震の最大振幅と震央距離との関係が明らかにされたので，100 km の最大振幅によつてB型地震の magnitude が与えられたことになる．しかしB型地震はその規模からいつて極めて小さいのでB型地震のエネルギーを求める目的のためには，別のエネルギースケールを導いた方が適当と考えられる.

13. 結　語

1934年以来1969年に至る浅間火山の地震についてその概要を報告したが，今後実施すべき諸問題を指摘することに主眼をおいた.

過去35年に亘つて多くの人の協力によつて観測を継続できたことはいうまでもない．これらの方々に厚く感謝の意を表したい．特に荒牧重雄博士は同火山の地質学的研究を20年余に亘つて行なつたが，同博士よりしばしば地質学的見地よりの貴重な助言を得た．ここに同博士に謝意を表したい.

また1960年に浅間火山観測所観測費が認められるまでの25ヵ年に亘つて，主として日本学術振興会，服部報公会，文部省科学研究費等によつて，観測，研究を実施することができた．この機会に関係各位に感謝の意を表したい.

Fig. 30. Asama Volcano Observatory.

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Fig. 31. Smoked paper recorders for continuous seismic observations.

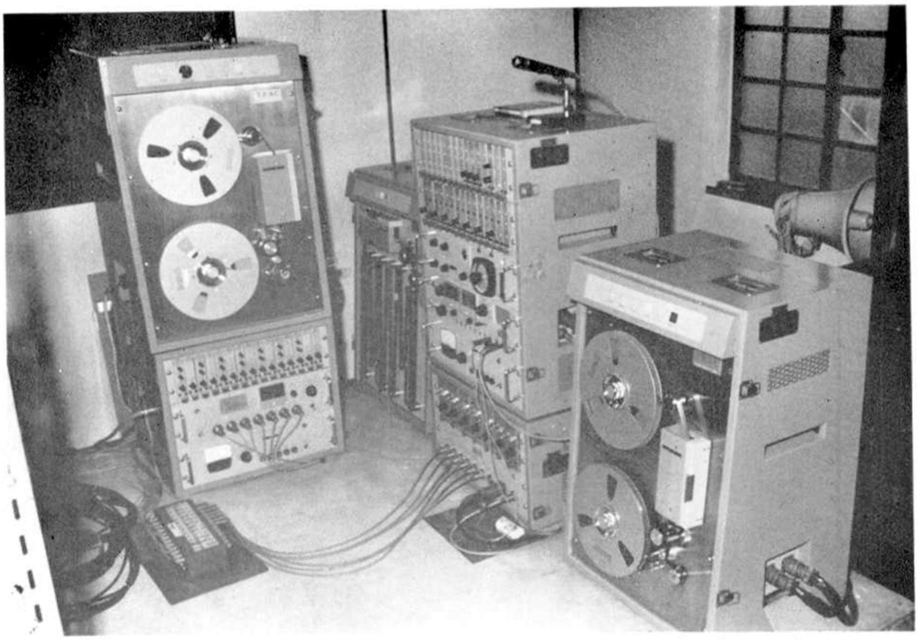

Fig. 32. Seven-channelled tape recorder for seismometric observation.

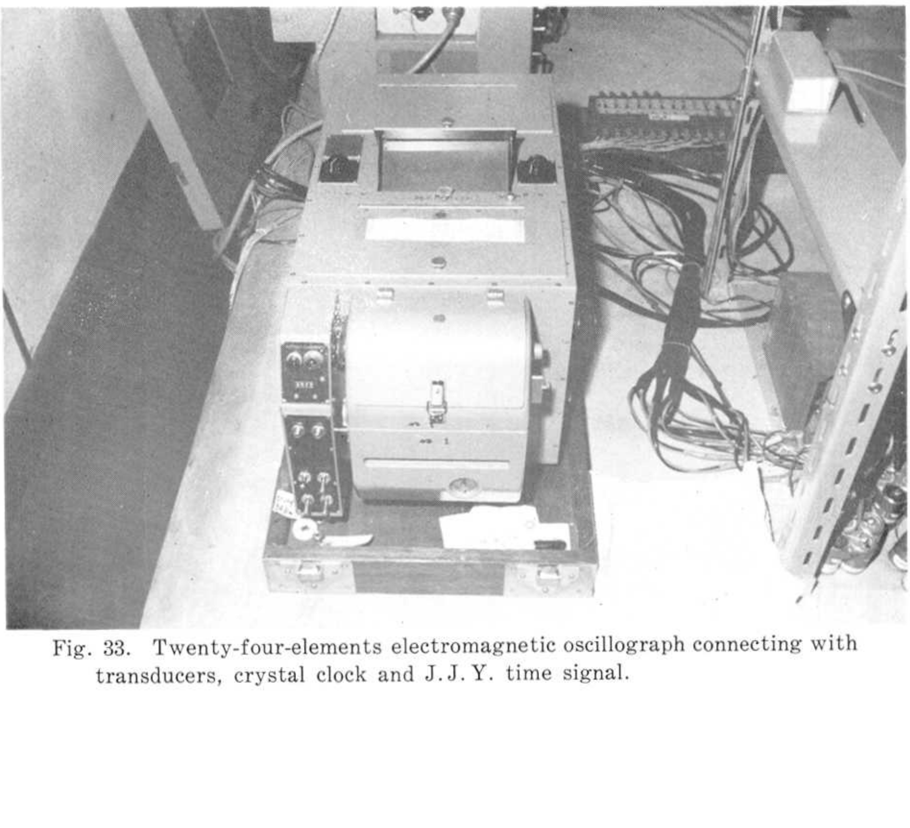

Fig. 33. Twenty-four-elements electromagnetic oscillograph connecting with transducers, crystal clock and J. J. Y. time signal.

