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42. *Fundamental Research for Predicting Volcanic Eruptions. (Part 2)*

Seismometrical Surveys of Volcanoes in Japan and Volcano Sotará in Colombia.

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Contents

1. Introduction

In the previous paper which discussed the same problem, one of the writers reported mainly the general features of earthquakes originating from volcanoes and the crustal deformations on and near volcanoes. Also he introduced, as an example, the empirical formula convenient for predicting volcanic eruptions of Mt. Asama, based on the frequency of the B type earthquake which took place near the summit crater of the volcano. In order to obtain a reliable relation between the seismic frequency and the outbreak of eruption, it is necessary to continue seismometrical observations for quite a long time and to gain more experience of volcanic eruption of respective volcanoes. However, we do not have volcano observatories established for all the volcanoes in the world equipped with highly sensitive instruments including seismographs.

Therefore, a temporary investigation is indispensable to obtain useful information regarding volcanic and seismic activities. Generally speaking, as a first step towards prediction of volcanic eruptions, it is important to know the normal state of volcanoes in respect of their seismic, geodetic and geothermal features, because the abnormal state of volcanoes or the phenomenon of eruption will only be determined by a comparison with its normal state.

On the other hand, the problem concerning the prediction of volcanic eruptions may also be studied from the historical events at the regions with different characteristics in the outbreaks of strong earthquakes of tectonic origin and in their volcanic eruptions. For example, it is well-known that several volcanoes in the Chilian Andes often erupted soon after a large-scale earthquake in the Pacific Ocean off the land of Chili. Seismic and volcanic activity of volcano Meakan in Hokkaido increased remarkably soon after the first Tokati earthquake ($M=8.2$) on March 4, 1952, and Volcano Tokati in Hokkaido became extremely violent in its seismic activity soon after the second Tokati earthquake ($M=7.8$) on May 16, 1968.

Since we find a lot of the same phenomena when reviewing the historical records, it will be necessary to pay attention to the volcanoes located near the epicenters of big earthquakes.

In this paper, the writers report in a condensed form the result of temporary seismometrical observations of Volcanoes Hakone, Huzi, Oomuro-yama and Sotará in Colombia, etc.

2. Seismographs applied to the seismometrical investigations

In order to elucidate the present state of volcanoes and to contribute to the development of research on the above-mentioned problem, a research group was organized in 1965, consisting of the volcano geophysicists and seismologists on the staffs of Hokkaido University, Tohoku University, the University of Tokyo, Nagoya University and Kyoto University. They are divided into seven working teams. Since 1965, seven teams of our research group for predicting volcanic eruptions have covered a lot of dormant and active volcanoes with the temporary seismometric survey. The names of volcanoes covered are listed in

Table 1. Volcanoes covered with the seismometrical survey. (Research Group for Predicting Volcanic Eruptions.)

Team	1965	1966	1967	1968
YOKOYAMA (Hokkaido Univ.)	Huzi	Tokati	Tokati Tarumai	Tokati Esan
SUZUKI (Tohoku Univ.)	Huzi	Zao	Zao	Yake (Akita) Zao
MINAKAMI (Tokyo Univ.)	Huzi	Nasu Hakone Kutinoerabu Sotará	Kusatu-sirane Midagahara Hakone	Oomuro Hakone Arenal
SHIMOZURU (Tokyo Univ.)	Huzi	Koozu-sima Unzen	Miyake-sima Oosima	Oosima Kirisima
IIDA (Nagoya Univ.)	Huzi		Yake (Nagano)	Yake (Nagano)
KUBOTERA (Kyoto Univ.)	Kuzyu	Unzen	Turumi Yuhu	Kinposan Kuzyu
YOSHIKAWA (Kyoto Univ.)	Huzi	Kutinoerabu	Kaimon Kutinoerabu	Kaimon

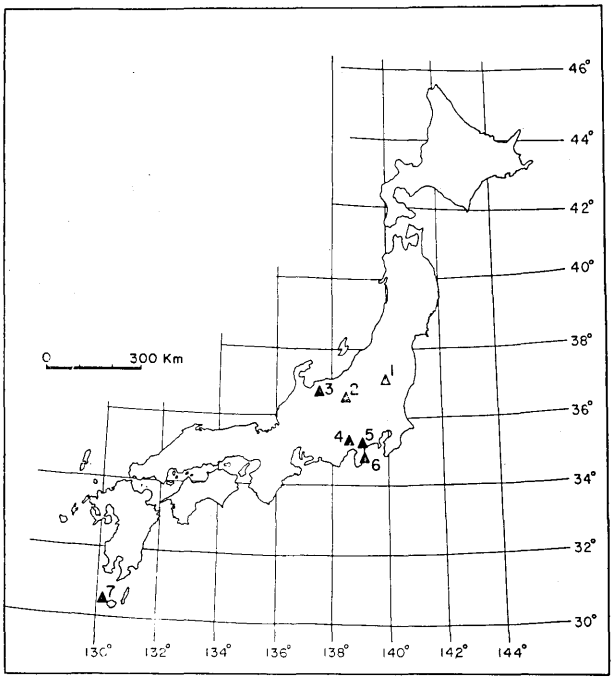


Fig. 1. The geographical position of the volcanoes which were covered by the writers' seismometrical survey.
1: Nasu, 2: Kusatu-sirane, 3: Midagahara, 4: Huzi
5: Hakone, 6: Oomuro, 7: Kutinoerabu

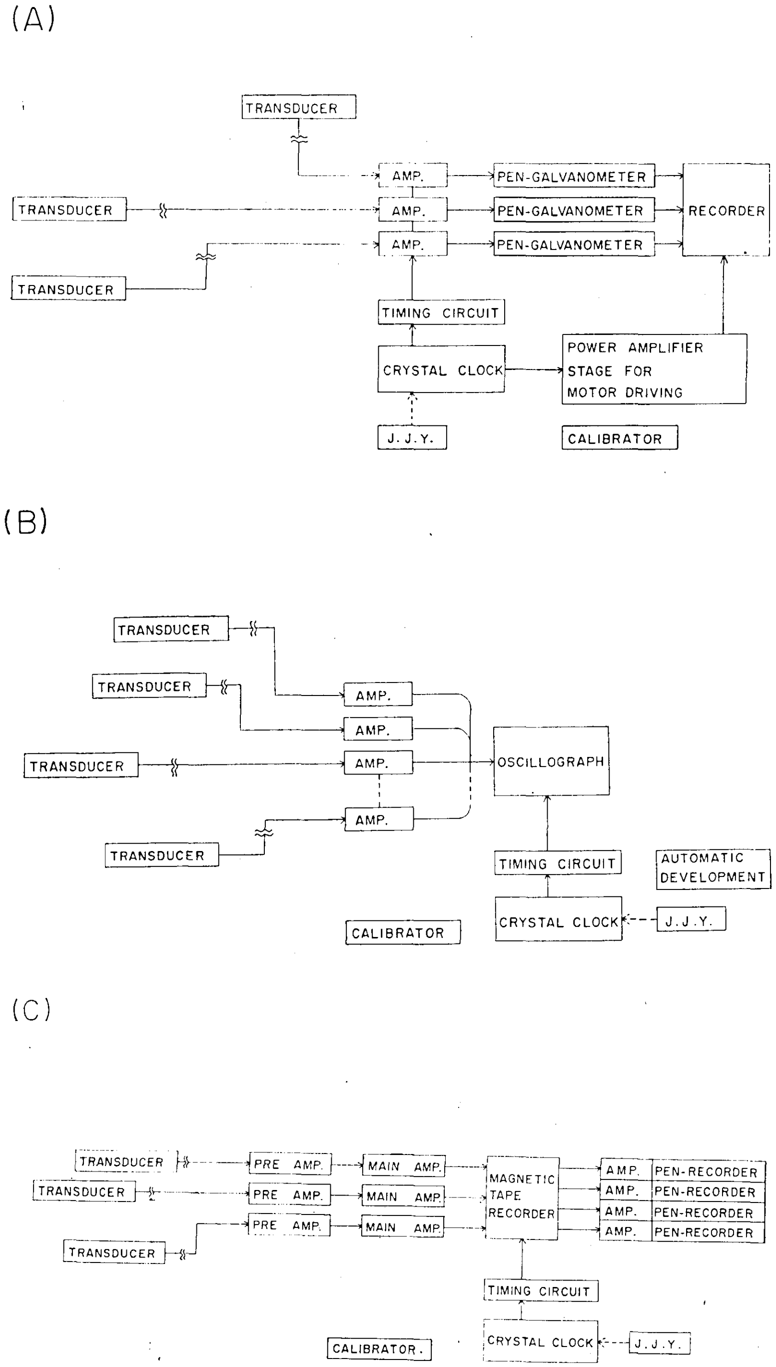


Fig. 2. (A), (B), (C). The block diagrams of the seismographs which were applied for the present seismometrical survey of volcanoes.

Table 1.

The writers' team, organized in 1965, has carried out a series of temporary observations of volcanoes in a dormant state where no permanent observatory has been established.

For the seismometrical investigation of volcanoes, the writers applied a telemetering method with transmission wire, the transducer set at various places on a volcano being connected with the recorder through the amplifier. The transducers used for the purpose are of 1.0 and 0.3 second period. The writers used three kinds of recorders; the first consists of the pen-galvanometer with smoked paper for continuous observation, the second an oscillograph with 12 elements and with bromide paper, and the third the data-corder with magnetic tape. These three apparatus are illustrated in the form of block diagrams in Fig. 2.

These seismographs are applicable to the displacement one in some cases and to the velocity or acceleration one according to the purpose of respective investigations and the nature of earthquake motions.

The characteristic curves of the above instruments are illustrated in Fig. 3. The sensitivity and magnification of the seismographs are adjustable in a range according to the purposes of the research and to

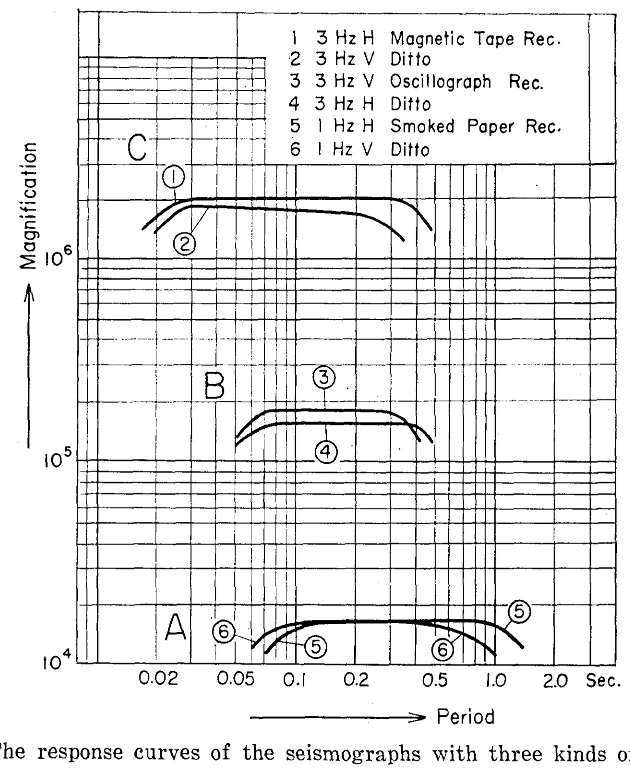


Fig. 3. The response curves of the seismographs with three kinds of recorder.

the noise level.

The method described above is useful and convenient for the seismometrical observation of volcanoes, because the electric supply is required at the recorder station only and nothing at the transducer station.

3. The 1959-1960 and 1966 earthquake swarms of Volcano Hakone

Volcano Hakone, situated at the south-eastern foot of Volcano Huzi (Fuji), has no essential eruption in the historical records though the fumarolic activity is still active on the flank of the central cones Kamiyama and Komaga-dake. However, a land-slide often took place on the flank of the central cone, Kamiyama, especially along the northern flank in historical time. It is not yet made perfectly clear whether the land-slides at Hakone were caused by the usual mode along a steep slope independent of the volcanic activity or had a close connection with the subterranean vapour pressure as in the case of the 1888 Bandai-san eruption. According to the investigation of the 1953 Hakone land-slide, the writers found that it started from a fumarolically active place on the steep northern slope of Soounzan and that a lot of fumarole and sources of hot springs were extremely active on the slide plane. Therefore, it is reasonable to assume that in such Hakone land-slides some would at least have originated from the vapour pressure of volcanic origin such as the eruptions of Bandai-san and Kusatu-sirane.

On the other hand, we have frequently experienced in recent years earthquake swarms including strong ones inside the Hakone caldera resulting in some slight damage to dwelling houses and roads inside the caldera.

Though the Volcano Hakone is situated near Tokyo and convenient for investigation, the seismological and other geophysical studies of Volcano Hakone were not made up to the 1959 Hakone earthquake swarm. The earthquake swarm was so strong that people living in the Hakone area were worried about a possible eruption or land-slide. However, the writers had made temporary seismological observations since October 1959 in compliance with the request from the Kanagawa prefectural Government. Our seismometrical observations at Hakone were made up till the end of March, 1968, and were continued with other geophysical observations by the Hot Spring Research Institute, Kanagawa prefecture. Besides the seismometrical observations, the writers carried out continuous observations of the geothermal temperature at Oowaku-zawa, the fumarolic and permanently sliding area along a steep valley, and the triangulation in the same area by means of Wild's theodolite.

The writers set up in October, 1959, a seismometrical net-work on the northern slope of Kamiyama where a transducer was set at four places. These transducers were connected by wire to the recorder respectively which was set at the Kamiyu recorder station located 2 km north of the summit of Kami-yama as illustrated on the map of Fig. 4. Besides the above seismometrical net, Ishimoto's acceleration seismograph with three components was set at the recorder station for the recording of earthquakes.

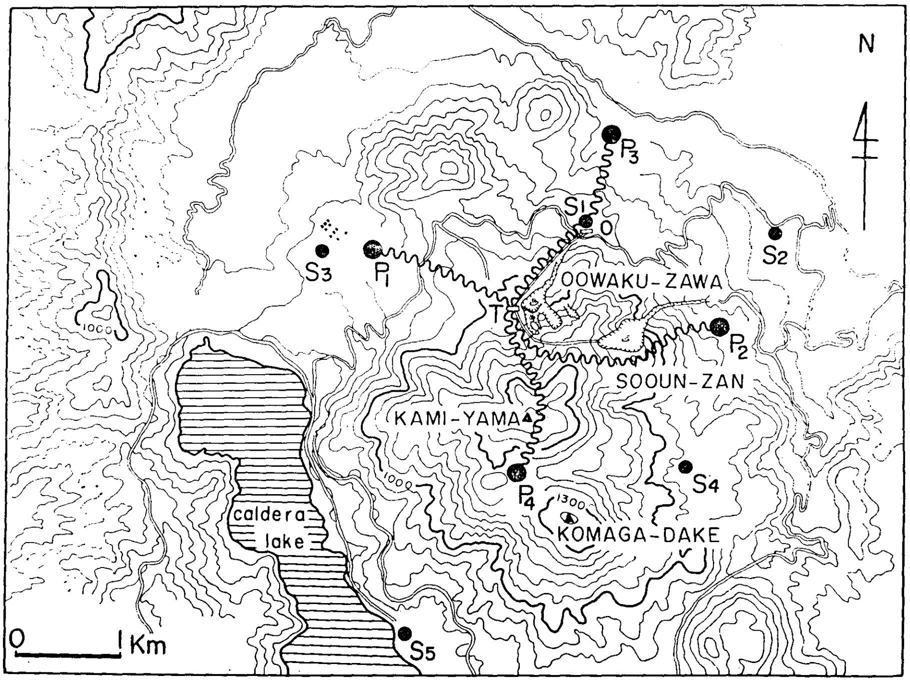


Fig. 4. The topographical map of Volcano Hakone and the locality of the seismometrical net-work.
P_1—P_4: locality of transducer
S_1—S_5: locality of Ishimoto's acceleration seismograph

In addition to the continuous seismometric observations mentioned above, another net-work was established for the special purpose at both seismically active and calm stages, though only for a short period.

In 1959-1960 and 1966, we observed remarkable seismic activity inside the Hakone caldera. The mode of seismic activity in Hakone including the above two cases has usually been in the form of a swarm similar to seismic activity in other volcanic regions.

These earthquakes were observed in the above seismometrical networks, their hypocentral positions being given on the basis of S-P. As

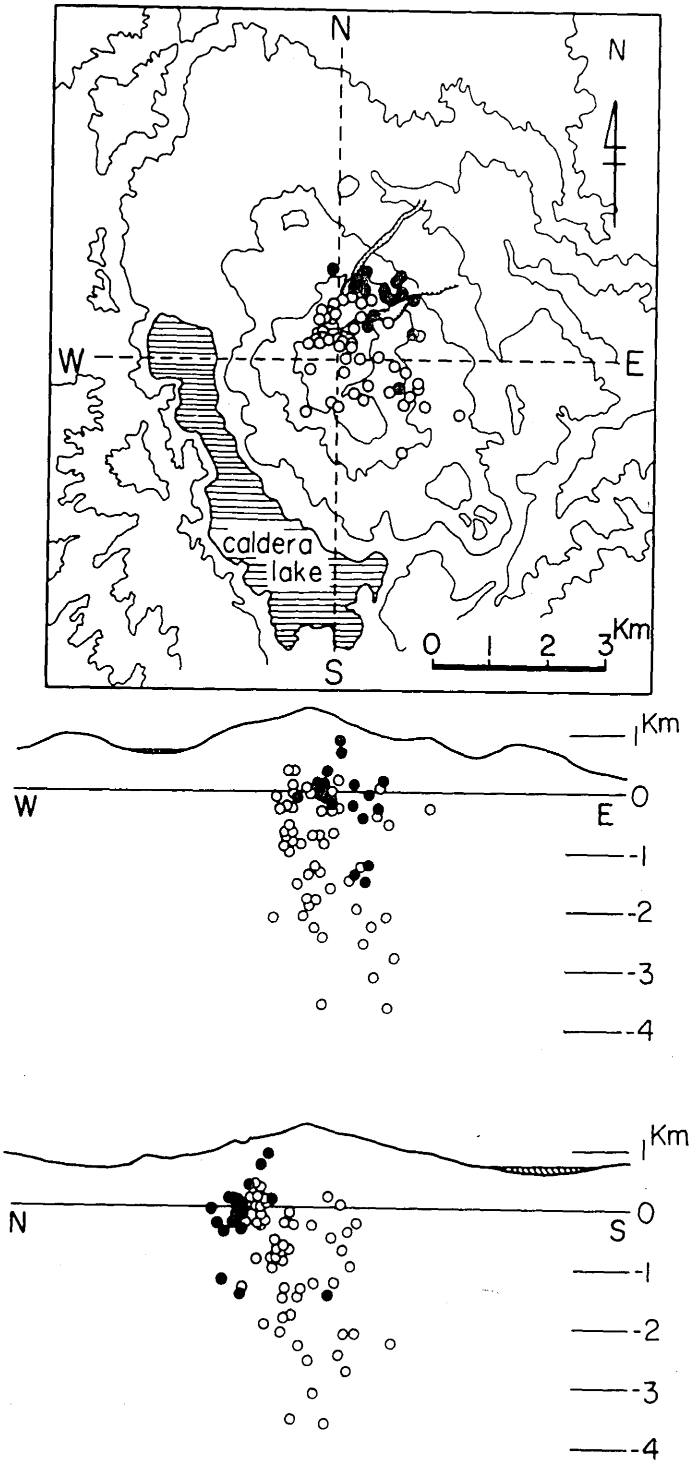


Fig. 5. The hypocentral distributions of the 1959-1960 and 1966 Hakone earthquake swarms.
opened circle: the 1959-1960 earthquakes
closed circle: the 1966 earthquakes

is seen in Fig. 5, the epicenters of both the 1959-60 earthquakes and the 1966 earthquakes concentrated in a narrow area from the summit of Kami-yama to the Oowaku fumarolic field, their hypocentral depth being found in a range from 0.5km to 4.0km. The 1966 epicenters shifted slightly to the north by 0.9km as compared with those of former earthquakes, and the 1966 hypocentral depth was less than 1.5km. In other words, the 1966 earthquakes took place just below the Oowaku-sawa and Su-zawa fumarolic fields, their depths being extremely shallow.