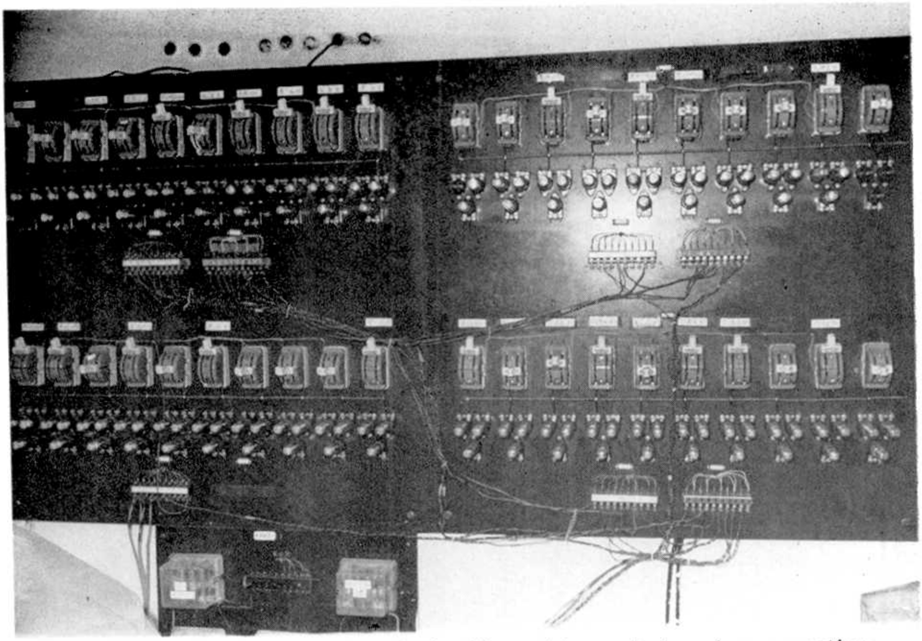

Fig. 34. The distributing board of cables and transmission wires connecting the seismograph recorders in the Observatory with transducers at each station.

Fig. 35. Ishimoto's seismographs and the recorder for the transducers of 5.0 sec in vibration-period, set at Stn. Nakanosawa.

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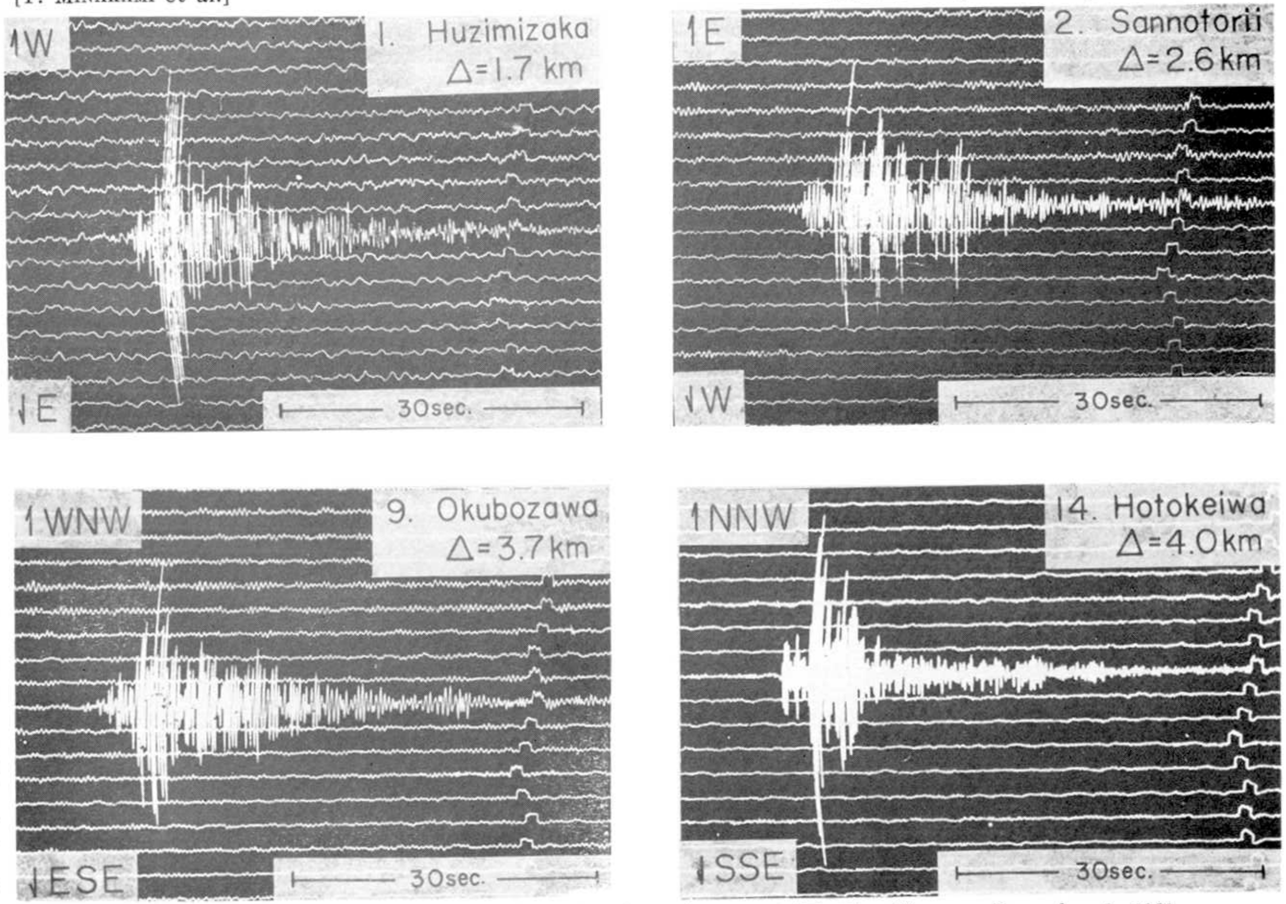