According to the investigation of hot springs in the Hakone area made by Y. Oki and others, the temperature of such springs at Gora, located at the northern foot of Kami-yama and down the Suzawa river, showed a sudden anomalous rise of more than 20°C after May 23, 1967 and this anomalously high temperature still lasted. From the fact that the anomalous phenomenon of the Gora hot springs appeared just one year after the 1966 earthquake swarm and the hot spring water of the Gora area originated mainly from the Suzawa fumarolic field or the epicentral area of the 1966 earthquakes, it is reasonable to assume that the extremely shallow earthquakes from May to July in 1966 must

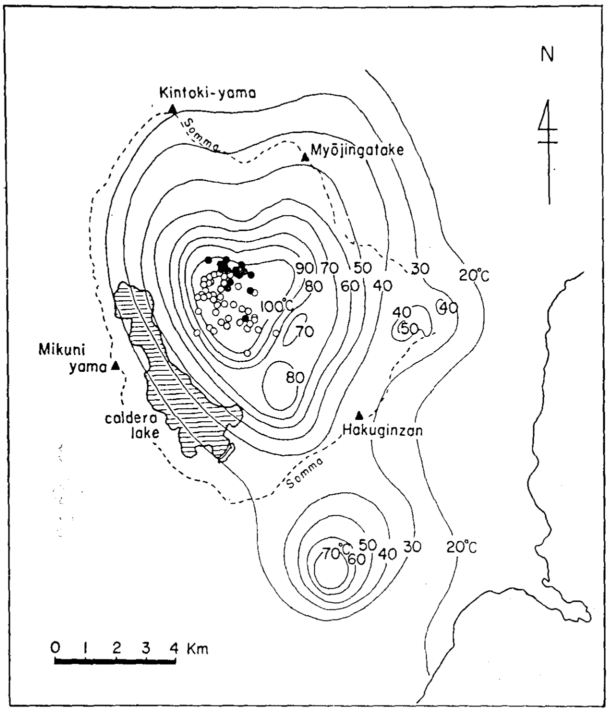


Fig. 6. The epicentral distribution and the isothermal lines of the geothermal temperature at the depth of sea-level. (After Y. Oki et al., 1968)

have been caused by an abnormal increase of vapour pressure under the Suzawa fumarolic field, or by the abundant heat supply to the above-mentioned field from the deeper part.

On the other hand, Y. Oki measured the geothermal temperature at various depths in the Hakone caldera and its adjacent area by utilizing a number of boring holes which had been made for arriving at the source of hot springs. He drew isothermal lines of the geothermal temperature, which were reduced to the value at the depth of sea-level. As can be seen clearly on the map at Fig. 6, the 1959-1960 and 1966 epicenters are located where the geothermal temperature at the depth of sea-level are higher than 100°C, the isothermal line of 100°C perfectly agreeing with the outer margin of the epicentral areas in the 1959-60 and the 1966 earthquake swarms.

As described above, the Hakone earthquakes provides an important clue to the study of the connection between earthquakes originating from a volcano and the heat supply from the deep part under a volcano.

4. The seismicity at the normal or calm period of Volcano Hakone

It will be necessary to describe in outline the seismic activity of Volcano Hakone by means of the seismic frequency based on the seismic observation carried out with the above-mentioned network since October, 1959. For this purpose, the writers investigated the distribution of daily seismic frequency of earthquakes originating from the volcano.

In Table 2, the monthly frequency of the Hakone earthquakes during that period is listed together with the days covered by operation of the seismometrical net. As described above, the writers used two kinds of seismographs, one of which was Ishimoto's acceleration seismograph for earthquakes strong enough to be felt by persons, the other a seismograph with higher sensitivity of displacement magnification 5000.

During the observation the two earthquake swarms, of which one continued from September 1959 to May 1960 and the other from May to September 1966, were observed in the Hakone seismometrical net in the period from September 1959 to March 1969. In order to make clear the seismicity at calm state or normal state of Volcano Hakone, the daily seismic frequency was obtained from the result of observations in the seismic calm period in which the above two periods were excluded. As a result, the daily seismic frequency is given by 0.10/day based on the acceleration seismograph, and by 0.36/day from the higher sensitive displacement seismograph mentioned above. The writers believe that the above two values will be useful for judging from the seismic observation whether Volcano Hakone is active or not.

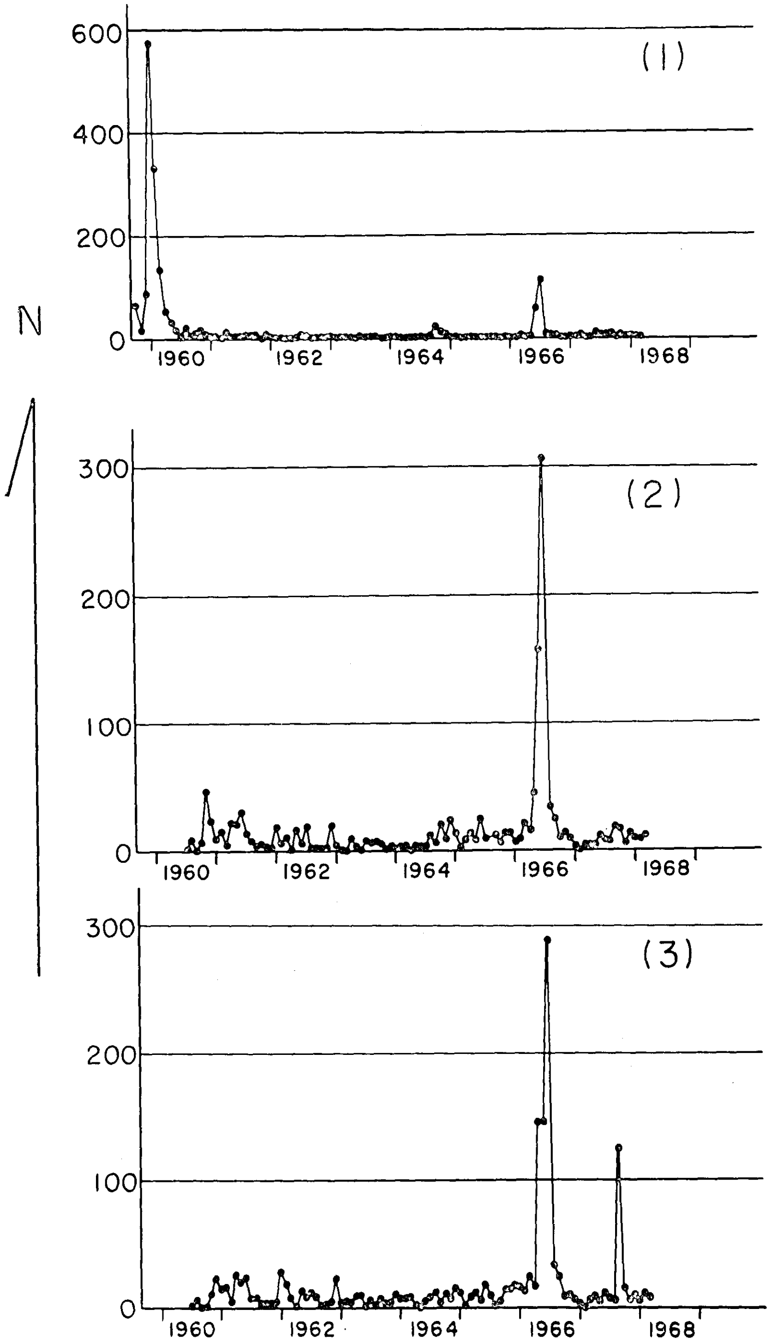


Fig. 7. The monthly frequency of the Hakone earthquakes.
(1): observed by Ishimoto's acceleration seismograph at Station T.
(2): observed by high sensitive displacement seismograph at Station P_2.
(3): observed by high sensitive displacement seismograph at Station P_4.

Table 2. Monthly frequency of the Hakone earthquakes observed with the Ishimoto's acceleration seismograph and the displacement seismograph.

Month	Monthly freq. (Acceleration)	Number of days covered	Monthly freq. (Displacement)	Number of days covered
1959				
Oct.	65	23		
Nov.	16	30		
Dec.	87	31		
1960				
Jan.	572	31		
Feb.	332	29		
Mar.	135	31		
Apr.	51	30		
May	31	31		
June	15	30		
July	4	31		
Aug.	20	31		
Sept.	4	30		
Oct.	10	31		
Nov.	18	30	57	29
Dec.	8	31	24	28
1961				
Jan.	4	31	10	25
Feb.	4	28	15	21
Mar.	3	31	5	31
Apr.	12	29	22	19
May	3	31	21	31
June	3	30	30	30
July	4	29	14	31
Aug.	5	30	7	25
Sept.	5	30	4	30
Oct.	5	31	5	31
Nov.	0	25	3	28
Dec.	7	17	3	16
1962				
Jan.	2	31	19	21
Feb.	1	28	7	28
Mar.	1	31	11	31
Apr.	0	27	1	28
May	0	31	16	31
June	2	30	6	21
July	8	31	19	23
Aug.	5	31	2	7
Sept.	0	30	3	26
Oct.	1	31	2	20
Nov.	2	25	3	11
Dec.	2	29	20	31
1963				
Jan.	2	24	4	25
Feb.	1	22	1	9
Mar.	1	25	0	3
Apr.	3	30	10	30
May	1	31	4	20
June	1	30	1	27
July	4	31	8	31
Aug.	1	31	7	31
Sept.	2	30	7	25
Oct.	3	31	6	26
Nov.	0	30	2	18

(to be continued)

Table 2. (continued)

Month	Monthly freq. (Acceleration)	Number of days covered	Monthly freq. (Displacement)	Number of days covered
Dec.	0	31	4	30
1964				
Jan.	2	31	2	19
Feb.	2	29	4	29
Mar.	1	31	4	27
Apr.	0	30	1	13
May	0	31	4	25
June	2	30	4	27
July	3	31	4	22
Aug.	1	31	12	29
Sept.	4	30	6	17
Oct.	21	31	21	31
Nov.	12	30	9	28
Dec.	7	31	24	31
1965				
Jan.	1	31	13	31
Feb.	1	28	2	28
Mar.	0	31	9	31
Apr.	1	30	14	30
May	1	31	8	31
June	1	30	25	30
July	1	31	9	30
Aug.	1	31	—	0
Sept.	1	30	12	23
Oct.	1	31	6	31
Nov.	0	30	13	21
Dec.	1	31	14	30
1966				
Jan.	0	31	7	30
Feb.	0	28	9	23
Mar.	5	31	21	31
Apr.	2	30	16	30
May	3	31	45	31
June	57	30	158	30
July	112	31	306	31
Aug.	8	31	34	31
Sept.	5	30	25	27
Oct.	5	31	10	31
Nov.	0	30	14	30
Dec.	2	31	10	31
1967				
Jan.	1	31	3	30
Feb.	2	28	0	15
Mar.	6	31	4	9
Apr.	1	30	4	17
May	2	29	4	31
June	10	30	11	30
July	6	31	8	31
Aug.	6	31	7	31
Sept.	8	30	19	30
Oct.	2	31	17	31
Nov.	7	30	6	29
Dec.	4	31	14	31
1968				
Jan.	3	31	10	30
Feb.	2	29	9	24
Mar.	2	31	12	31
Total	1792	3043	1386	2298

It must be added here that besides the two earthquake swarms described above, a smaller scale earthquake swarm sometimes manifested for a few days or hours and in some cases a series of extremely shallow and micro earthquakes only were recorded by the transducer set near the top of Kamiyama as in the case of the earthquakes on September 8, 1967.

Table 3. The seismic frequency of the September 8, 1967 earthquakes recorded at the four stations.

Date	Ninotaira	Kamiyama	Kozuka-yama	Onsenso
Sept., 1967				
6	0	0	0	0
7	3	3	3	3
8	4	112	4	3
9	0	0	0	0
10	0	0	0	0

According to the seismometrical observation on the Hakone caldera over the last nine years, the earthquakes took place at a depth from 0.5km to 4km under the Oowaku-sawa and Su-zawa fumarolic fields in a form of swarm, while the micro earthquakes of shock type took place for few days or hours also in a form of swarm near the top of Kamiyama.

The relation between the maximum amplitude of an earthquake and its frequency was studied for these Hakone earthquakes and, as a result, the value of Ishimoto-Iida coefficients was found to be 2.6 for the 1959-1960 earthquakes and 2.6 alike for the Hakone earthquakes during the period from January 1961 to March 1968.

5. Temporary seismometrical investigations of Hakone with the high sensitive seismograph

In order to study more precisely the nature of the Hakone earthquakes, the writers set the observation net in Kamiyama and its northern flank with the high sensitive seismographs for the following periods in Table 4. For the purpose, the oscillograph with 12 components and the magnetic tape were used as the recorder apparatus.

Since the sensitivity of the instruments used in the above experiments was outstandingly higher than that in the continuous observation, several earthquakes originating from the volcano should at least have been expected to be recorded in the above covered times even at the

Table 4.

	Date	Time covered	Magnification of instrument
First experiment	October 30-November 2, 1967	25 hours	$2\text{-}5\times10^6$
Second experiment	September 12-14, 1968	27 hours	$2\text{-}5\times10^6$
Third experiment	January 20-27, 1969	35 hours	$2\text{-}5\times10^6$

calm period of Hakone, if Ishimoto-Iida's relation materialised without the lower limit. However, no Hakone earthquake was recorded in the period of the three experiments mentioned above, though a series of earthquakes which took place at another place were recorded at the writers' net-works.

Judging from the result of the seismometrical observations at Hakone over the last nine years and the special seismometrical experiments, it seems that the Hakone earthquakes have a maximum seismic frequency in the maximum amplitude, of near 0.05 micron, at the epicenter.

In the first seismometrical experiment, we were fortunate in catching the following earthquake with the high sensitive net. Its arrival times at five transducer stations are listed in Table 5, together with S-P and the direction of the initial motion.

Table 5. The arrival time, S-P and the direction of the initial motion of the earthquake on November 2, 1967.

Station	Arrival time	S-P	Initial motion
	$0^h\ 21^m$		
Simoyu	52.50 sec	3.69 sec	up
Oowaku-zawa	52.41	3.48	up
Kamiyama	52.55	3.66	up
Kozuka-yama	52.38	3.41	up
Onsenso	52.21	3.39	up
Ninotaira	52.47	3.78	up

Based on the arrival times at the five stations, the direction of the epicenter and the apparent velocity of the initial wave, that is, P wave were obtained and the epicentral distances from these stations were given approximately by S-P. As is seen in Fig. 8, the direction of the epicenter and the apparent velocity were given by N 55°50′ and 7.1 km/sec respectively, and the distance from the net was estimated at about 25km. Therefore, the epicentral position would be on the eastern middle flank of Mt. Huzi (Fuji), or on the middle distance between

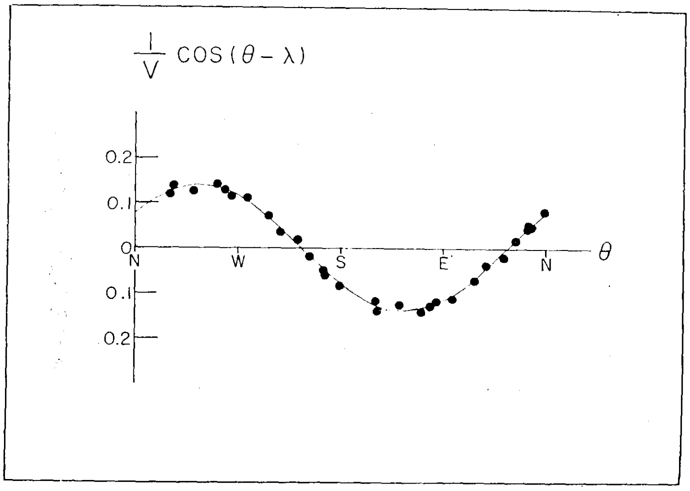


Fig. 8. The direction $(\theta-\lambda)$ to the epicenter from the Hakone net and the apparent velocity (V) of the earthquake at 0h 21m on November 2, 1967.

Hoei-zan and Ko-huzi, its hypocentral depth being estimated at several kilometers. Seeing the geographical position of Volcano Huzi, the writers believe that the seismological and geophysical observations at Hakone will be exceedingly useful and important not only for the volcanological study of Volcano Hakone, but also for the seismological study and for observing any activity of Volcano Huzi.

6. Seismometrical survey of Volcano Huzi (Fuji)

Although Volcano Huzi has been in a dormant state for the last two hundred and fifty years, Huzi has experienced a lot of eruption in historical time, of which the 1707 one is the most recent. Therefore, it will be natural to expect that the Volcano Huzi may become active again as in its 864 and 1707 eruptions. It is, however, rather strange that we have no permanent observatory at Mt. Huzi for obtaining continuous information concerning the seismic and volcanic phenomena originating from the volcano.

For making up the lack of information, all members affiliated to the research group for prediction of volcanic eruptions, carried out a temporary seismometrical observation at six places on the flank and skirt of Mt. Huzi during the period from 3rd to 13th October, 1965.

Since the summarized report about the above observation has already been made in a condensed form, the result made by the writers' team is mentioned briefly in this paper.

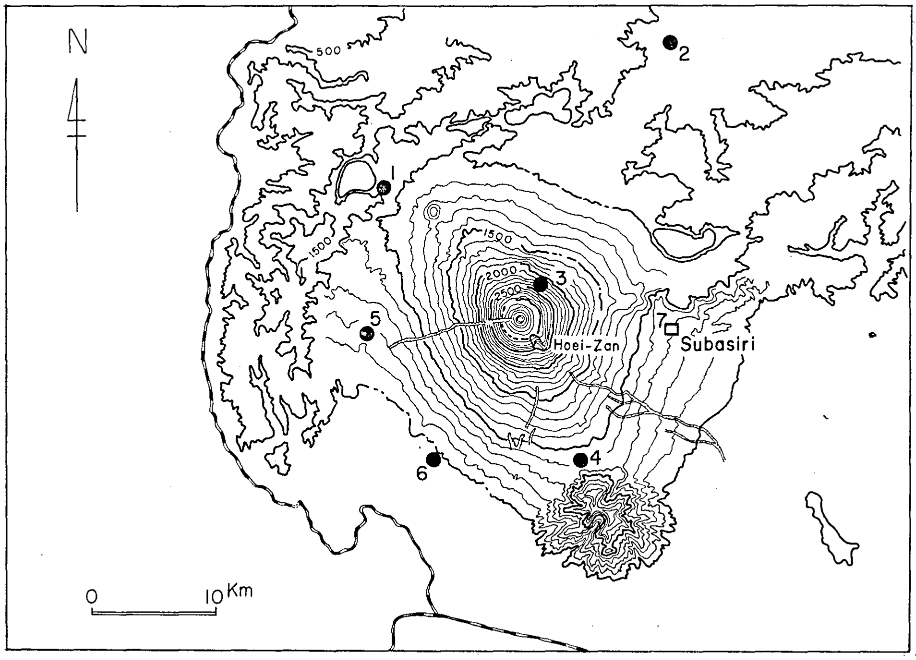


Fig. 9. The topographical map of Volcano Huzi (Fuji) and the localities of the temporary seismometrical stations.
closed circle, 1—6: seismograph station
7: Subasiri seismograph station

Besides the above-mentioned observation over a period of ten days, the writers set the seismographs with three components at Subasiri, located 12 km east of the summit, observations being carried out continuously during the period from September 18, 1965 to March 31, 1966. As the Subasiri area is thickly covered by the 1707 scoriae and the ground noise quite

Table 6. Monthly seismic frequency observed at Subasiri.
F: S-P≦5.0 sec.
F′: S-P>5.0 sec.

Month	F	F′
1965		
Sept. 18—30	0	12
Oct. 1—31	3	27
Nov. 1—30	4	45
Dec. 1—31	1	31
1966		
Jan. 1—31	1	27
Feb. 1—28	1	28
Mar. 1—31	6	40

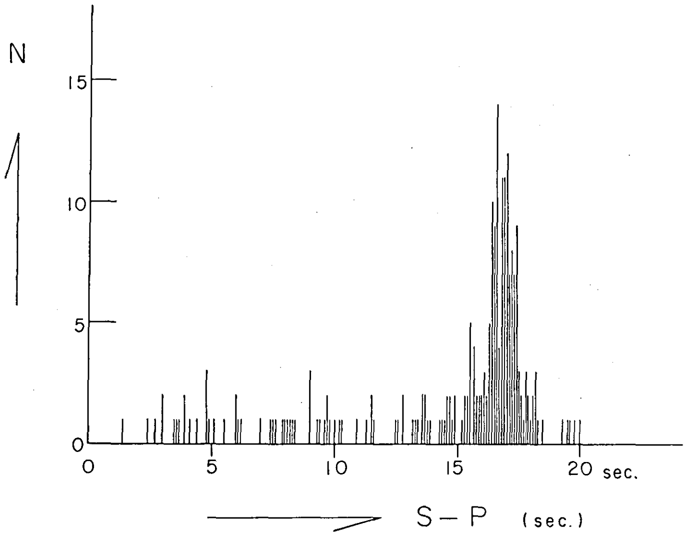


Fig. 10. The frequency distribution of S-P which were observed at Subasiri, the eastern foot of Mt. Huzi.

considerable, the seismograph was adjusted to 5000 in magnification. In Table 6, the seismic frequency observed at Subasiri is given, in which earthquakes are classified into two groups according to S-P.