Fig. 36. The typical A earthquake originating from Asama at 07h 29m 30 sec on December 8, 1961.

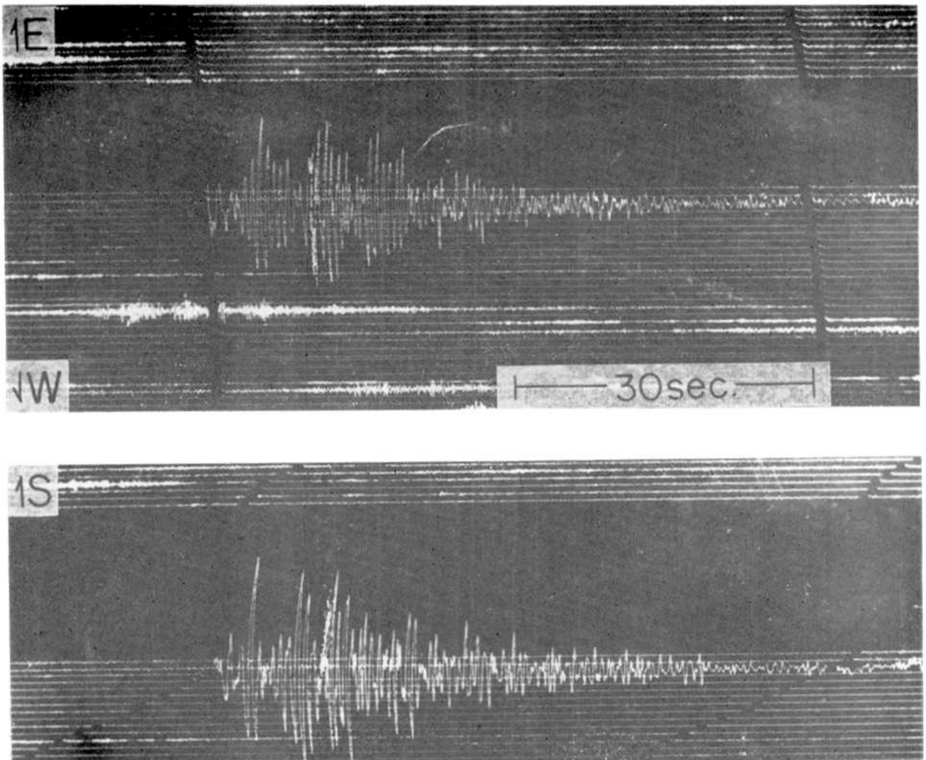

Fig. 37. The explosion earthquake at 20h 17m on September 15, 1961, observed with the low sensitive seismographs at Asama Volcano Observatory.

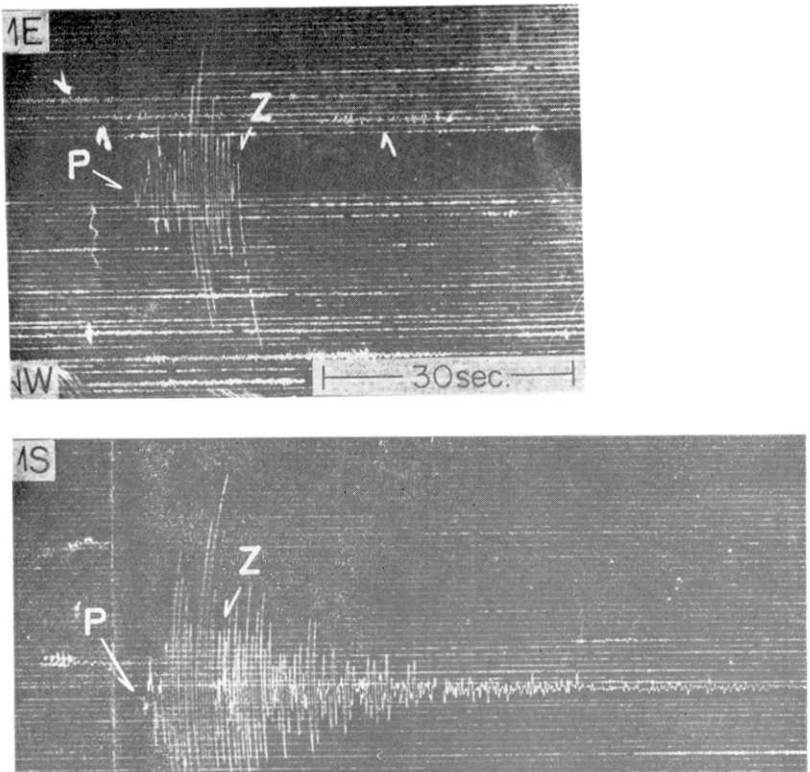

Fig. 38. The explosion earthquake on June 11, 1955, observed with the low sensitive seismograph at Asama Volcano Observatory.