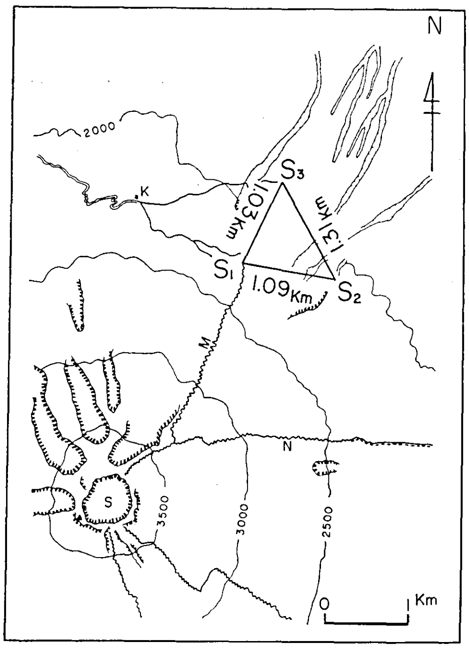


Fig. 11. The tripartite seismometrical net which was established temporarily on the northern middle flank of the volcano.

The S-P distribution with respect to 226 earthquakes recorded at Gogome is illustrated in Fig. 10, in which earthquakes of 16–18 seconds in S-P are outstandingly predominant. These earthquakes originated mostly from the Matusiro area in central Japan, which was not a usual state. Five earthquakes out of 226 were less than 3.0 seconds in the value of S-P, which would certainly have originated from Mt. Huzi and near its eastern foot.

On the other hand, the writers took part in the October 1965 observation made by the research group mentioned already, and the writers' team set temporarily a seismometrical tripartite net on the northern middle flank, Yosida-Gogome, as is seen in Fig. 11. In the tripartite observation, the tape recorder was applied and the magnification adjusted to a range from 120000 to 600000. As a result of the observation, which was made during the night from 21h to 02h to avoid traffic noise with the high sensitive seismograph, 92 earthquakes were recorded during 55 hours. These 92 earthquakes originated mainly from the Matusiro area.

As is seen on the map of Fig. 11, the present tripartite network was established on the steep slope of the northern middle flank of Huzi and the altitudes of the three places, on which a vertical transducer was set, were 2295 m, 2060 m and 1885 m respectively.

In Table 7, are represented the azimuth showing the direction of the epicenter and apparent velocity based on the arrival times observed

Table 7. The azimuths of the epicenters and the apparent velocities of the P seismic wave observed at Gogome at the northern flank of Mt. Huzi.

(Azimuth clockwise from north)

Date	Time	App. Vel. (corrected)	App. Vel.	Azimuth (corrected)	Azimuth
1965	h m s	km/sec	km/sec	°	°
Oct. 3	23 57 28.87	5.4	4.4	7.4	6.0
4	02 41 46.12	32.9	8.4	−26.4	−6.5
〃	22 58 42.36	6.1	4.9	52.8	39.6
5	00 42 43.01	6.2	6.2	−103.4	−75.0
〃	02 06 14.81	8.6	6.0	−60.4	−37.0
6	02 28 06.13	4.4	4.1	13.1	12.0
〃	22 10 53.95	4.1	4.0	13.5	13.3
〃	23 14 56.95	5.9	7.1	123.7	119.6
7	23 09 41.47	23.6	9.3	−82.2	−22.7
8	01 21 09.34	4.3	4.1	6.4	5.9
〃	02 08 50.75	5.5	4.6	−53.9	−42.9
〃	02 10 17.60	7.9	5.8	64.6	41.7
〃	02 21 46.32	5.8	5.6	−96.6	−73.3
〃	03 12 15.71	6.6	7.8	−122.7	−86.5
〃	22 45 56.30	5.7	4.5	4.7	3.7
9	00 51 43.55	5.0	4.3	9.2	7.8
〃	03 00 50.16	5.7	4.5	15.2	12.2
〃	03 05 14.83	50.6	12.1	146.6	187.5
〃	22 24 14.91	6.8	5.3	61.4	43.1
〃	23 26 34.73	10.3	6.7	69.2	37.4
10	22 01 50.08	4.3	4.1	17.1	16.0
〃	22 31 34.73	4.7	4.1	5.8	5.2
〃	22 38 04.45	5.9	4.8	−47.3	−36.1
11	00 49 37.09	4.1	4.0	3.6	3.6
〃	00 50 51.22	12.5	7.0	60.2	29.0
〃	01 16 07.52	4.2	4.0	24.0	22.8

with the above tripartite observation. The same table also shows the above two quantities corrected according to the effect of height difference of the three places, in which the propagating velocity passing through the mountain was assumed to be 4.0 km/sec.

According to the seismometrical observations at Yosida-Gogome and Subasiri, it can be said that the A type earthquake originating from Huzi was recorded once a month or twice per three months by the seismograph of which the magnification was adjusted to 4000, and five or ten earthquakes per month by the sensitive seismograph higher than 100,000 in the displacement magnification.

7. Seismometrical survey of Volcano Oomuro-yama, Izu Peninsula

Volcano Oomuro-yama, situated at 37 km south of Volcano Hakone, still keeps topographically a regular small cone. According to the field investigation, H. Kuno, H. Toya and other geologists suppose that Oomuro-yama had erupted five or six thousand years before. In addition, Oomuro-yama is located near the epicentral region of the 1930 Ito earthquake swarm which was investigated seismometrically and geodetically by the staffs of this Institute.

In order to make clear the present seismic activity of Volcano Oomuro-yama and of the past epicentral region of the 1930 Ito earthquakes, the writers made a seismometric survey with the high sensitive seismograph at Totari village located 2 km north of the top of Oomuro and 4 km south-west of the 1930 epicentral area. The seismometric observation with a seismograph, its magnification adjusted to 15000, was made during the period from January 18 to 28, 1969, and the higher sensitive seismographs with the four channels tape recorder, of which the magnification was adjustable in a range from 50000 to 200000, were operated for 67 hours in the above period. During the period, the seismograph recorded 45 earthquakes, of which S-P was distributed from 1.9 sec to 34.0 sec. Of these earthquakes, three S-P were less than 5.0 sec. Although the southern part of the Izu Peninsula was seismically not in an active state during the period, it will not be evaluated as the normal state or calm state of this area on account of too short a period of observation.

Therefore, it is indeed desirable that a seismometrical survey at the region should be carried out at least once a year.

For the convenience of the next survey, the arrival times, S-P, etc. for the above-mentioned three earthquakes are represented in Table 8, and the locality of the seismographs in the 1969 survey is illustrated in Fig. 12.

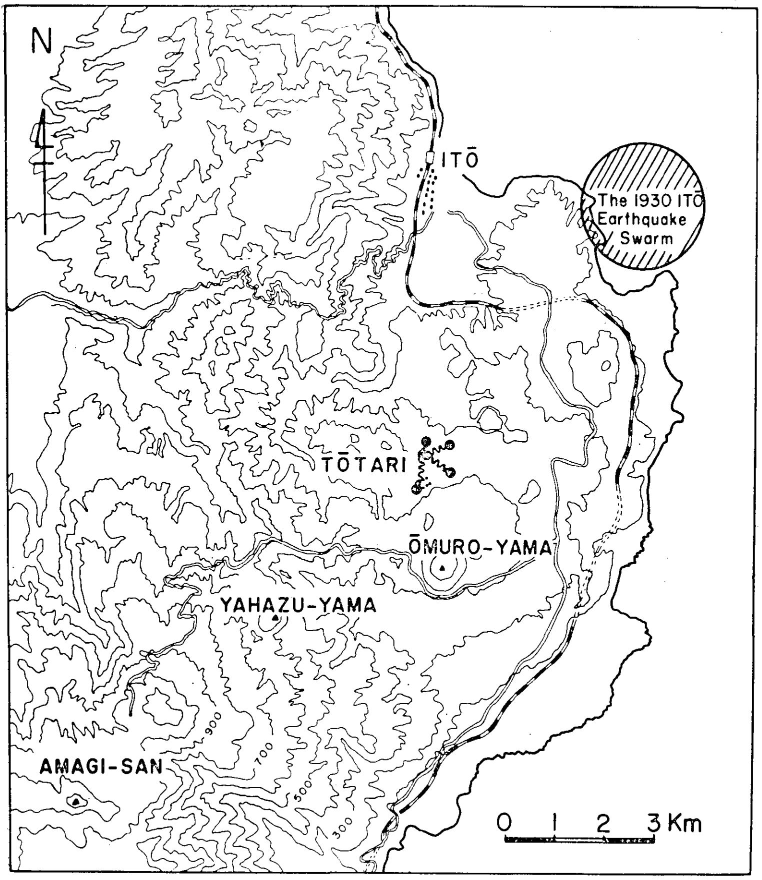


Fig. 12. The topographical map of Volcano Oomuro-yama and its vicinity and the locality of the temporary seismometrical net at Totari, the northern foot of Oomuro-yama.

Table 8. The arrival times, maximum amplitudes and S-P for earthquakes near Volcano Oomuro-yama.

Date	Time	Max. amp.	S-P	In. motion
Jan. 20	11h 53m 01.5s	E-W 0.92 micron N-S 2.33 U-D 2.10	4.3 sec 4.2 4.1	E 0.07 micron S 0.07 U 0.25
Jan. 21	13h 45m	E-W 0.52 micron N-S 0.87 U-D 0.55	2.2 sec 2.3 2.3	W 0.04 micron N 0.11 U 0.10
Jan. 21	15h 13m	E-W 5.55 micron N-S 6.63 U-D 5.64	1.9 sec ? 1.9	E 0.45 micron N 0.08 U 1.16

In the above table, the former earthquake was recorded with the high sensitive net at Hakone, too, its epicenter estimated as being at the central part of Izu Peninsula between Hakone and Oomuro-yama. The latter two earthquakes will naturally be located near Volcano Oomuro, judging from their values of S-P.

8. Seismometrical survey of Volcano Kusatu-sirane

Volcano Kusatu-sirane, located nearly at the central part of Honsyu and 28 km north of Volcano Asama, erupted at the summit craters and at the margin in 1882, 1897, 1900, 1902, 1905, 1925, 1927, 1932, 1937–38 and 1942 according to the record. These eruptions in historical time will be classified into so-called phreatic explosions, their ejecta appearing not to consist of fresh lava and lava fragments but of volcanic detritus and mud-like ash with solid sulphur. The 1932 eruption was studied

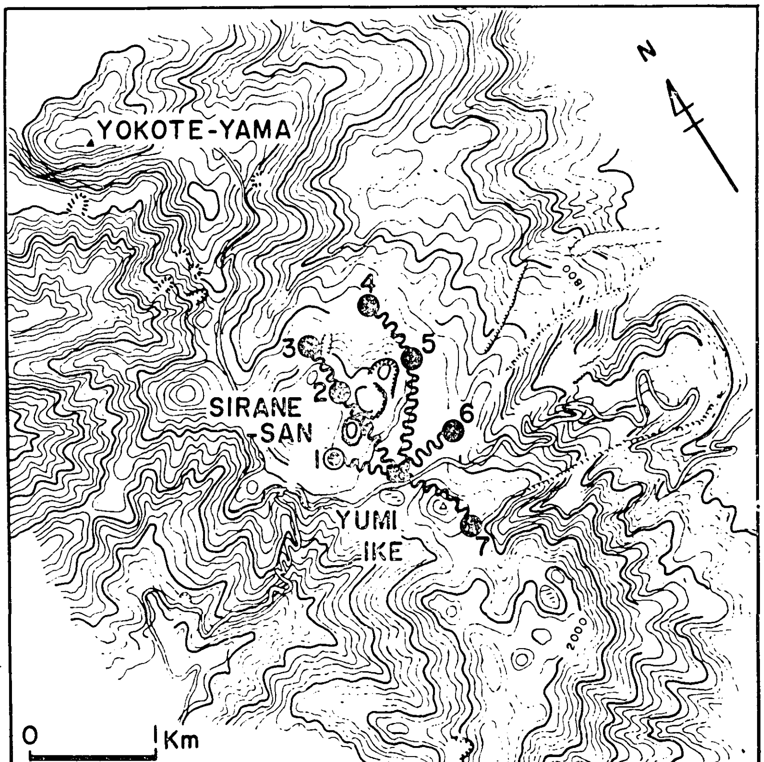


Fig. 13. The topographical map near the summit of Volcano Kusatu-sirane and the locality of the temporary seismometrical net-work.

volcanologically by H. Tsuya, and the 1937–38 and the 1942 eruptions were investigated by one of the writers from the seismological and geophysical stand-points.

According to the field investigations in the period from 1934 to 1948 the fumarolic activity was exceedingly active in one of the three craters, Yugama, which is situated between the other two craters. However, fumarolic activity of the crater has been absent almost completely during the last ten years.

In order to investigate the activity of Kusatu-sirane, the writers made a seismometric survey with the sensitive seismographs on the volcano during the period from July 30 to August 14 in 1967.

The three-component seismograph of magnification 3000 in displacement amplitude was operated through the period as a monitor, the transducers at seven places being operated only a few hours every midnight merely because of avoiding ground noise caused by traffic and other artificial disturbances. The localities of these transducers are shown in Fig. 13.

According to the result of the observation, the lower sensitive seismograph recorded 184 earthquakes during the period, out of which 115 were less than 3.0 sec in their values of S-P. The seismic frequency during the period is shown in Fig. 15 in a form of daily frequency.

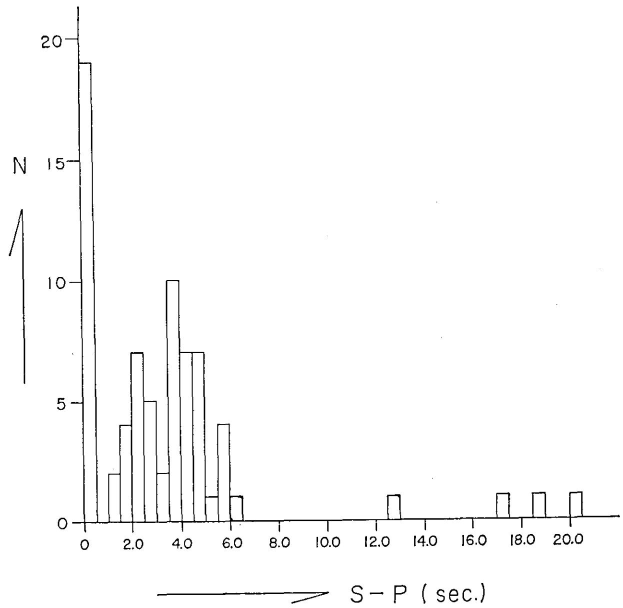


Fig. 14. The histogram of S-P of earthquakes recorded with the temporary seismometric net-work which was established on the summit of Kusatu-sirane.

Table 9. Daily frequency of earthquakes observed at Volcano Kusatu-sirane during the period from July 30 to August 14, 1967.

Date	Daily freq. S-P≦3.0 sec.	Daily freq. S-P>3.0 sec.	Total
July			
30	2	1	3
31	4	12	16
Aug.			
1	2	3	5
2	8	9	17
3	2	7	9
4	1	8	9
5	1	18	19
6	3	4	7
7	1	8	9
8	2	8	10
9	4	19	23
10	3	12	15
11	3	11	14
12	1	11	12
13	1	9	10
14	0	8	8
Total	38	148	186

It will be natural to assume that 38 earthquakes out of 186 in Table 9 originated from Volcano Kusatu, of which the values of S-P were less than 3.0 seconds.

Judging from the features of the earthquake motions on the seismograms, it seems that various types of earthquakes including the A and B type took place in the volcano during the period.

On the other hand, the seismometric observation with the oscillograph recorder was carried out for 24 hours and 27 earthquakes originating from Sirane and its adjacent region were recorded by the vertical transducers at the seven places of which the localities are shown on the map at Fig. 13.

The hypocentral positions of these earthquakes were given by the P arrival times and S-P at the seven places.

As to earthquakes of which the hypocentral positions were expected within the seismometrical net based on the value of S-P and the distribution of the P arrival times, their hypocentral positions and the propagating velocity of the P wave were determined by the P arrival times from the graphical method introduced by K. Hukutomi. While as to those of which the hypocentral position was inferred outside the net, their hypocentral positions were determined by their direction of the hypocentral position given by a series of P arrival times, the epi-

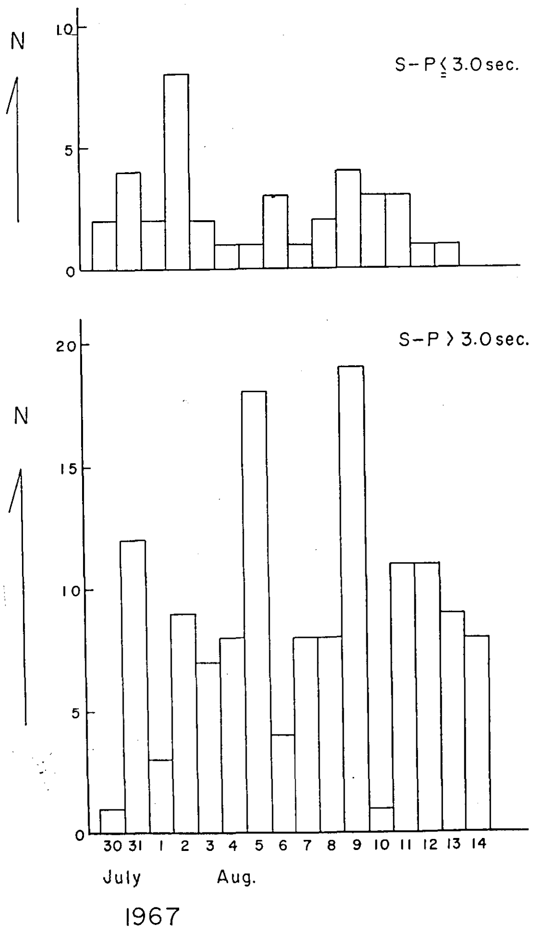


Fig. 15. The daily frequency of earthquakes which were observed by the writers' seismometric net during the period from July 31 to August 13, 1967.

central distance given by S-P and the following assumption with respect to the structure of the volcano and its vicinity; the following model was adopted as the structure of the region which consists of a surface layer, 3 km in thickness and 3 km/sec in the velocity of the P wave given by the former method, and of the velocity of 6.1 km/sec under the layer, given by the 1955 experiment of blast.

In Table 10 (a), (b), the hypocentral depth of 17 earthquakes and the P propagating velocity are represented, and the map at Fig. 16 illustrates the geographical distribution of their hypocentral positions. As is seen in Table 10 (b) and in Fig. 16, the epicentral positions of the Kusatu-sirane earthquakes of the A and B types were distributed on and around the summit craters, their hypocentral depths being in a range from 0.2 km to 3.0 km and 1.8 km on an average. The average velocity of the P wave which propagates from the earth's surface of the volcano to a depth of 3.0 km was 2.9 km/sec.

The hypocentral positions of the shallow earthquakes obtained by the graphical method were re-examined on the assumption of the homogeneous velocity of the P wave, 3.0 km/sec. From the result of the graphical method with respect to the velocity, the above assumption was accepted.

The geographical positions of the earthquakes given by the above two methods are illustrated in Fig. 16. As can be seen on the map at Fig. 16, the two results agree quite well, as far as the epicentral position is concerned. However, the hypocentral depths by the graphical

Table 10, (a). The arrival times at seven places for the earthquakes originating near the summit of Volcano Kusatu-sirane.