P: P wave, Z: air shock.

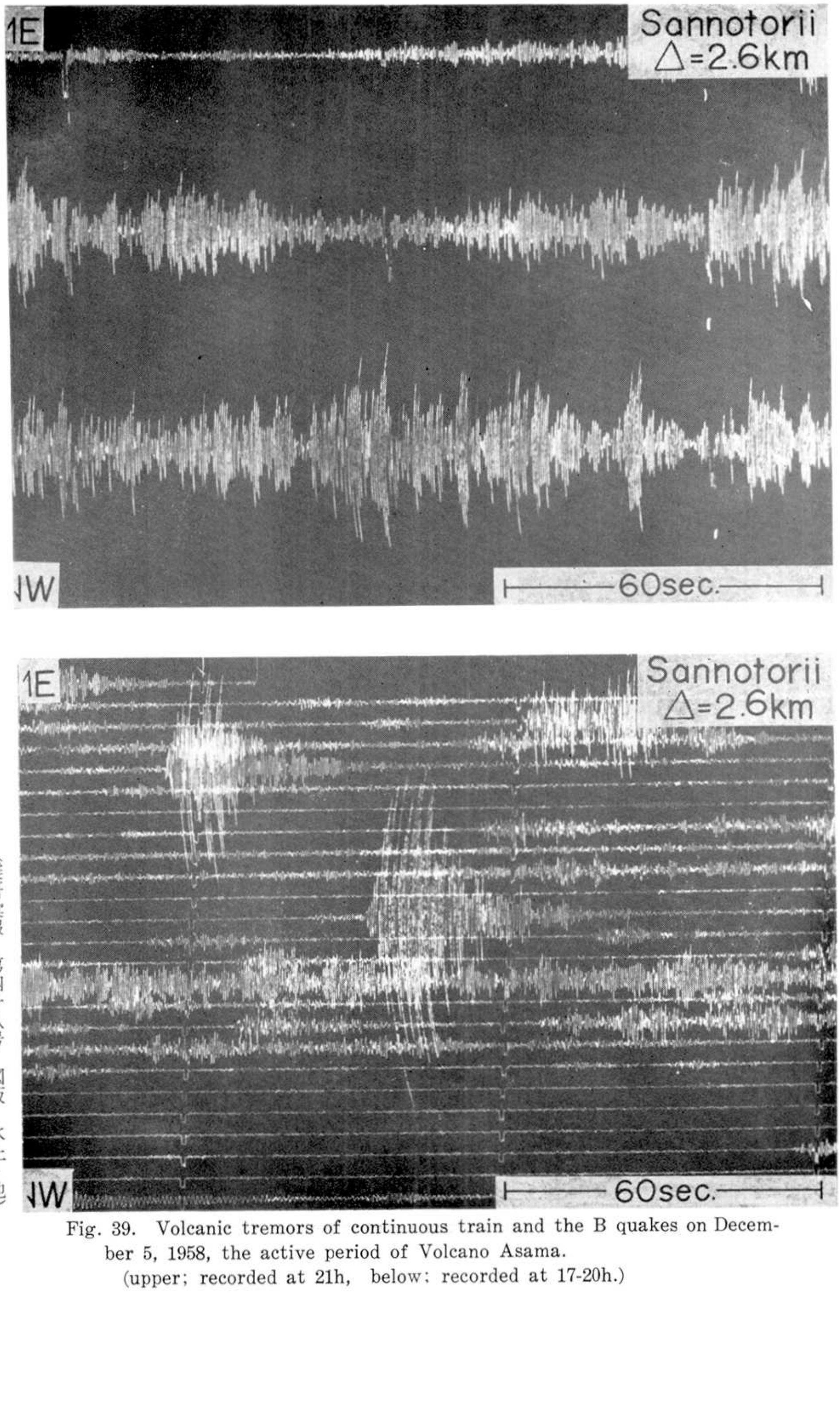

Fig. 39. Volcanic tremors of continuous train and the B quakes on December 5, 1958, the active period of Volcano Asama.
(upper; recorded at 21h, below; recorded at 17-20h.)

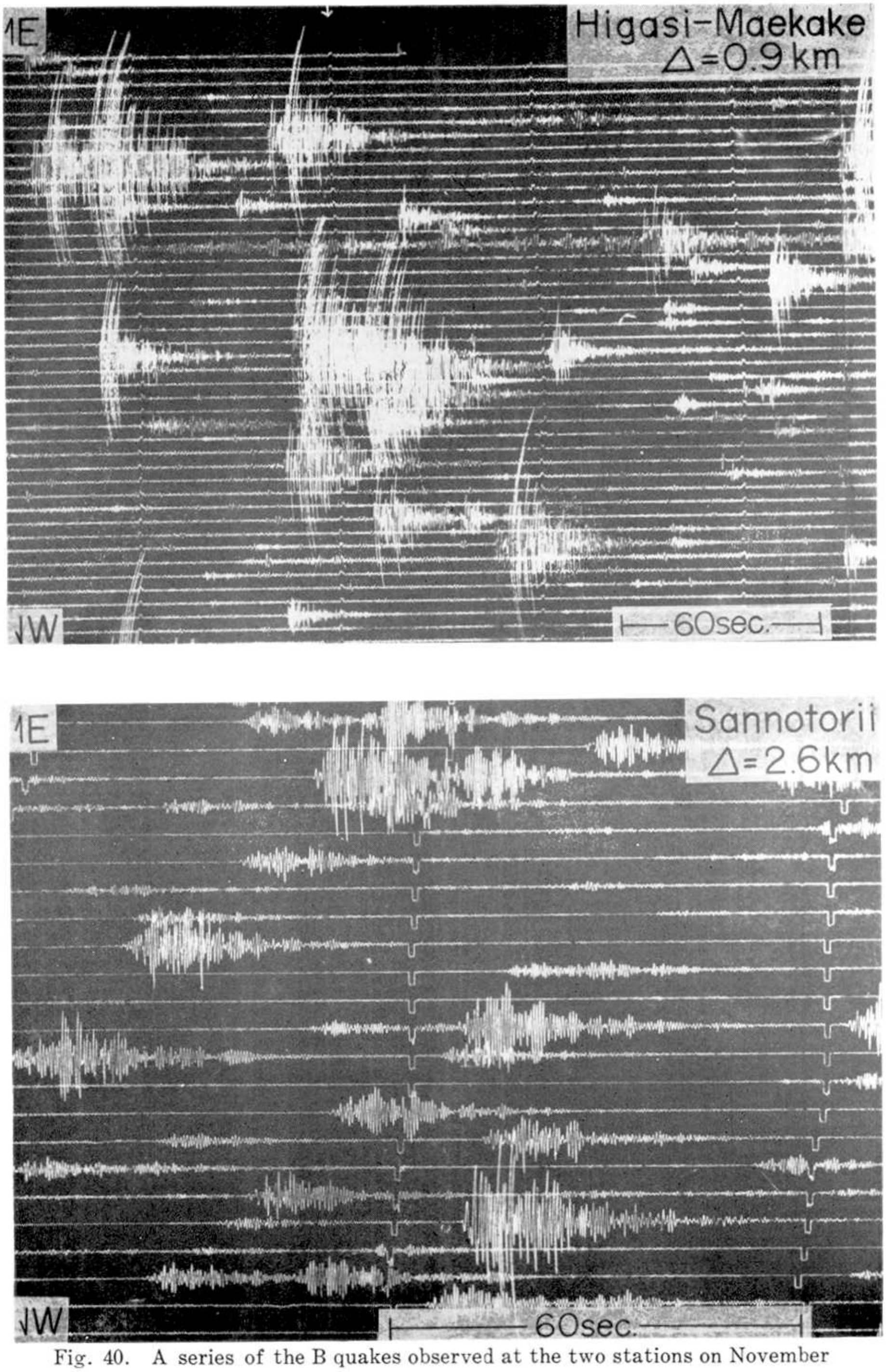

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Fig. 40. A series of the B quakes observed at the two stations on November 9, 1958 (upper) and December 26, 1958 (below).