Eqk. No.	Date and Time	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
1	July 31, 19h 56m 35s	.61	.64	.67	.70	.68	.69	.68
2	〃 20h 32m 18s	.60	.58	.62	.60	.54	.64	.79
3	Aug. 1, 21h 58m 54s	.65	.65	.67		.72	.64	.94
4	2, 22h 12m 19s	.43	.40	.48	.42	.38	.44	.58
5	〃 22h 26m 40s	.26	.26	.29	.24	.22	.34	.42
6	Aug. 3, 0h 30m 06s	.14	.12	.19	.20		.15	.31
7	〃 18h 35m 15s	.33	.33	.57	.35	.31	.36	.80
8	〃 19h 03m 41s	.66	.15	.69	.65	.61	.66	
9	〃 19h 14m 23s	.23	.25	.25	.28	.27	.33	.31
10	〃 19h 54m 40s		.78		.82	.78	.82	.88
11	〃 21h 23m 02s	.59	.58	.64	.55	.54	.59	.66
12	Aug. 4, 18h 36m 06s	.20	.24	.27	.30	.31	.29	.27
13	〃 18h 54m 43s	.77	.79	.83	.83	.83	.86	.85
14	〃 18h 59m 10s	.49	.51	.53	.53	.55	.55	.55
15	〃 22h 09m 05s	.66	.68	.64	.62	.61	.67	.86
16	Aug. 5, 19h 25m 40s	.61	.65	.65	.69	.65	.68	.69
17	〃 20h 33m 03s	.00	.04	.04	.10	.10	.10	.07

Table 10, (b). The geographical positions of the epicenters and the hypocentral depths for the earthquakes near the summit craters of Volcano Kusatu-sirane.

The origin of the coordinate is taken at Station No. 1, the x-axis is to the east, y-axis is to the north and z-axis downward.

(A) given by the graphical method

(B) given by a computor on the assumption of the constant velocity (3.0 km/sec) for the P wave.

Eqk. No.	(A)				(B)		
	x	y	z	v	x	y	z
	km	km	km	km/sec	km	km	km
1	0.06	−0.12	2.0	3.0	−0.03	−0.06	2.6
2	0.47	0.38	0.5	3.2	0.46	0.37	2.0
3	0.90	0.45	2.0	3.0	0.67	0.24	2.6
4	0.57	0.27	0.2	3.6	0.60	0.31	2.0
5	0.38	0.36	0.3	3.8	0.41	0.37	2.1
6	0.44	0.46	1.0	2.0	0.53	0.51	2.1
7	0.55	0.30	1.4	2.7	0.52	0.25	2.4
8	0.63	0.46	2.0	3.0	0.55	0.35	1.9
9	−0.10	0.25	3.0	2.7	−0.20	0.24	3.1
10	0.50	0.30	2.0	2.8	0.45	0.20	2.3
11	0.60	0.20	1.5	2.5	0.60	0.20	1.5
12	−0.20	−0.20	2.0	3.5	−0.17	−0.17	2.4
13	0.25	0.10	1.5	3.3	0.28	0.10	2.2
14	−0.08	0.00	3.0	2.7	−0.07	0.00	3.0
15	0.58	0.62	3.0	2.5	0.60	0.58	3.1
16	0.07	−0.05	2.0	2.6	0.06	−0.06	2.0
17	0.10	0.05	2.2	3.0	0.04	0.04	2.7

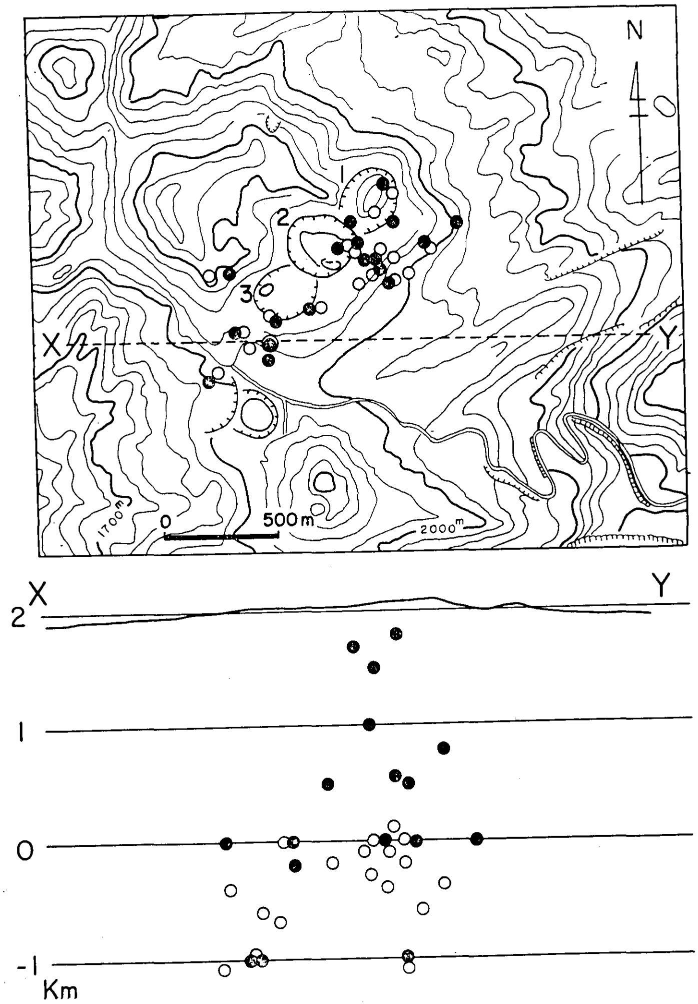


Fig. 16. The hypocentral distribution of the earthquakes originating from the summit part of Kusatu-sirane which were observed by the temporary seismometric net.

closed circle : given by the graphical method,
opened circle: given on the assumption of homogeneous seismic velocity (3 km/sec),
1, 2, 3 : summit craters.

method were distributed from the earth's surface to a depth of 3 km but, on the other hand, those given by the other one concentrate at a depth from 2.0 km to 3.0 km, because the latter method is assumed by the constant velocity of the P wave or 3.0 km/sec in that case.

In the period of the 1937-1942 eruptions of Kusatu-sirane, one of the writers made seismometrical observations near the summit crater. As a result, a series of shallow earthquakes and volcanic tremors of continuous train were observed, though the sensitivity of the seismograph was seriously low as compared with the present one. Especially, a series of micro earthquakes were observed on May 30, 1938, the values of their S-P being in a range from 0.1 sec to 2.0 sec. However, since the observation at that time was made only at one place 100 m south of the summit crater, the hypocentral positions were not estimated precisely, though their origins were estimated near the summit craters.

Besides the 1967 earthquakes near the summit craters mentioned above, a series of earthquakes were observed in the seismometrical net during the period, of which S-P were in a range from 1.9 sec to 2.7 sec, their P phase being exceedingly predominant in the vertical component as compared with that of former earthquakes. Their hypocentral positions, as already mentioned, were determined on the basis of the arrival times of the P wave and on the assumption of the horizontal structure con-

Table 11, (a). Arrival times of the earthquakes which took place at the south-western foot of Volcano Kusatu-sirane on August 2, 1967.

Eqk. No.	Date and Time	Stn. No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
18	Aug. 2 22h 59m 45s	.53	.55	.55	.57	.59	.59	.55
19	〃 23 05 37	.19	.20	.20	.23	.24	.26	.20
20	〃 23 11 10	.72	.73	.73	.75	.77	.79	.74
21	〃 23 15 09	—	.79	.78	.80	.82	.83	.81
22	〃 23 21 30	.63	.66	.67	.70	.70	.70	.63
23	〃 23 21 41	—	.24	.19	.24	.29	.39	.39
24	〃 23 37 51	—	.89	.89	.90	.93	.97	.93

Table 11, (b). S-P, apparent velocity, direction of the epicenter (clockwise from north), the hypocentral depth and the epicentral distance for the earthquakes on August 2, 1967.

Eqk. No.	S-P	Apparent vel.	Azimuth	Depth	Δ
18	2.50 sec	14.3 km/sec	256.3°	16.1 km	6.8 km
19	2.59	13.5	254.5	16.5	7.6
20	2.67	16.5	257.2	17.7	6.5
21	2.44	22.4	280.5	16.6	4.3
22	—	11.0	240.7	—	—
23	2.53	7.0	308.2	10.1	14.1
24	1.88	12.5	285.3	11.2	5.3

cerning the distribution of the propagating velocity. As a result, the epicentral positions of these earthquakes were found to be at the western flank of the volcano as illustrated at Fig. 17, and their hypocentral depths estimated at a range from 10 to 15 km which is remarkably

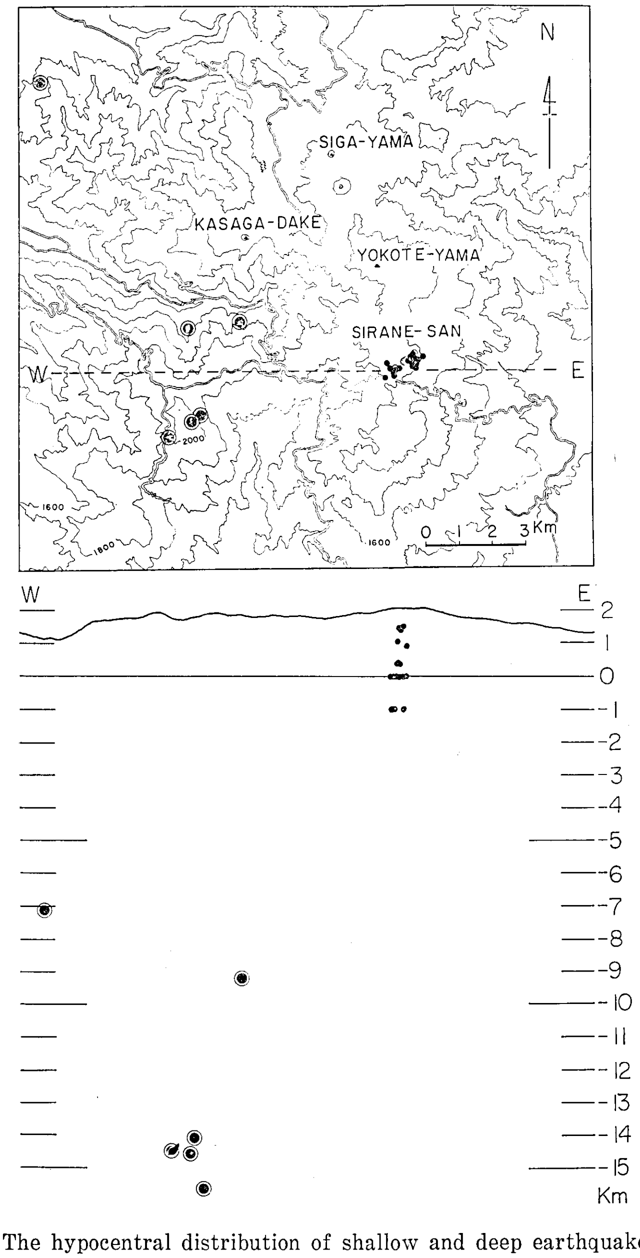


Fig. 17. The hypocentral distribution of shallow and deep earthquakes originating from the western side and the summit of Volcano Kusatu-sirane.

deeper than those of the former earthquakes near the summit craters. It is necessary to state that most of the latter earthquakes took place on August 2, 1967, in the form of a minor earthquake swarm.

The writers investigated the relation between the seismic frequency and its maximum amplitude for the Kusatu-sirane earthquakes. For the purpose, the Kusatu-sirane earthquakes were divided into two groups according to their S-P, of which one is less than 3.0 sec in S-P including the summit earthquakes and the other more than or equal to 3.0 sec in S-P. As a result, Ishimoto and Iida's coefficient was given as 2.8 for the former earthquake group, and 1.8 for the latter. Seeing that the hypocentral positions of the earthquakes of the former group were extremely shallow, less than 3 km, and those of the other markedly deeper than the former, the above values of the coefficient harmonize with the following interpretation of phenomena respectively.

It is well-known that Ishimoto's and Iida's coefficient usually shows a range between 1.8 and 2.0 for the earthquakes of tectonic origin of which the hypocentral depths are, in general, found to be deeper than about 10 km. Therefore, it will be natural to draw the conclusion that the value of the coefficient depends on the heterogeneity of the hypocentral region or on the hypocentral depth, not on the mechanism of the earthquake.

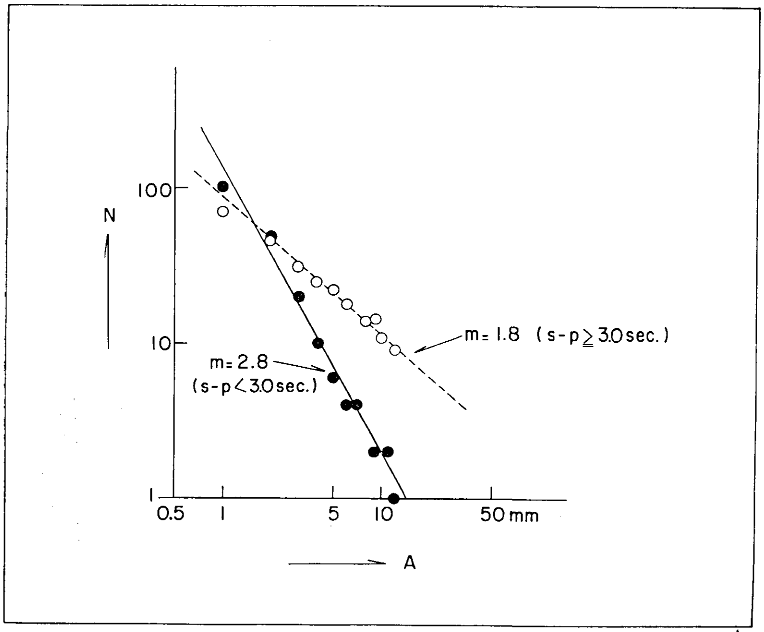


Fig. 18. The relationships between the maximum amplitudes and the frequencies of the Kusatu-sirane shallow and deep earthquakes which were observed during the period from July 30 to August 14, 1967.

9. Seismometrical survey of Volcano Nasu

In order to obtain information of the seismic features of Volcano Nasu-dake, the writers made a temporary seismometrical investigation of the volcano during the period from October 28 to November 14, 1966. The Nasu volcano is situated at the northeastern part of the Kanto Plain, 150 km north-east of Tokyo, and according to the historical record of eruption of the volcano, there were a total of five eruptions in 1397, 1408, 1810, 1846 and 1881.

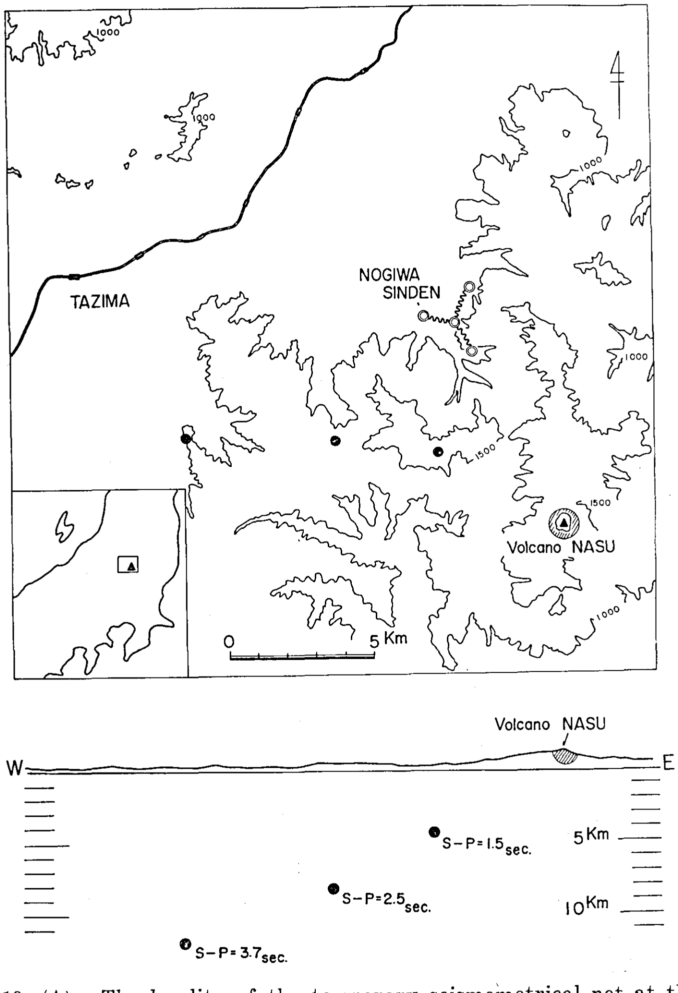


Fig. 19, (A). The locality of the temporary seismometrical net at the north-western foot of Volcano Nasu, and the hypocentral distribution of quakes which were observed by the net.
hatched area: the epicentral area of the B type quakes.

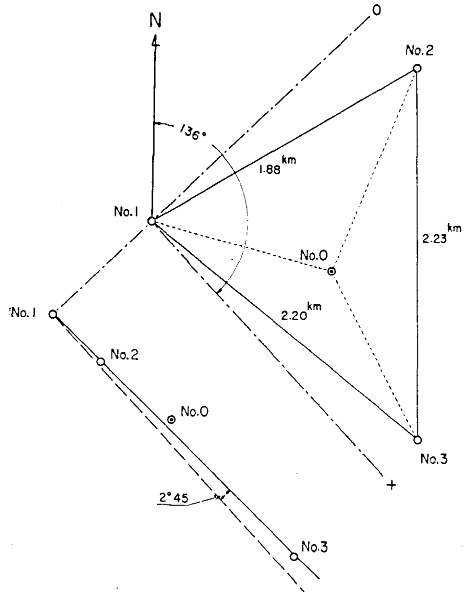


Fig. 19, (B). The tripartite seismometrical net established temporarily at the north-western foot, Nogiwa-sinden, of Volcano Nasu.

In recent years, the Volcano Nasu and its vicinity have become the famous place for sight-seeing and as a summer resort. Consequently people have come to pay special attention to the volcanic and seismic activity of the volcano. The Japan Meteorological Agency newly established in 1966 seismometrical observation of the volcano. The transducer set near the top of the volcano was connected with the recorder of the Utunomiya Weather Station by means of a wireless tele-metering system. The general tendency of activity of the Nasu volcano and the seismicity have been made clear by the above-mentioned observation, but we have no precise information regarding the hypocentral region of the A type earthquakes originating from the volcano. In order to make clear the locality of the Nasu earthquakes, the writers made a temporary seismometric observation at the north-western foot of the volcano, at Nogiwa-sinden village, 7.5 km distant from the top of Mt. Nasu, though the seismometric observation was limited to a short period.

For the purpose, a continuous observation at Nogiwa-sinden was made with the seismograph of three components during the period, and besides the above observation as the monitor, the vertical transducer was set at three places and connected with a oscillograph through the amplifier by means of transmission wire. The localities of the monitor seismograph and the three transducers are illustrated on the map at Figs. 19 (A) and (B).

According to the result of the continuous observation during that period, 246 earthquakes were recorded in which the duration of the preliminary tremor or S-P were distributed from 1.0 sec to 25 sec. As the Matusiro earthquake swarm was exceedingly active during the present observation, a number of Matusiro earthquakes were observed by the writers' seismometrical net at Nogiwa-sinden. In Fig. 20, which represents the frequency distribution of S-P observed with the above net, we find a remarkable predominant frequency of range from 18 sec to 22 sec in S-P, which corresponds to that of the Matusiro earthquakes. In the same histogram, another pike of the seismic frequency is found in a range from 1.0 sec to 5.2 sec of S-P which will certainly have originated from Volcano Nasu and its vicinity.