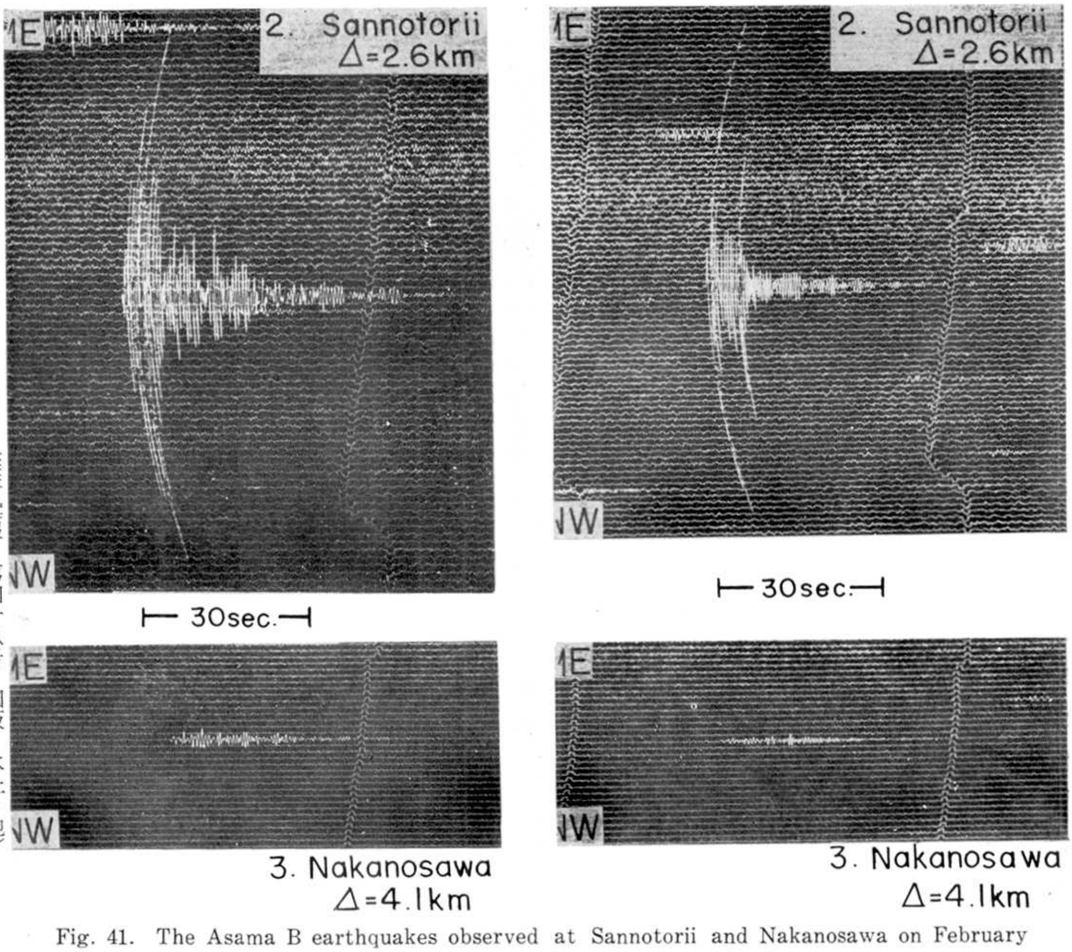

Fig. 41. The Asama B earthquakes observed at Sannotorii and Nakanosawa on February 12, 1959, showing the remarkable attenuation of their amplitudes.
(left; recorded at 0h 44m 30s, right; recorded at 0h 58m 20s.)

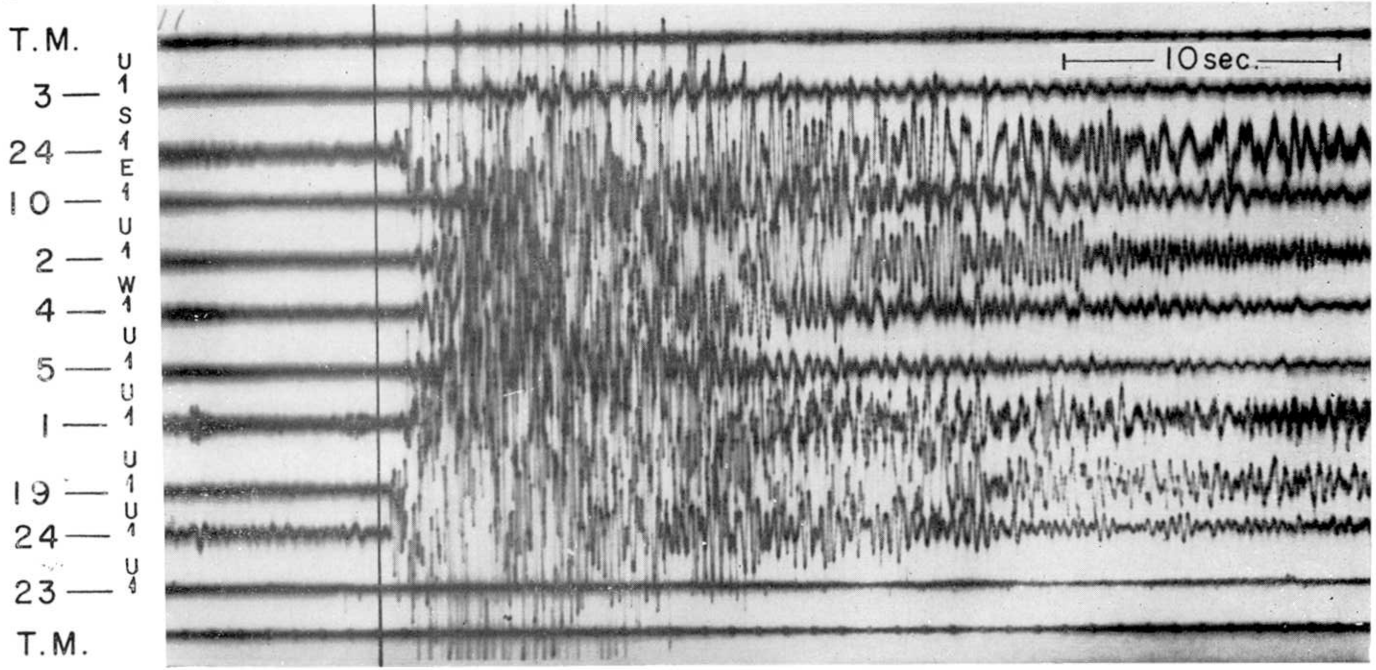

Fig. 42. The seismogram of the B quake obtained with transducers set at a series of the stations on the volcano. (Numerals on the left column indicate station No. in Table 3.)