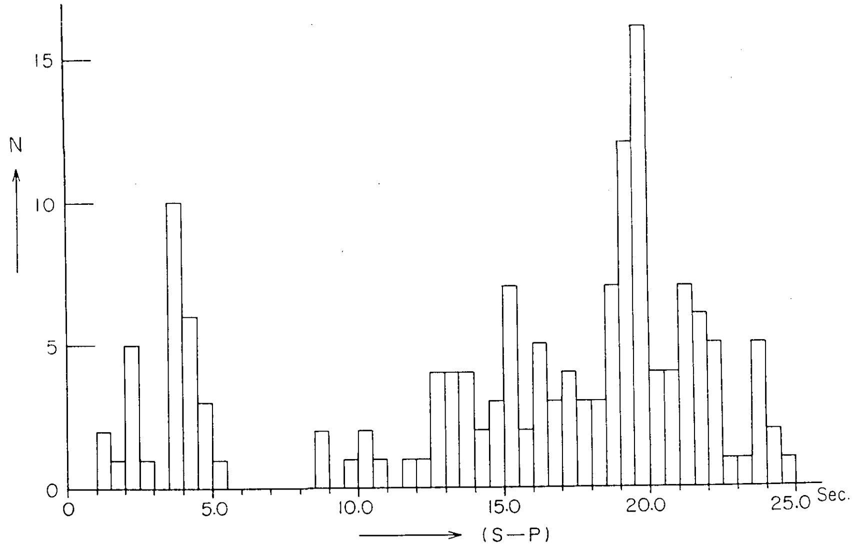


Fig. 20. The frequency distribution of S-P of the earthquakes which were observed by the net at the north-western foot of Mt. Nasu

On the other hand, 16 earthquakes which were recorded by seven transducers at the four places mentioned above and recorded by an oscillograph with the time signal of J. J. Y., in which 8 earthquakes were studied with respect to their origins, using the arrival times of the P wave.

In order to determine their hypocenters, the writers took the difference of the altitude of the four places into account, and fortunately these four places were approximately on a plane inclined by 2.8° to the horizontal. Thus, the direction of the wave front or that of the epicenter and the apparent velocity were obtained, which are illustrated in Fig. 21.

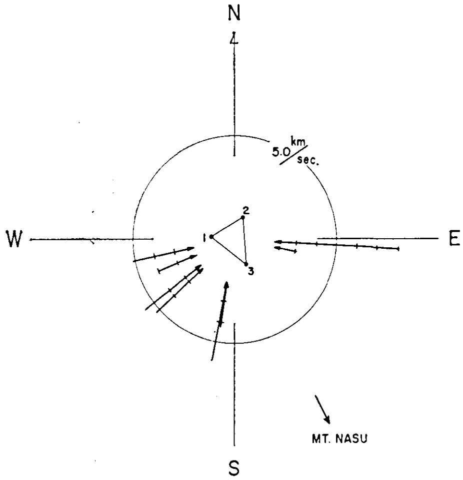


Fig. 21. The directions of the epicenters given by the arrival times at the tripartite net and the apparent velocities of P wave.

Three earthquakes out of the above eight were placed at the summit of Volcano Nasu nearer than 10 km in their epicentral distance.

we must touch on the continuous observation made by the Japan Meteorological Agency in which a transducer on the summit of Mt. Nasu is connected with the recorder set at Utunomiya city, 46 km distant of the volcano, by means of the wireless telemetering system.

It must be also added here that Y. Koshikawa and H. Kameyama made a temporary seismometrical observation near the summit crater of the volcano in 1962 and in 1963.

In reviewing the result of these seismometrical observations, the earthquakes originating in and near the Volcano Nasu are divided into two groups based on S-P, of which one group consists of earthquakes of from 0.1 sec to 1.8 sec in S-P, and the other of those in a range from 1.9 sec to 4.5 sec. The former earthquakes are extremely shallow in depth and concentrate only in the summit crater of a fumarolic active state. Therefore, the earthquakes of the former kind will be classified into the volcanic B type earthquake, which were not caught by the writers' seismometrical net because of quite a long distance from the summit crater.

The latter earthquakes were also observed with the writers' net as described above and their origins were placed at the western foot of the volcano some 10 km deep. Therefore, these earthquakes will be reasonably classified into the A type volcanic earthquake.

Studying the hypocentral distribution in Fig. 21, we are conscious of the fact that the nearer the summit crater the epicentral position is located, the shallower the hypocentral depth is. The same phenomenon is reported by K. Yoshikawa concerning the hypocentral distribution of the 1968 earthquakes originating from Volcano Sakura-zima and its surrounding Aira caldera.

Judging from the result of the seismic observations made by J.M.A. over the past several years and the temporary observations by Y. Koshikawa, it can be said that the monthly frequency of the B type quake is in a range between 20 and 40 in the normal state of Volcano Nasu and that of the A type in a range from 20 to 30, though it is required to make further investigations in order to draw any final conclusion.

10. Seismometrical survey of Volcano Midagahara

Volcano Midagahara is located on the western flank of Mt. Tateyama which consists of gneiss grano-diorite. Although the volcano has made no historical eruption, the fumaroles, Zigokudani, situated at the eastern part are still active.

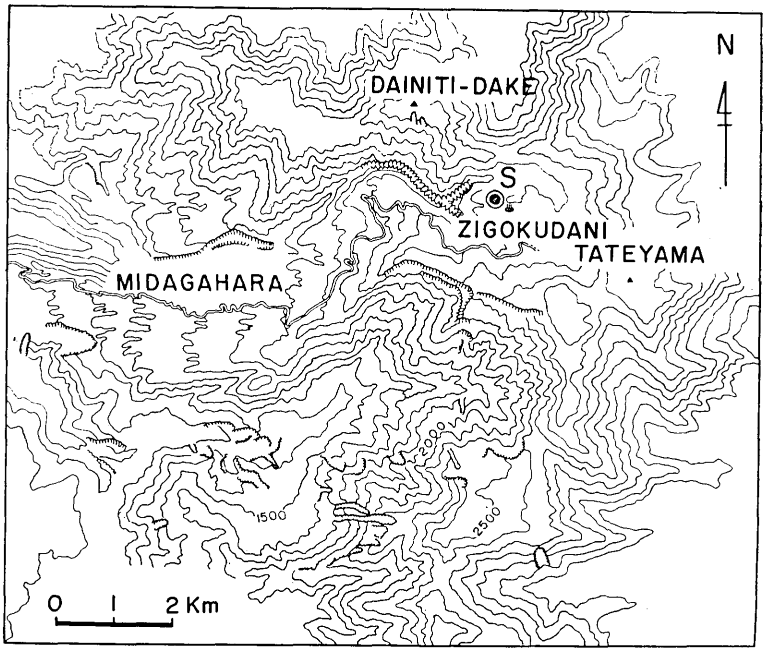


Fig. 22. The topographical map of Volcano Midagahara and its neighbourhood and the locality of the temporary seismometrical net(s).

Since a seismometrical investigation of the volcano has never been made, the writers carried out a seismometrical survey near the fumarolic area with the sensitive seismograph for a few days from August 17, 1967.

The seismograph recorded the following seven earthquakes, of which S-P were less than 6.0 sec in duration.

Although the period covered with the instrumental observation is too short to estimate the usual seismicity of the Midagahara volcano,

Table 12.

Date	Ar. time	S-P	Max. amp.	In. mot.
Aug. 18	12h 34m	5.9 sec	0.35 micron	down
〃	15 22	6.0	0.10	up
Aug. 19	09 52	4.8	0.40	up
〃	22 39	1.2	0.26	up
Aug. 20	00 36	—	0.11	—
〃	00 46	—	0.12	—
〃	03 37	4.2	0.45	up

it can be reasonably said that the A type earthquake originated from the volcano in a period of three days.

11. The 1966 eruption of Kutinoerabu-zima on November 22

Kutinoerabu-zima, an insular volcano, which is located 135 km south of Sakura-zima and the city of Kagosima, erupted toward 11 h 35 m on November 22, 1966, after a repose of 21 years and is still active in 1969, though on a small scale.

The nature of the historical eruption of Kutinoerabu-zima is classified into the phreatic or steam explosion, of which the ejecta mainly consist of volcanic detritus, crushed rock fragments and fine ash.

The eruption on November 22 was of quite a large scale and resulted in 3 persons being injured and in serious damage to forest and cultivated land on account of the fall of ejecta. Seeing that the field fire broke out at several spots by the fall of ejecta of a large size, a part of the ejecta would be of a high temperature at the time of eruption. According to the report by H. Tanakadate, the same phenomenon manifested in the eruption on December 24, 1933, which was outstandingly of a large scale.

As soon as the writers had obtained information concerning the outbreak of the 1966 eruption, they planned to carry out a field investigation of the eruption in order to make clear its dynamical energy and the nature of seismic activity followed by the phreatic eruption.

The field investigation commenced on November 27, five days after the first eruption and continued till December 8, for the purpose of estimating the volume of its ejecta and to obtain evidence necessary for calculating the initial velocity of the ejecta.

It was fortunate that they found a lot of holes made by the fall of volcanic detritus and, at the same time, scores of fallen trees indicating the angle of their fall.

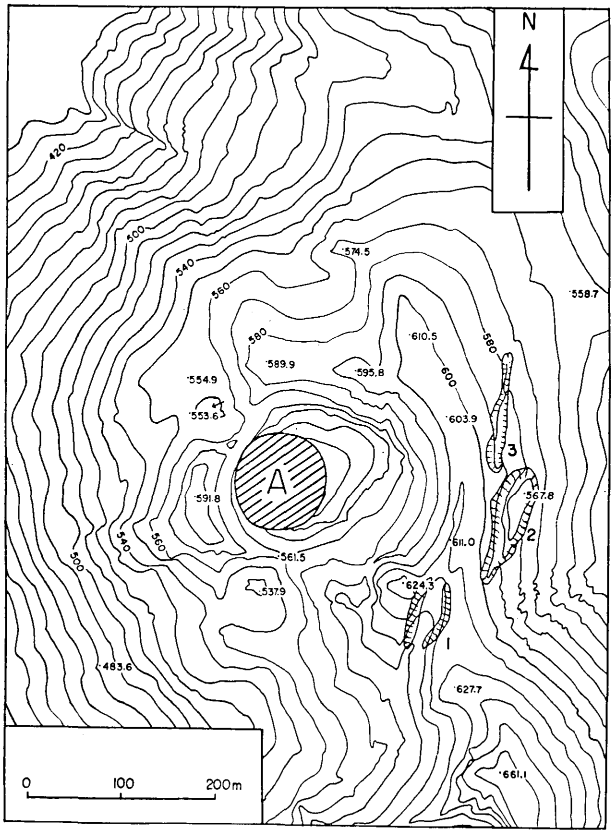
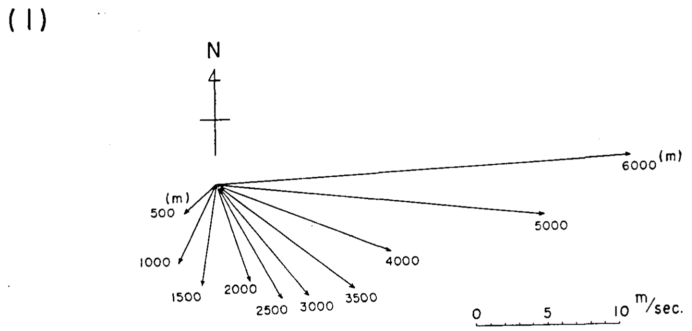


Fig. 23. The topographical map near the summit of Kutinoerabu and the localities of the 1966 crater (A) and the 1945 craters (1, 2 and 3).

On the basis of these data, the initial velocities of ejecta were calculated with respect to comparatively large detritus which had not been seriously affected by the air and wind resistance during their flight from the crater.

As can be seen in Table 13, the initial velocities of detritus were in a range between 132 m/sec and 224 m/sec, and 177 m/sec in their mean value. Therefore, it can be said that the ejecta of the November 22 eruption were ejected from the summit crater with an initial velocity of about 180 m/sec.

On the other hand, we found a several characteristics in the geographical distribution of ejecta according to the sizes of the ejecta as is seen clearly on the map at Fig. 24. The volcanic detritus of a comparatively large size is distributed in a form of a narrow area on the western and north-eastern flank of the volcano in Fig. 24, which is directed by the initial velocity at the summit crater and almost inde-



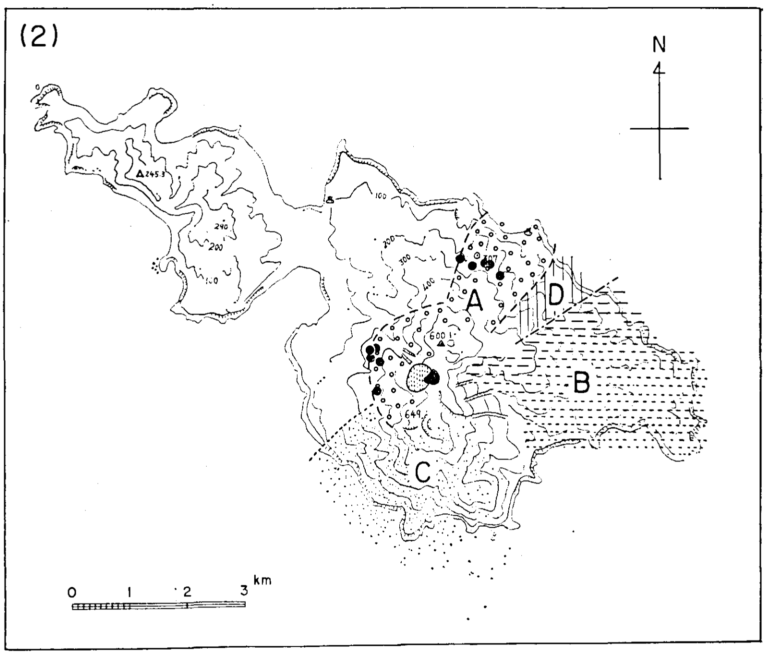


Fig. 24. The geographical distribution of the ejecta from the eruption of Kutino-erabu on November 22, 1966, and the distribution of the upper wind velocity.
A: bombed area, B: lapilli and gravel
C: volcanic ash, D: no ejecta

pendent of the wind direction. On the contrary, the extremely fine ejecta like fine ash, which was elevated above the crater with vapour up to 5000 m according to the J. M. A. report, was sent by the upper wind and then by the gradient wind in the falling away toward the directions of the winds respectively. According to an investigation of the same problem in Volcano Asama, the ash from the explosive eruption which rose above the crater higher than three or four thousand meters was influenced mainly by the prevailing west wind and fell on

Table 13. The horizontal distance of flight, the fall angle of volcanic detritus and their initial velocity.

No.	Horizontal distance	Fall angle	Size (Diameter)	Initial Velocity
1	1000 m	72°	50—60 cm	132 m/sec
2	950	78	40—50	155
3	1150	78	40	169
4	1200	74	60	151
5	1100	80	30	179
6	2100	74	30	224
7	2050	66	30	161
8	2150	75	50—60	204
9	2150	75	50	204
10	2130	73	30	194

the eastward area. Therefore, it can be said that, in the above-mentioned case, the ash fall area depended mainly on the direction of the upper wind and was not so much affected by the gradient wind.

The detritus of small sizes and the rock fragments like gravel had an intermediate character between large size and fine ash in their flight motion, which usually depended not only on the initial velocity given in the crater but also strongly on the gradient wind and slightly on the upper wind. Therefore, the geographical distribution on the earth's surface of these intermediate ejecta is, in general, complicated and different from the bomb and ash areas. This is why these ejecta of the intermediate sizes were not so highly elevated above the crater as the fine ash-like ejecta, the effects of the wind to the flight of ejecta depending mainly on their size.

As can be seen on the map of the distribution of the present ejecta, the bomb, the ash area and the area of the intermediate ejecta are clearly separated, while, at 9h on the same day of the eruption, the wind velocity and direction were observed at various altitudes at Yosino, Kagosima, 130 km north of Kutinoerabu, the result of the observation being in Table 14.

Although the above wind observation was made at a distance of 130 km from Kutinoerabu and about three hours before the outbreak of the November 22 eruption, the wind distribution on and high above the volcano was not so different from that described above.

In the map at Fig. 24, it is most remarkable that the bomb area extends to the north-eastern side of the volcano and to the western side of the crater and that no bomb area exists on the eastern and southern sides of the crater. The above one-sided distribution of volcanic detritus

Table 14. Direction and velocity of the wind measured clockwise from the north. (After Kagosima Weather Station)

Altitude	Direction	Velocity
0.0 km	340°	3 m/sec
0.5	49	4
1.0	26	6
1.5	9	7
2.0	340	7
2.5	331	9
3.0	320	10
3.5	307	12
4.0	291	13
5.0	276	23
6.0	267	29

of large size was caused by the topography of the crater and the vent of the crater floor, which have no relation with the effect of the wind. However, the fine ejecta covering the southern flank and skirt of the volcano was caused by both the upper and gradient winds. The abundant ash, which rose up to nearly 5000 m above the crater, flew to the west at an altitude between 5000 m and 2000 m and then changed direction to north-east by the effect of the gradient wind at an altitude from 2000 m to the earth's surface. As a result, it is certain that the ash fell on the south-eastern area of the volcano.

On the other hand, it seems that the ejecta of intermediate size like volcanic gravel, which was not elevated so high as the ash, flew from the crater to the east side of the volcano not only by the initial velocity given, but also by the north-east gradient wind.

At a rough estimation the total mass of the ejecta in the eruption on November 22, 1966, would be approximately 10^5 tons. Therefore, the kinetic energy of the eruption would be about 10^{19} ergs and the pressure at the time of outbreak nearly 300 atmospheric pressures. Judging from the nature and magnitude of eruption, the 1966 Kutinoerabu eruption is almost similar with the 1932 and 1945 eruptions of Volcano Kusatu-sirane.

It will be necessary to add here that Volcano Kutinoerabu-zima newly erupted on 21 and 29 December, 1968, but such were not so violent as the 1966 one.

12. Seismometrical survey of Volcano Kutinoerabu-zima

The writers established a temporary seismometrical center at Kutinoerabu island as soon as possible after the outbreak of the present eruption, and set the transducers at six places on the volcano and one recorder station at Maeda village, of which the locations are shown on the map at Fig. 25.

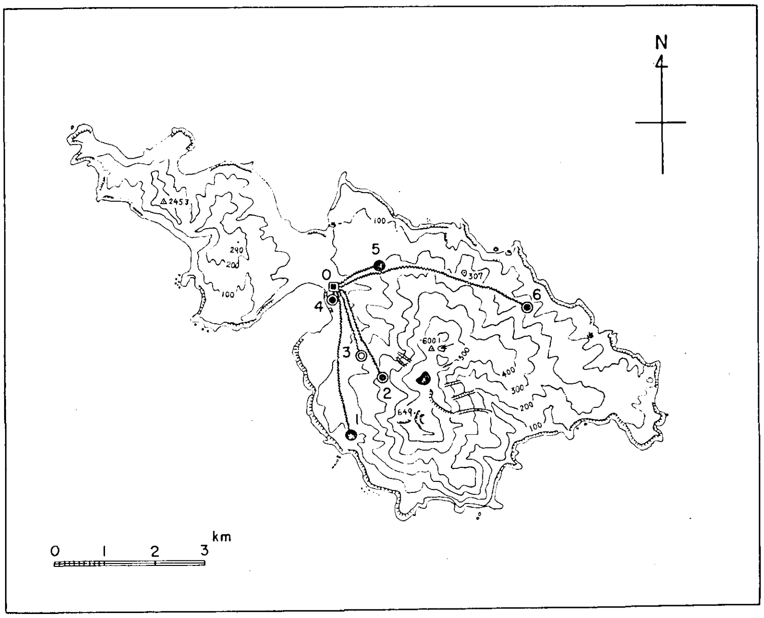


Fig. 25. The seismometrical net-work established temporarily on Island Kutinoerabu.

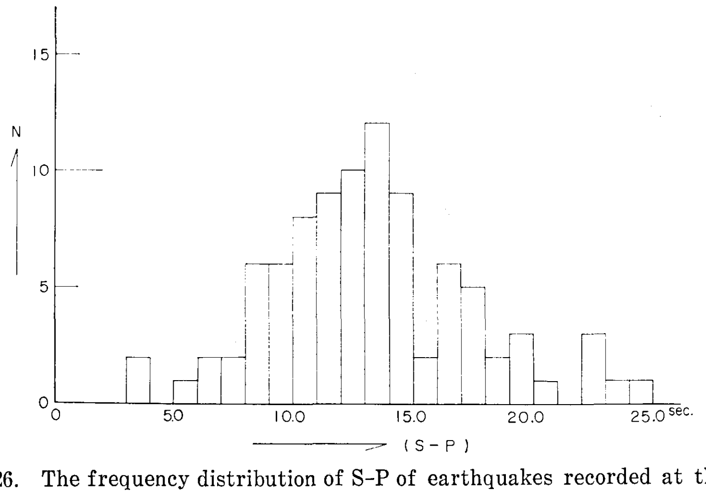


Fig. 26. The frequency distribution of S-P of earthquakes recorded at the present seismometrical net on Island Kutinoerabu.

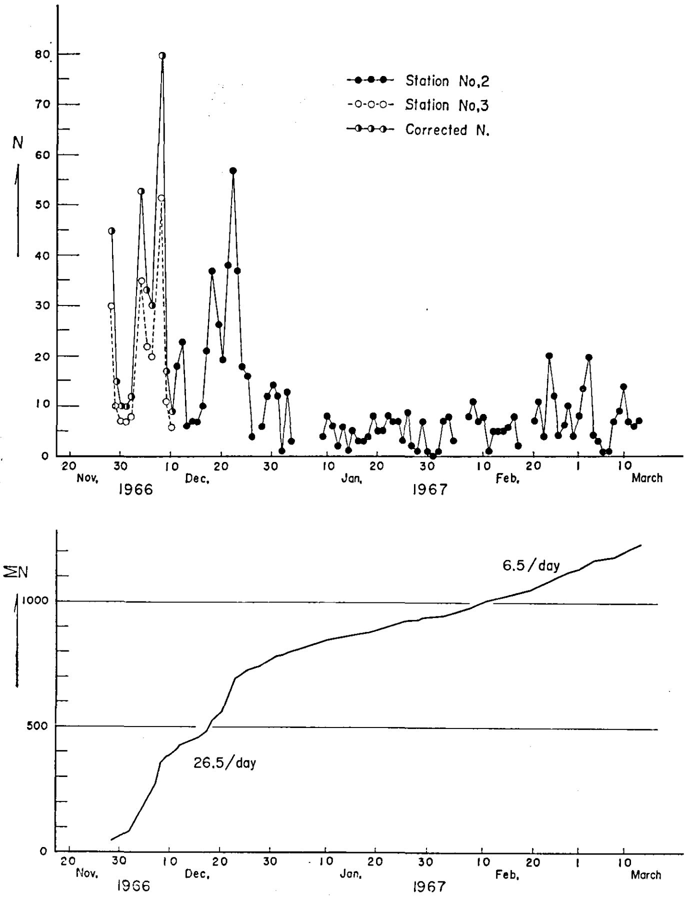


Fig. 27. The daily frequency of the B type earthquake originating near the summit crater of Kutionoerabu.

For the purpose, they applied the transducers of vertical and horizontal components with the periods of 1.0 sec and 0.3 sec, a series of pen-galvanometer for the smoked paper recorder, and an oscillograph of twelve elements for the precise observation of the arrival time of the initial motion and the nature of earthquake motions. These seismographs were adjusted in a range from 10000 to 150000 in magnification, and continuous observation commenced on November 27, 1966. As a result, a series of B type earthquakes and volcanic tremors were recorded with the seismometrical net above-mentioned.

In Fig. 27 and Table 15 (a), (b), the seismic activity of the volcano is represented in a form of the daily frequency of the B type earthquake, which was obtained with the transducer placed at Stations 3 (Yamagoya) and 2 (Rokugome).

Table 15 (a). Daily frequency of B type earthquakes originating from Volcano Kutinoerabu (observed at Stn. No. 3).

Date	Daily freq.	Date	Daily freq.	Date	Daily freq.
1966 Nov. 27	* 12	Dec. 2	** 9	Dec. 7	** 28
28	** 27	3	** 22	8	** 43
29	11	4	** 34	9	10
30	15	5	** 19	10	6
Dec. 1	** 9	6	23	11	7

Table 15 (b). Daily frequency of B type earthquakes originating from Volcano Kutinoerabu (observed at Stn. No. 2).

Date	Daily freq.	Date	Daily freq.	Date	Daily freq.
1966 Dec. 8	*** 12	Dec. 29	8	Jan. 18	4
9	** 17	30	12	19	8
10	10	31	15	20	5
11	18			21	5
12	** 23	1967 Jan. 1	** ?	22	8
13	** 6	2	** 10	23	7
14	7	3	** 4	24	7
15	7	4	?	25	3
16	12	5	—	26	8
17	23	6	—	27	2
18	40	7	—	28	1
19	30	8	1	29	7
20	19	9	4	30	1
21	37	10	8	31	0
22	40	11	6	Feb. 1	1
23	35	12	2	2	7
24	17	13	6	3	8
25	14	14	1	4	3
26	7	15	5	5	0
27	?	16	3	6	0
28	4	17	3	7	8

*: observation commenced at 14h 41m
**: volcanic tremor was recorded
***: observation commenced at 16h 25m

The relation between the maximum amplitude and its frequency was investigated in the two periods of the seismometric observation. As a result, the values of Ishimoto-Iida's coefficient were given as 2.4 in both the periods as is shown in Fig. 28.

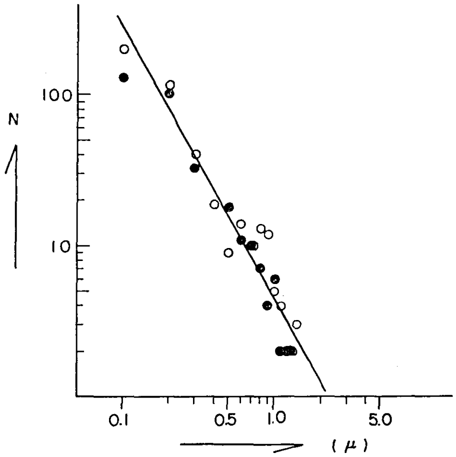


Fig. 28. The relation between the maximum amplitude and frequency of the earthquakes originating from the summit part of Kutinoerabu.
closed circle: quakes during Dec. 9-24, 1966
opened circle: quakes during Dec. 25—Apr. 10, 1967

In order to find the hypocentral position of earthquakes originating from the volcano, the writers used the oscillograph for recording precisely the arrival times of the initial motions at the six stations. However, the noise level at the Kutinoerabu island was quite high and disturbed by not only the volcanic tremor certainly originating from the active crater, but also by the vibration caused by the surf and wind. On account of these troublesome disturbances, the writers gave up trying to determine the hypocentral position based on

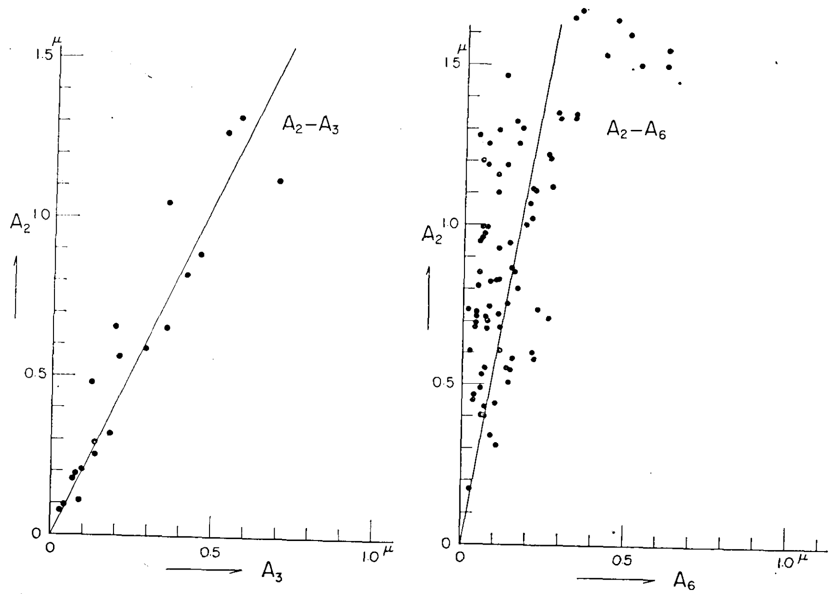


Fig. 29. The maximum amplitudes of the Kutinoerabu quakes at two stations.
A_2, A_3 and A_6: the maximum amplitudes at Stations No. 2, No. 3 and No. 6.

the arrival times of earthquakes, and used the method of the comparison of the maximum amplitude of the places. The maximum amplitude at station No. 2, for example, is compared with that at stations Nos. 3 and 6 as is shown in Fig. 29.

From the distribution of the maximum amplitude at these places, it is clear that the nearer the active summit crater the station is located, the larger the amplitude is. These earthquakes observed were evidently classified as B type and no A type was observed throughout the period of the present investigation. From the above-mentioned result of the observation, it is natural to conclude that these earthquakes were placed on and near the summit active crater and their depths were extremely shallow.

Soon after the first eruption of November 22, 1966, the inhabitants of the island were very anxious about whether another big eruption would be followed by lava flow on the incandescent state or not. They were also afraid of field fires that break out from the falls of ejecta as in the case of the first eruption.

However, after a few days of seismometrical observation, the writers attained the opinion that there would be extremely few probabilities of an amount of fresh lava being ejected, because no A type earthquake had taken place and the eruption would be related only to the surface part of the crater.

13. Seismometrical investigation of Volcano Sotará, Colombia

Volcano Sotará, belonging to the Andes Volcanic mountains, is situated at 2.2° N in latitude and 76.5° W in longitude, 380 km south-west of Bogota and 22 km south of Popayan. The volcano has no historical eruption. However, from May 1965, the people living on and around the volcano Sotará had been extremely uneasy about the possibility of the volcano erupting and causing great disaster. In order to prevent volcanic disaster and to relieve the inhabitants of anxiety, the Colombian Government requested the Japanese Government to send a mission for the investigation of Sotará. The writers were asked to organize a volcanological mission and to get information of whether Volcano Sotará and any other volcanoes in Colombia would be in a dangerous state or not, which, however, was indeed difficult.

The writers established a temporary seismometrical station at two places near Volcano Sotará, of which one was on the campus of the Faculty of Electronics, University of Cauca, 23 km south of the volcano, and the other at the village of Sotará (or Paispamba), 12 km north-west of the summit of Volcano Sotará.

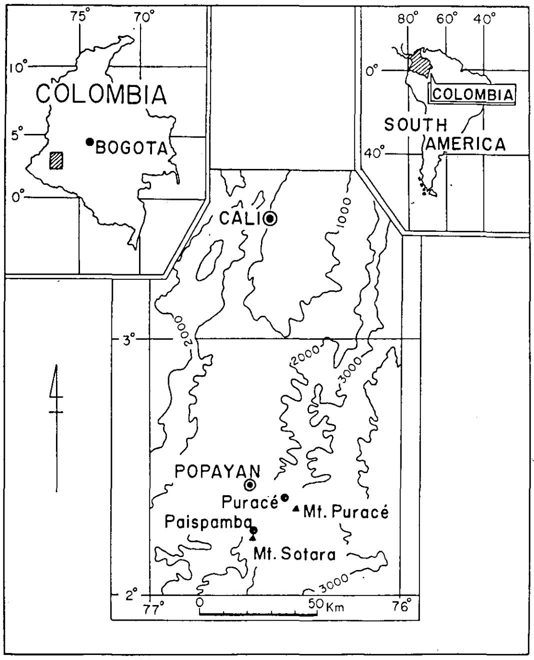


Fig. 30. Geographical position of Volcanoes Sotará and Puracé in Colombia.

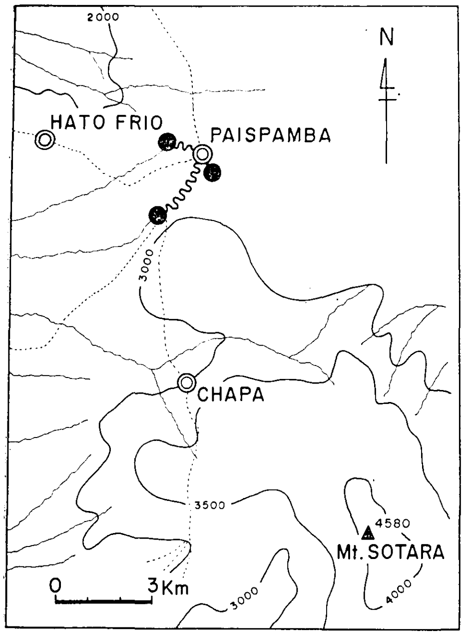


Fig. 31. Locality of the temporary seismometrical position at Paispamba at the north-western foot of Volcano Sotará.

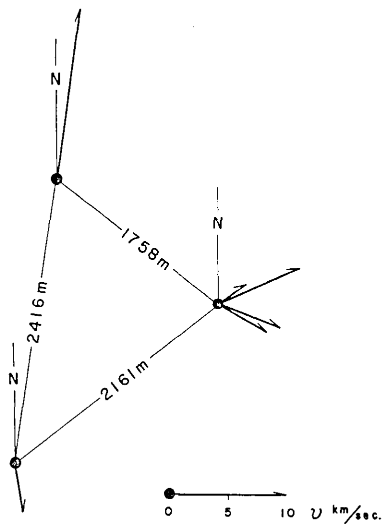


Fig. 32. The seismometrical tripartite net at Paispamba and the direction of epicenters and the apparent velocities.

During the period from January 13 to February 21, 1966, the seismometrical observation at the former place was made with a seismograph of which the magnification was adjusted in 5000.

Besides the continuous observation at the latter place with the seismograph of which the magnification was usually adjusted to 10000 and sometimes to 200000, the writers made a tripartite net-work at the same place with the recorder of magnetic tape, which was used in a range from 180000 to 800000 in magnification. Since the seismometrical observation was carried out over a long distance from the summit of Mt. Sotará, the writers used the seismographs of an exceedingly high sensitivity as described above, in order to catch any micro-earthquakes originating from the volcano.

The seismometrical observation at Paispamba was carried out for 27 days from January 18 to February 13, 1966, and as a result, 45 earthquakes were recorded of which S-P was distributed from 1.4 sec

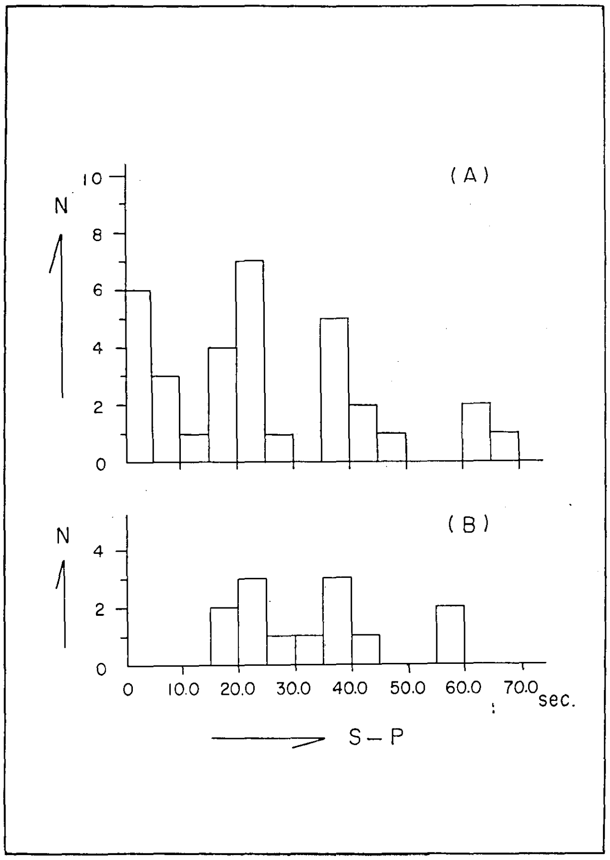


Fig. 33. The histograms of S-P of earthquakes observed at Paispamba (A) and Popayan (B).

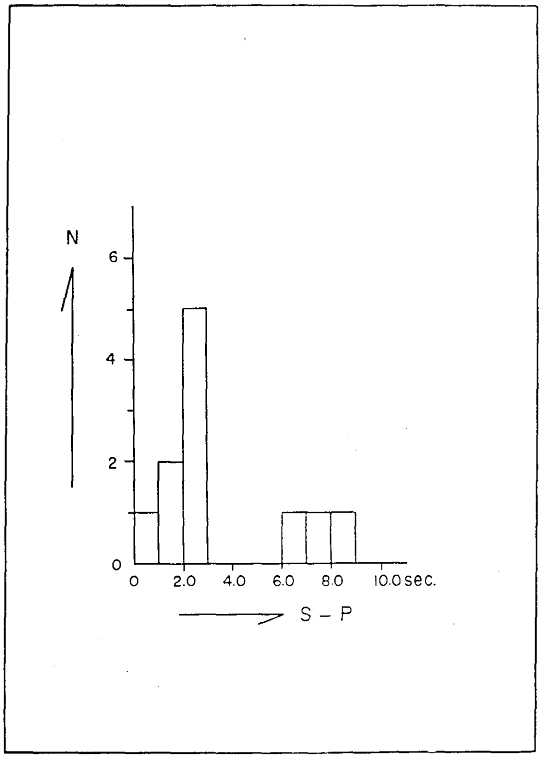


Fig. 34. The histogram of S-P less than 10 sec, observed at Paispamba.

to 63.5 sec. Judging from the values of S-P of these earthquakes, it seems that only two or three originated in and around Volcano Sotará.

These observed earthquakes consisted mainly of distant quakes which had no connection with Volcano Sotará. Since the region including Sotará had never been covered until then by a seismometrical net, date, time, S-P and maximum amplitude of these observed earthquakes are listed in Table 16 as a general information of the seismicity of the region.

On the other hand, the tripartite net recorded 6 earthquakes, and their arrival times at the three transducer stations were made clear as shown in Table 17.

Based on the arrival times, the direction of their epicenter, S-P and the apparent velocity are given in Table 18. Although the quake at 05 h 03 m, February 6 was located nearest to the seismometrical net, its epicenter was estimated at about 15 km south of the net, or approximately 6–7 km west of the summit crater of Sotará. Judging from the earthquake motion on the seismogram, its hypocentral depth was estimated to be nearly 3–5 km. On the other hand, no B type earthquake was observed during the period.

Table 16. The arrival time, S-P and the maximum amplitude of the earthquakes observed at village Sotará (Paispamba)

Date & Time	S-P	Max, ampl. U-D	S-P	Max. ampl. N-S	S-P	Max. ampl. E-W
h m	sec	micron	sec	micron	sec	micron
Jan. 19 23 56	18.8	0.31	18.7	1.78	17.7	2.12
20 13 23	53.0	0.23	50.8	0.62	50.5	0.62
21 13 24	42.0	0.62	42.0	1.31	42.0	1.56
22 00 17	—	0.10	—	0.24	35.3	0.31
〃 06 37	—	0.06	—	0.17	—	0.22
〃 12 32	—	0.21	—	0.45	—	0.36
23 04 36	—	0.11	—	0.26	—	0.20
〃 11 55	12.9	2.40	12.9	5.89	12.9	8.43
24 00 56	1.4	0.58	1.4	0.48	1.4	0.34
26 16 30	61.6	0.13	61.6	0.41	61.6	0.25
〃 22 46	—	0.87	24.2	3.87	—	2.36
27 02·16	—	0.74	23.0	2.90	—	1.63
〃 〃 19	—	0.25	22.6	0.83	—	0.55
28 00 12	—	0.06	36.2	0.15	—	0.14
〃 22 02	—	0.33	2.1	0.62	—	0.31
〃 〃 19	—	0.51	36.8	1.53	36.8	1.38
〃 〃 31	—	0.07	—	0.27	—	0.28
29 11 46	—	0.17	63.1	0.41	63.5	0.38
〃 22 19	—	0.26	69.4	0.64	—	0.50
30 01 33	18.5	2.16	18.4	3.90	18.3	2.98
〃 22 03	17.6	0.05	17.6	0.10	—	—
Feb. 1 04 09	—	0.08	—	0.19	—	0.14
2 06 05	35.8	1.03	35.8	2.06	36.0	2.05
〃 23 23	7.8	0.28	8.2	0.32	8.2	0.15
3 01 54	19.9	0.18	19.9	0.47	19.8	0.34
4 10 32	39.2	0.87	39.2	1.73	39.2	2.01
〃 11 40	—	0.23	—	0.25	—	0.19
〃 11 41	—	0.10	—	0.36	—	0.33
〃 21 30	38.4	0.15	44.5	0.70	44.5	0.62
5 03 16	9.0	1.78	8.9	2.85	—	—
〃 10 40	—	0.11	—	0.28	—	—
〃 18 43	—	0.09	—	0.13	—	0.11
〃 23 58	6.2	0.06	—	0.07	—	0.05
6 04 35	21.0	0.16	—	0.39	21.0	0.36
〃 05 03	—	0.07	—	0.11	—	0.10
〃 05 09	—	0.05	—	0.13	—	0.11
〃 12 22	23.8	0.06	—	0.18	—	0.14
7 04 44	21.2	0.09	—	0.20	—	0.21
〃 09 32	2.5	0.57	2.4	0.69	—	0.50
〃 11 09	—	0.11	—	0.34	—	0.28
8 15 36	—	0.56	0.6?	0.40	0.6?	0.48
9 15 32	—	0.09	—	0.42	—	0.34
11 00 03	2.2	0.07	—	—	—	0.03
12 11 39	1.9	0.09	—	—	—	—
13 01 13	—	0.06	—	0.22	—	0.15
〃 01 17	—	0.02	—	0.15	—	0.06
〃 08 47	23.6	0.08	23.3	0.20	—	0.10

Table 17. Arrival times of earthquakes recorded on the tape at village Sotará (Paispamba).