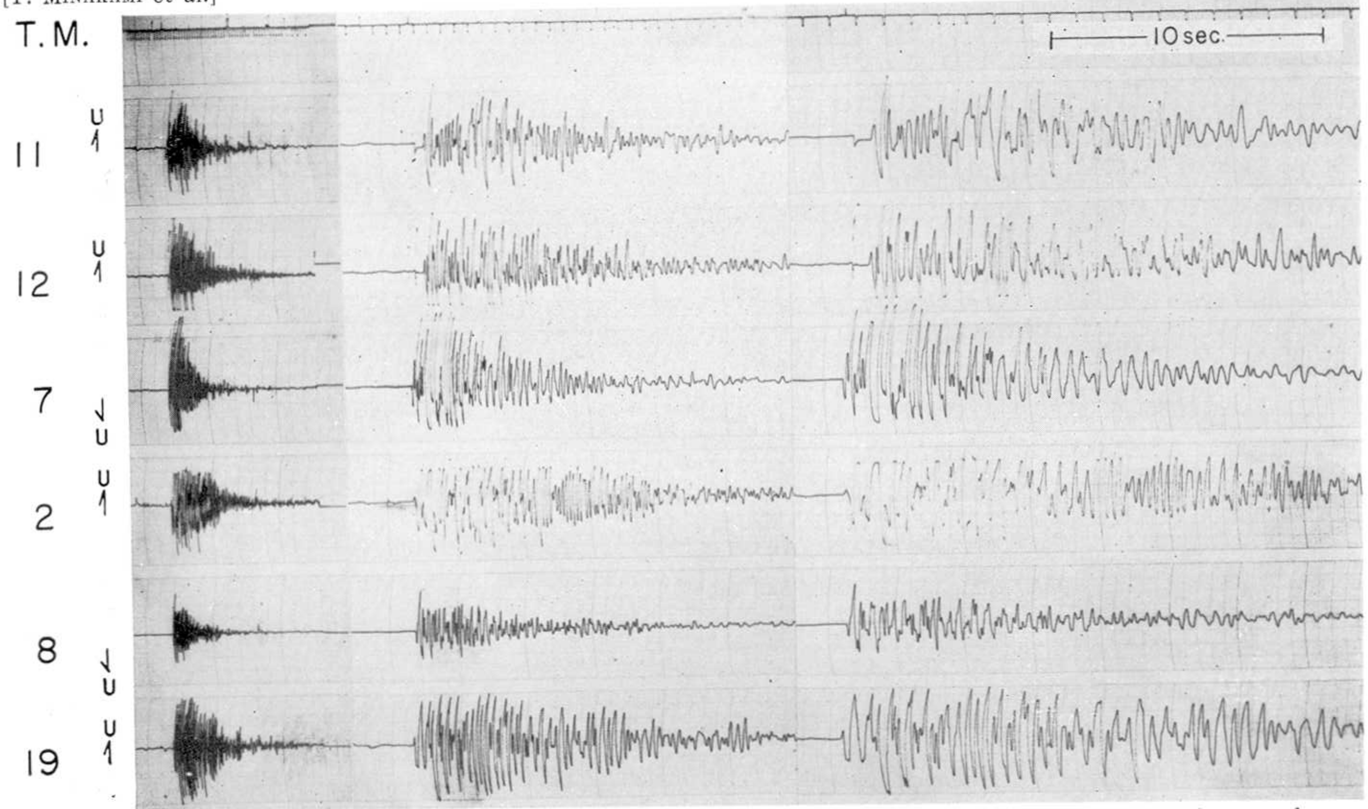

Fig. 43. Seismograms of the Asama B quake caught with the transducers at six stations on the volcano and seven-channelled tape recorder. (Numerals indicate station No. in Table 3.)