Earthquake No.	Date	Arrival time at each station Station 1	Station 2	Station 3
	h m	sec	sec	sec
No. 1	Jan. 30, 01 33	07.06	06.98	07.10
No. 2	〃 22 03	24.08	24.16	23.94
No. 3	Feb. 5, 03 16	43.61	43.79	43.44
No. 4	〃 23 58	28.02	28.11	27.82
No. 5	6, 04 35	04.43	03.95	03.77
No. 6	〃 05 03	46.64	47.17	46.88

Table 18. Azimuths of epicenter (φ), apparent velocity (V) and S-P for the earthquakes which are listed on Table 17.

Earthquake No.	φ, measured from N clockwise	V	S-P	Epicentral distance
		km/sec	sec	km
No. 1	8°00′	14.6	—	—
No. 2	67 10	7.8	17.3	160
No. 3	118 50	5.0	—	—
No. 4	110 30	5.8	6.2	50
No. 5	56 10	3.1	—	—
No. 6	172 00	2.5	2.5	15

According to the result of the continuous observation at Paispamba and at the University of Cauca, a few A type earthquakes took place, their magnitudes being so small that they were recorded only by the high sensitive seismographs. Therefore, the writers judged that Volcano Sotará was not active seismically but in a normal state, though the observation at the region was made only over a short period.

14. Geothermal investigation of Volcano Sotará

As the cattle on the flank of Volcano Sotará often went down to the foot and the inhabitants felt uneasy about a possible further eruption, the writers thought that a series of micro-quakes might originate from the volcano, or the geothermal temperature might show an abnormal rise on the summit or on the flank.

On account of the above, besides seismometrical observations, the writers paid attention to the state of the geothermal phenomena.

Volcano Sotará is covered by a green grazing surface from the top to its skirt and therefore, if the geothermal temperature was elevated in any part of this pasture, the colour of the grazing would be changed to brownish.

Therefore, the writers examined the colour of the pasture from the summit to the foot from a helicopter and on foot, but no grazing had changed colour.

On the other hand, the writers measured the geothermal temperature at a depth of 50 cm along the mountain route from Paispamba to the summit. The result of the geothermal measurement is shown in Table 19 (a), (b) with the altitude of the places where the measurements were

Table 19 (a). Geothermal temperature of Volcano Sotará along the route from Paispamba to the summit. (Feb. 1, 1966)

Measurement No.	Altitude	Time	Geothermal temp. (50 cm deep)	Air temp.
No. 1	3280 m	10h 30m	11.0°C	14.0°C
No. 2	3640	13 10	10.5	15.0
No. 3	3730	13 40	8.0	15.0
No. 4	3820	14 00	8.0	18.0
No. 5	3920	14 30	7.5	18.0
No. 6	4100	15 30	6.0	14.0
No. 7*	2600	10 00	15.0	20.0
No. 8**	2600	14 30	15.5	16.0

The measurements were made on Jan. 24* and Feb. 5.**

Table 19 (b). Water temperature of the summit crater-lake on Sotará. (Feb. 1, 1966)

Altitude	Time	Water temp.	Air temp.
4100 m	15 h 45 m	12.5°C	12.5°C

Table 20. The 1965 monthly and annual mean air temperatures at Popayan, 1760 m above sea level.

Month	Air temp.	Month	Air temp.
Jan.	18.2°C	Aug.	20.3°C
Feb.	19.2	Sept.	19.8
Mar.	18.7	Oct.	18.8
Apr.	18.3	Nov.	18.9
May	17.9	Dec.	19.2
June	19.9		
July	20.3	Annual mean	19.1

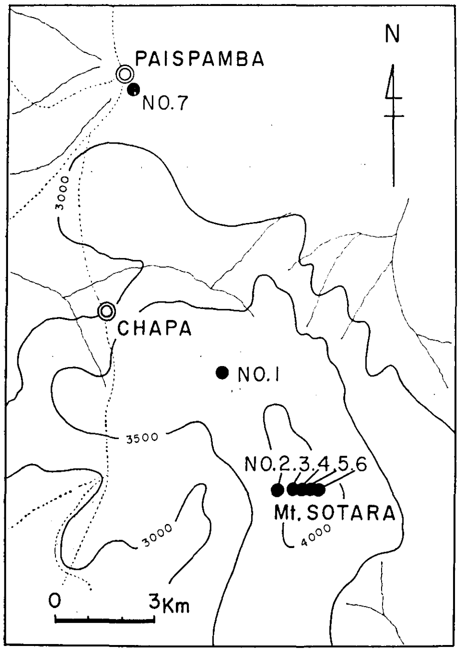


Fig. 35. The locality of seven places where the geothermal temperatures were measured.

made. In general, the effects by the diurnal variation of the air temperature are reduced nearly in a range of $\pm 1°C$ at a depth of 50 cm and the annual variation of the air temperature is also in a small range at the tropical region as in Colombia. As can be seen in Table 20, the monthly mean values of air temperature at Popayan are in a range of $19.1°C \pm 1.0°C$ throughout a year. Therefore, it will be reasonable to infer that the geothermal temperature at a depth of 50 cm in the present case indicates approximately the annual mean value of the air temperature at the place where the measurement was made, if it is geothermally in a normal state.

In order to examine whether the values of the measured geothermal temperature were normal

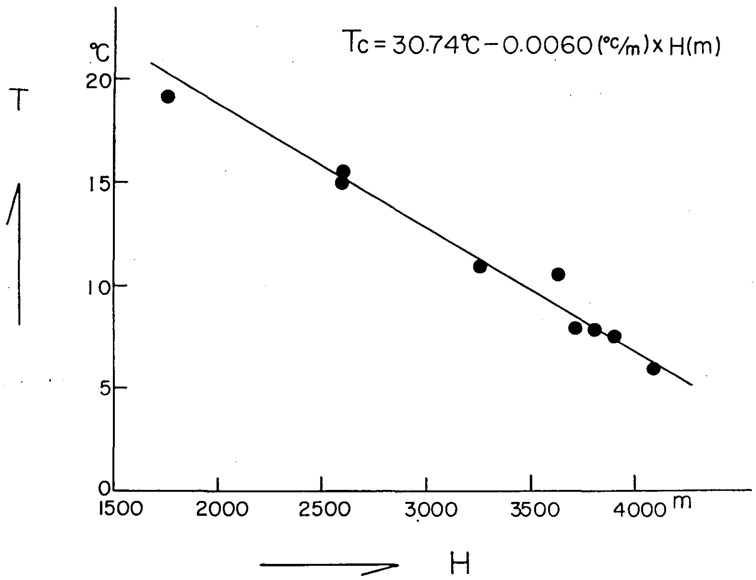


Fig. 36. The relation between the altitude of measured places and the geothermal temperatures at the depth of 0.5 m on Volcano Sotará.

or not, the relation between the geothermal temperature and the altitude was investigated and compared with the annual mean value of the air temperature. As a result, it was elucidated that the decrease of the geothermal temperature according to the altitude is given as $6.0°C \times 10^{-3}/m$ as is shown by the following formula, which is slightly smaller compared with that of the air temperature, ie. $6.5 \times 10^{-3}°C/m$.

$$T_G = 15.1°C - 6.00 \times 10^{-3}(°C/m) \times (H(m) - 2600\,m)$$

where T_G; geothermal temperature of Mt. Sotará
H; altitude of the measurement point

On the other hand, these geothermal temperatures in each altitude are equivalent to the annual mean air temperature at respective altitudes expected from that at Popayan situated at an altitude of 1760 m and 22 km north of Paispamba.

Therefore, it was reasonable to draw a conclusion that in Volcano Sotará there was no abnormal phenomenon not only in the seismicity of the volcano, but also in the geothermal distribution.

After the observation and investigation of Volcano Sotará, the writers carried out a seismometrical survey of Volcano Puracé which is situated 30 km east of Popayan, though only for a short period. However, no earthquake and volcanic tremor originated from Puracé. Consequently, Volcano Puracé was not found to be active, either. The writers earnestly recommended the establishment of a volcano observatory to obtain continuous data concerning the seismic and volcanic activity of Volcanoes Sotará and Puracé.

15. Resumé

It will be one of the obligations of volcano geophysicists to find a method for predicting volcanic eruptions to prevent human life from disaster caused by such eruption.

According to historical records and recent instrumental observations we found a lot of unusual phenomena before eruption at respective volcanoes, as in the cases of historical eruptions of Volcano Usu which were preceded by a series of felt quakes, and in the 1965 eruption of Volcano Taal which was preceded by a remarkable rise of the water temperature of the crater lake.

From the forerunning phenomena of eruption, it seems that earthquakes including volcanic tremors are most common to volcanoes, even though the nature and magnitude of their eruptions are very different from each other.

On the other hand, it is certainly the orthodox procedure for predicting volcanic eruptions to obtain continuous information concerning seismic activity and other phenomena from a permanent volcano observatory at respective volcanoes which may again become active.

However, in actual fact, only a few percent of volcanoes have volcano observatories equipped with instruments necessary for the purpose in question. For compensating for the lack of a permanent observatory, it is indispensable to cover these volcanoes with temporary observations by instruments of high sensitivity.

From the above view-point, the writers have made a series of temporary observations mainly with sensitive seismographs on many volcanoes not only in Japan but also in the Circum Pacific region.

In the present paper, the writers have dealt with the results of temporary seismometrical observations of Volcanoes Hakone, Huzi, Kusatu-sirane, Kutinoerabu, Oomuro-yama, Midagahara, Nasu in Japan and Sotará in Colombia.

Since, in the temporary investigations of these volcanoes except Hakone and Kutinoerabu, the observation covered a period shorter than one month, this is insufficient for determining the seismic level at the usual or normal state of the respective volcanoes. Therefore, it is necessary and we hope it will be possible to carry out repeatedly instrumental observations at each volcano in the near future.

In conclusion, the writers wish to thank the prefectural Governments of Kanagawa-ken, Kagosima-ken and Toyama-ken, and people living in the area of the respective volcanoes in these prefectures for their cooperation and the facilities granted us during the investigations and observations.

The writers' appreciation is also extended to Mr. N. Gyoda and Mr. M. Hagiwara for their assistance in the seismometrical observations and Miss T. Utsunomiya, Miss K. Hirai, Miss K. Fujii and Mrs. T. Kinoshita for their assistance in the preparation of the manuscript.

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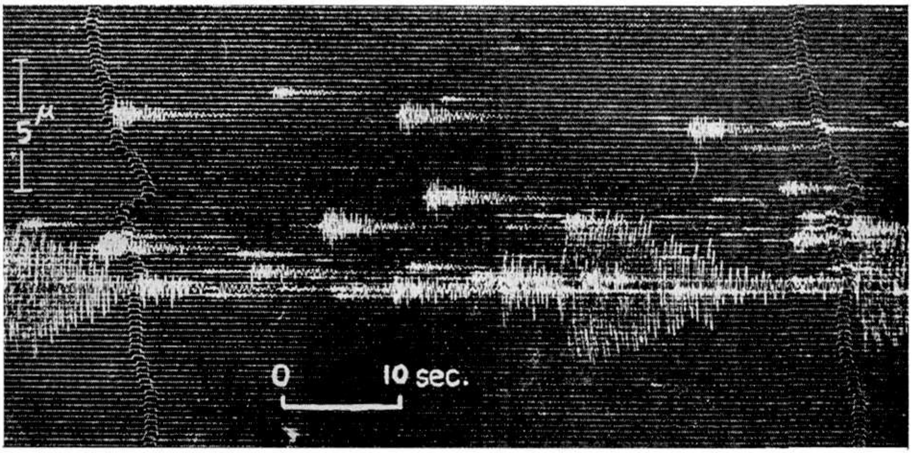

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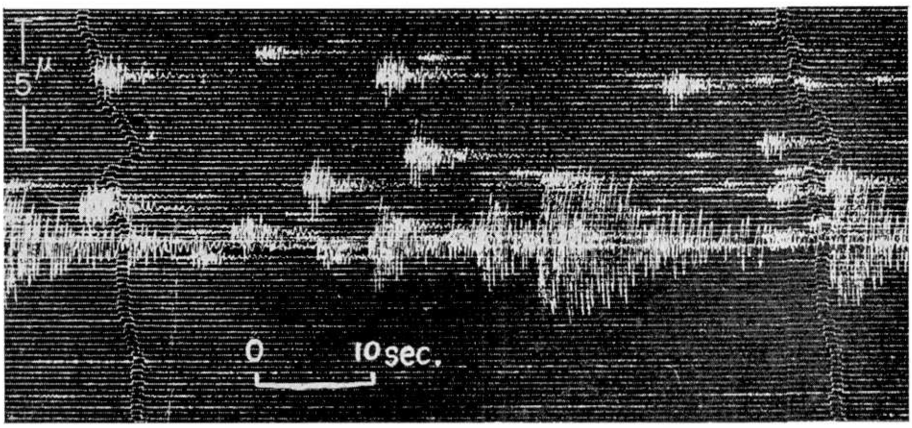
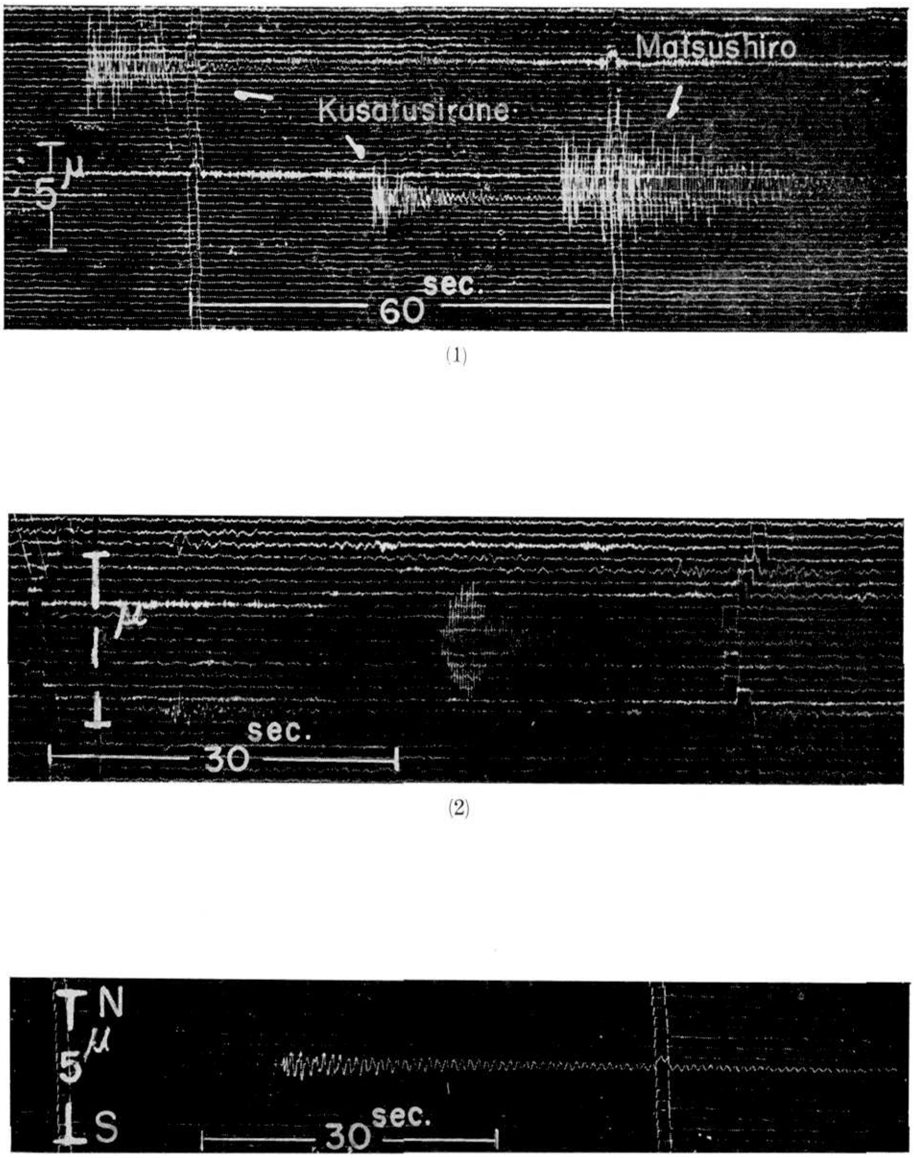


(2)

Fig. 37. The seismograms of the 1966 earthquake swarm originating from Kamiyama and Oowaku-sawa, Volcano Hakone. (July 24, 1966, 4h 05m).

(1): observed by the Kozukayama transducer (P_3),

(2): observed by the Ninotaira transducer (P_2).



(1)

(2)

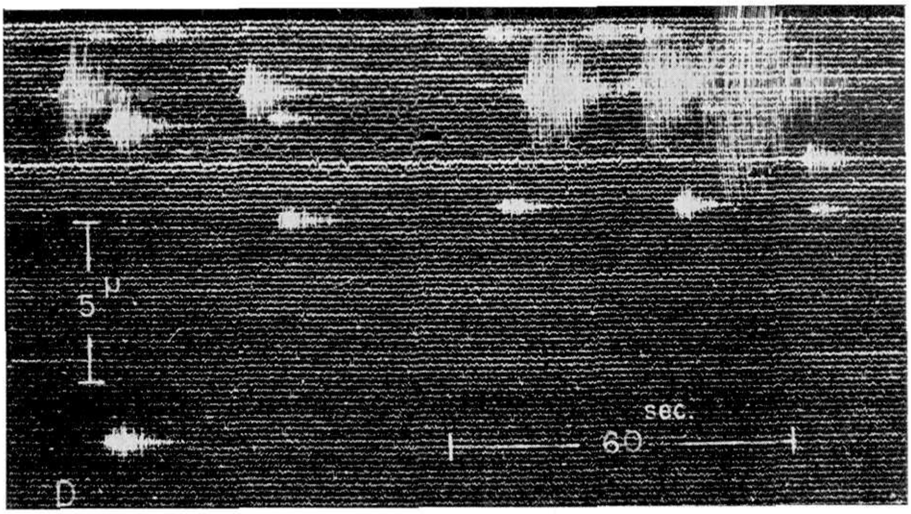
(3)

Fig. 38. The seismograms of the B type earthquakes originating near the summit craters of Volcano Kusatu-sirane.

(1): August 5, 1967, 04 h～07 h,

(2): August 6, 1967, 5 h 59 m 35 s,

(3): July 31, 1967, 01 h 53 m 23 s.



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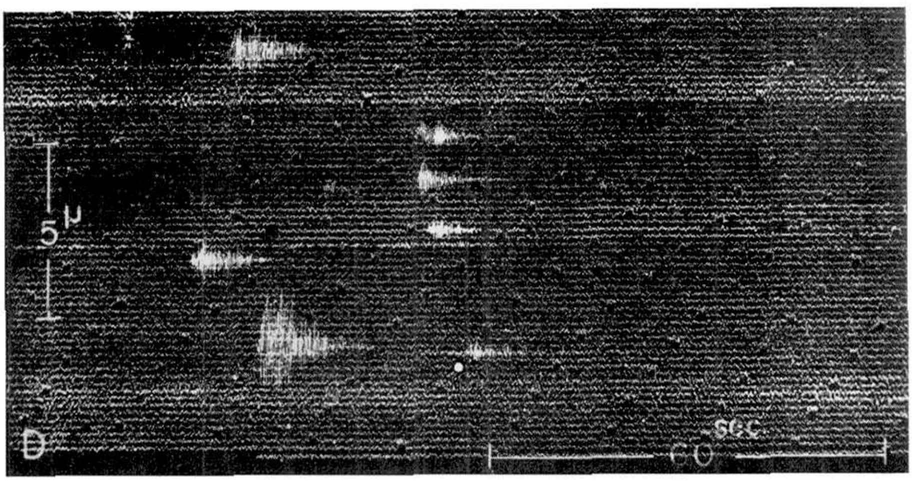


(2)

Fig. 39. The seismograms of the B type earthquakes originating near the summit crater of Volcano Kutinoerabu.
(1): December 7, 1966, (2): December 8, 1966.