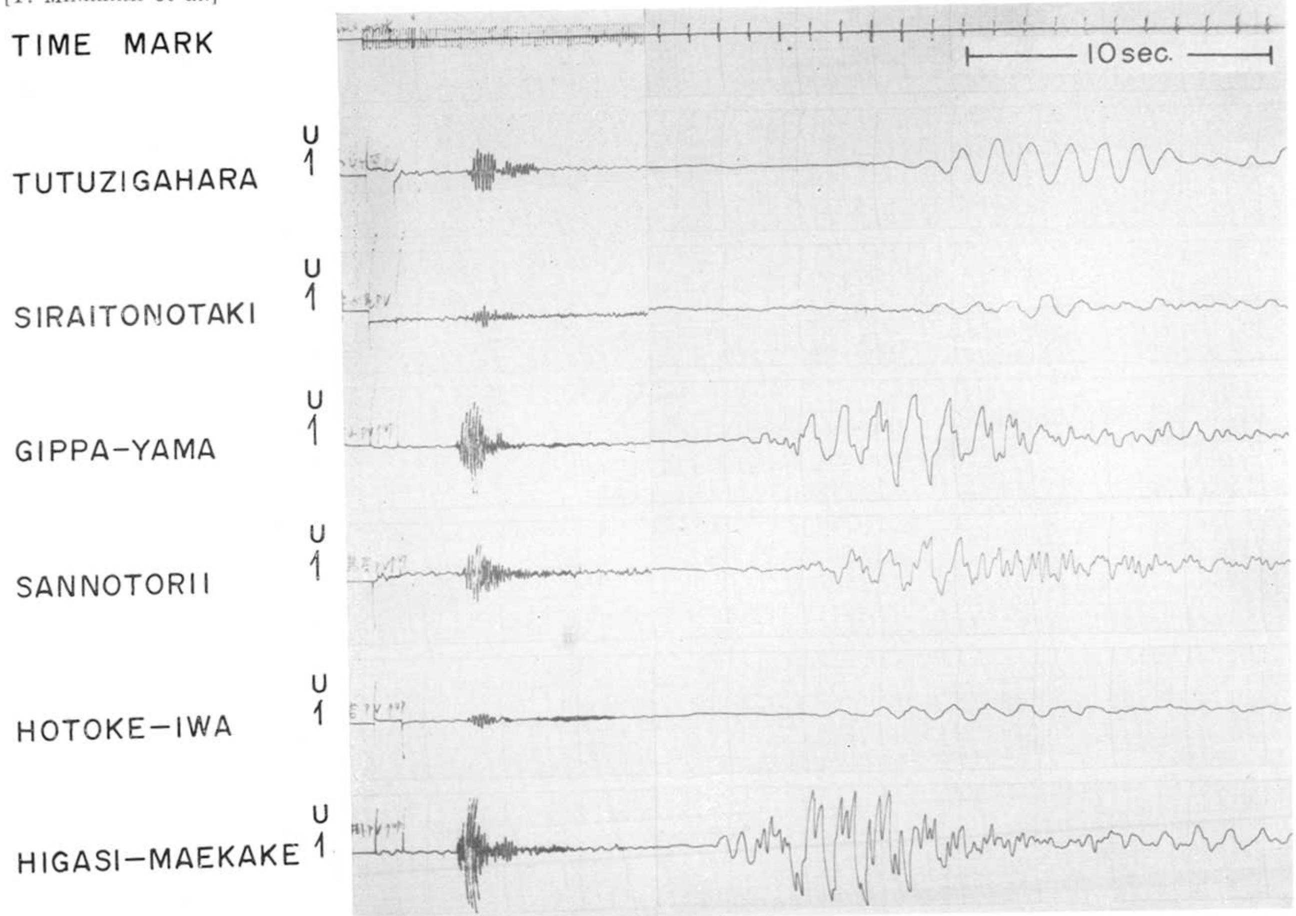

Fig. 44. The Asama B quake observed with the seven-channelled tape recorder, at 16h 56m, May 3, 1965.

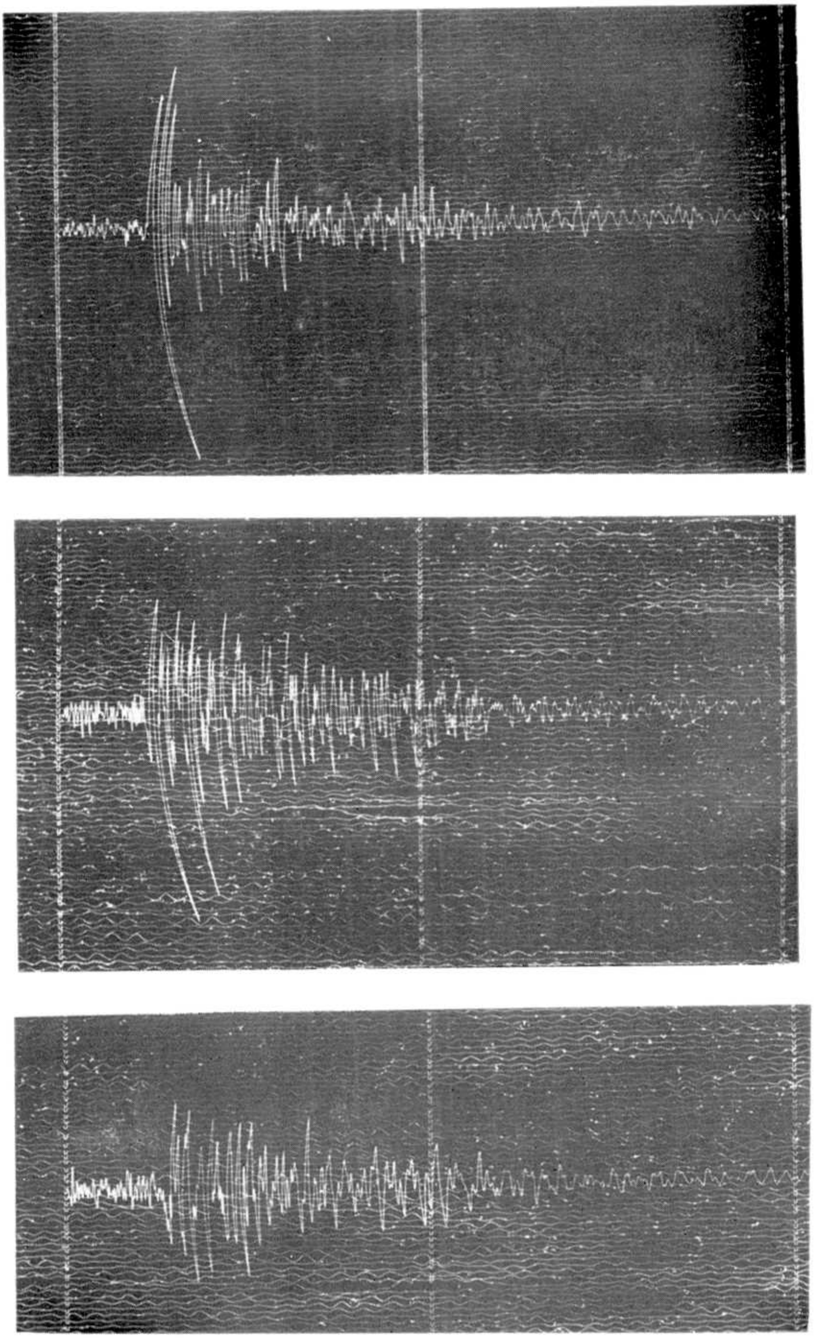

Fig. 45. The seismograms recorded with the seismographs of which the periods of the transducers are adjusted to 5.0 sec. (The earthquake on June 27, 1969, 35°56′, 139°31′, 90 km.)

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