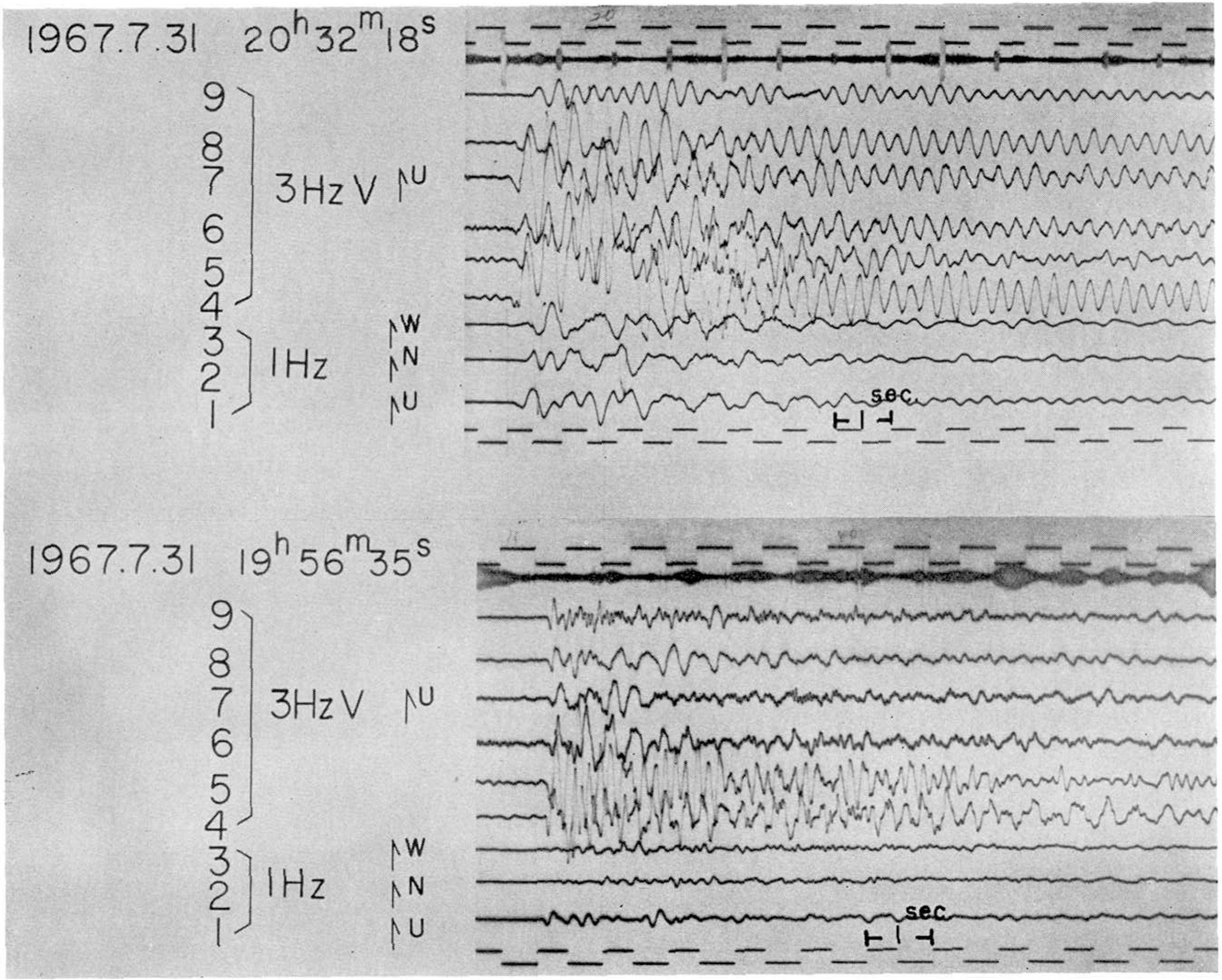
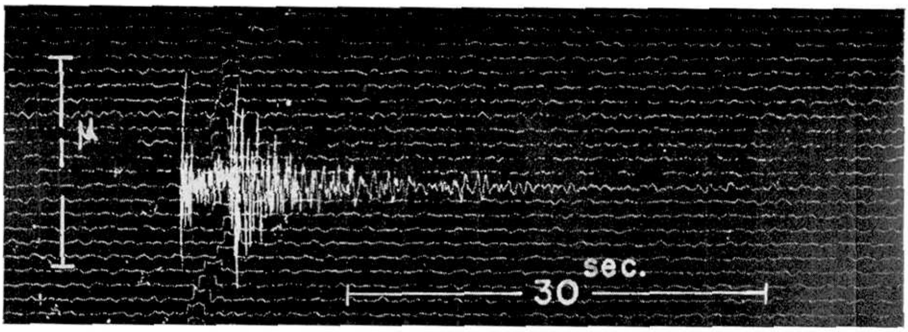


Fig. 40. The seismograms of the B type earthquakes originating near the summit craters of Volcano Kusatu-sirane.



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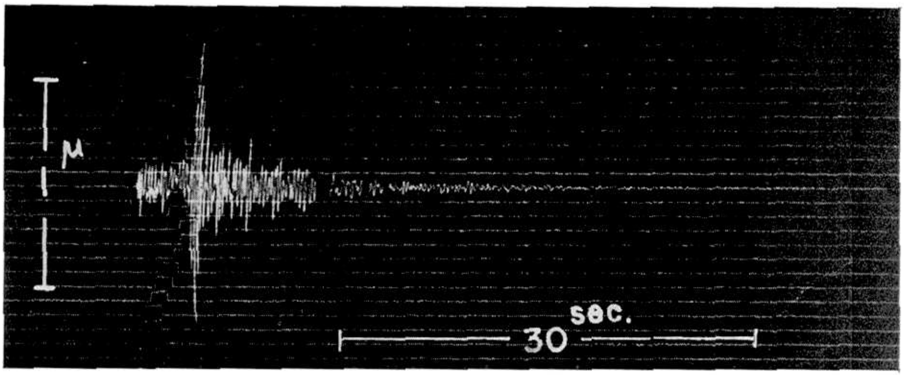

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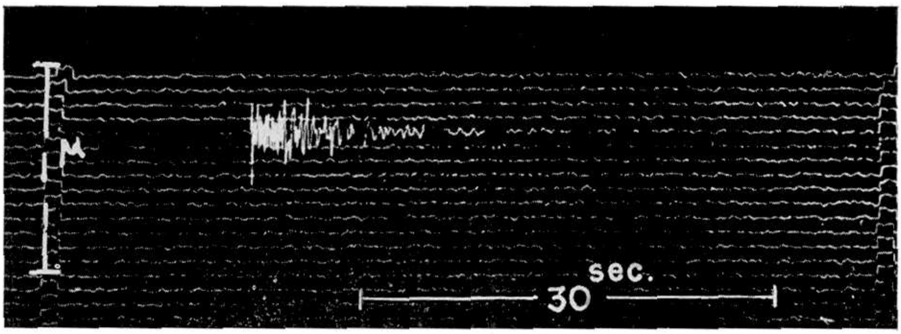
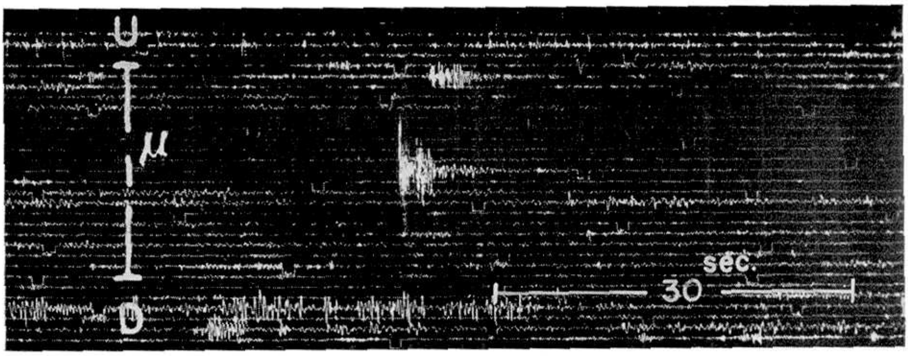


(3)

Fig. 41. Seismograms of the earthquakes originating from the vicinity of Volcano Nasu.
(1): November 9, 1966, 22 h 27 m 55 s, (U-D),
(2): 〃 , (S-N),
(3): November 13, 1966, 07 h 19 m 15 s, (U-D).



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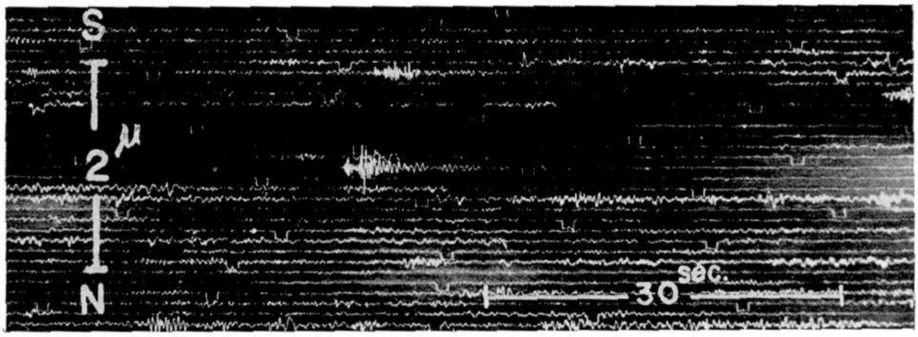
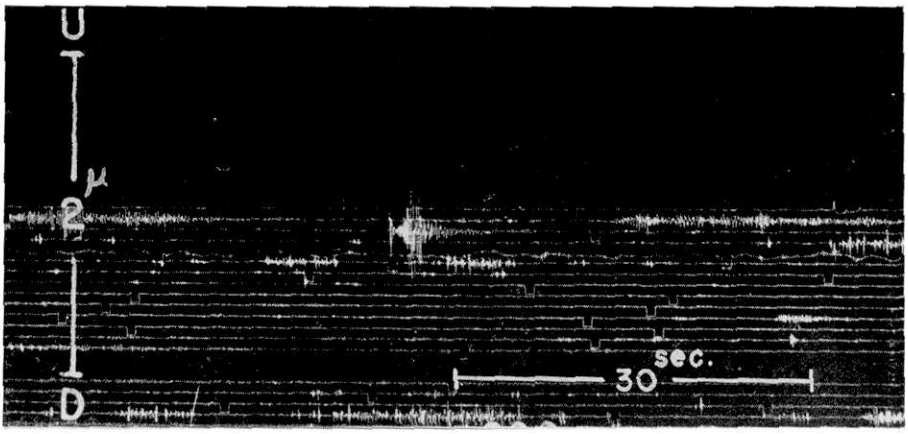


(2)



(3)

Fig. 42. The seismograms of the A type earthquakes originating from Volcano Sotará, Andes mountains, and its vicinity.

(1): January 24, 1966, 0 h 56 m (U-D),
(2): 〃 (S-N),
(3): January 28, 1966, 22 h 08 m (U-D).

Fig. 43. Volcano Sotará, Colombia, on January 30, 1966.

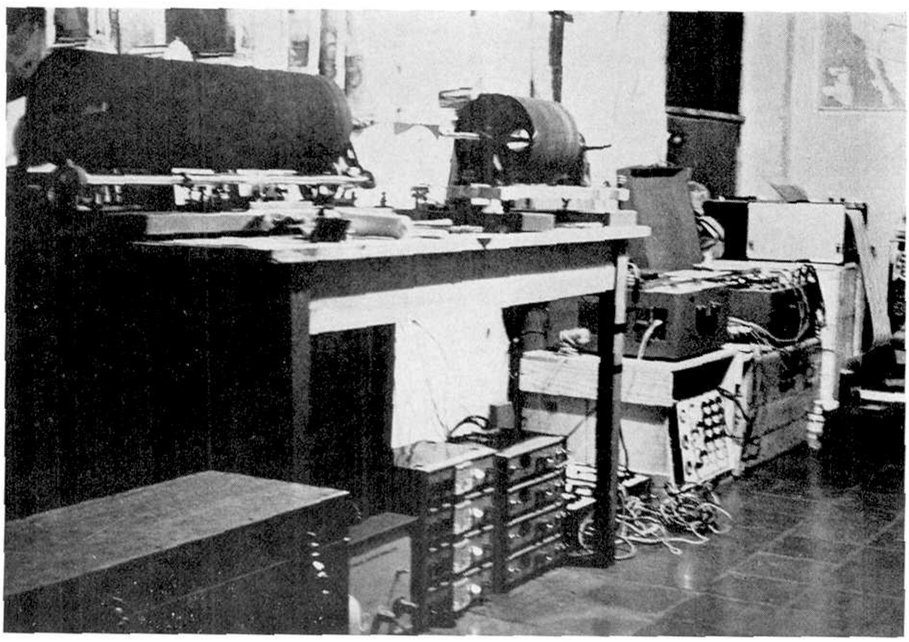


Fig. 44. The temporary seismometrical station established at Village Paispamba on the northern foot of Volcano Sotará.

Fig. 45. The summit crater of Volcano Sotará on January 30, 1966.

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Fig. 46. The summit crater of Volcano Puracé on January 30, 1966.

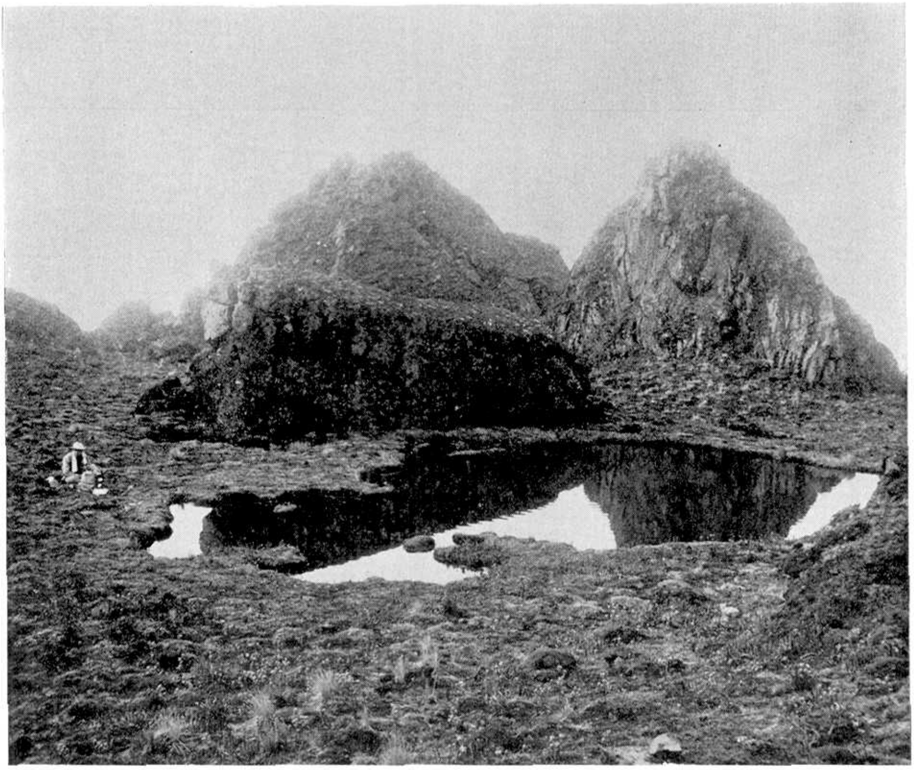

Fig. 47. The crater lake on the summit of Volcano Sotará.

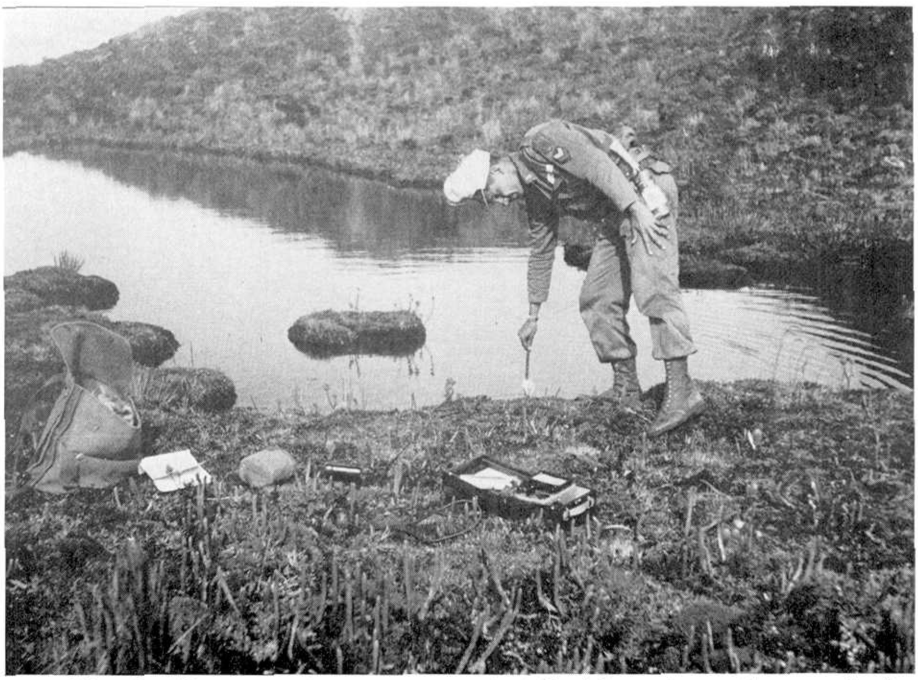

Fig. 48. The temperature measurement of the lake water on the summit of Volcano Sotará on February 1, 1966.

42. 噴火予知に関する基礎的研究 (II)

日本の諸火山及びコロンビア国ソタラ火山の地震計測学的調査

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平賀士郎
宮崎　務
内堀貞雄

本研究の第 1 報に於いて，火山に発生する地震及び火山の地殻変動と，噴火現象との関連について述べた．又その際，浅間山に於ける地震の連続観測の結果を用いて，火口附近に密集して発生する B 型火山地震の頻度を，統計的に取扱った．その結果，噴火発生前の地震頻度と，平穏時の頻度との比較から，噴火を予知するための実験式を求め，1，2 の実例に適用して，ほぼ満足する結果を得たことについても報告した．

言うまでもなく，噴火を予知するためには，平常時の地震頻度，その他，火山に発生する現象の状態と，噴火前のこれ等の現象の状態との相違を，明らかにすることによって達成できるものであろう．そのためには，噴火の危険のある火山に於いて，適切な計器による連続観測を実施する必要がある．しかし日本のみならず，世界各国の火山中そのような火山観測所を持つ火山は 10% 以内である．

それを補うために，火山の常時観測を行っていない，又は充分な観測の行なわれていない火山について，臨時の地震観測を行ない，各火山の平常に於ける地震発生の状態を，明らかにすることによって，異常の状態であるか否かを，判断の基礎とする計画をした．火山活動の予知のためには，先づ平常時の状態を明らかにしておく必要があることは当然だからである．つまり，火山の診断方法を，確立したいとの目的を以って実施したものである．

幸い，火山現象とその予知について関心を持つ，北大，東北大，東大，名古屋大，京都大の研究者が集り，噴火予知の研究グループとして，1965 年に組織され，ほぼ同じ方法の規準を定めて，火山地震の臨時観測を実施した．研究グループは，7 つの作業班に分れているが，本報告は，筆者等の班が行った観測，調査結果の概要である．

筆者等が調査を行った火山は次の通りである．

昭和 40 年　富士火山，箱根火山
昭和 41 年　口永良部島火山，箱根火山，那須火山
昭和 42 年　草津白根火山，阿弥陀ケ原火山，箱根火山
昭和 43 年　箱根火山，大室山．

上記の火山中，箱根火山は 1959 年以来連続地震観測を行ったので，その震源の位置及び平常時の地震頻度を明らかにすることが出来た．且つ上記観測期間中に 1959～1960 年に亘る著しい群発地震及び 1966 年の小規模の群発地震が発生したが，いづれも箱根カルデラ内の神山中央丘を中心として，発生したものである．

口永良部島に 1966 年 11 月 22 日に発生した水蒸気爆発の調査及び，同島に於ける地震観測を 4 ケ月に亘って実施した．B 型火山地震が山頂の活動した火口の附近に集中して発生したが A 型地震は起らなかった．その理由で，地下やや深所の熔岩の噴出は，発生しないであろうと判断したが，結果として誤ってはいなかった．

他の火山に於ける観測期間は短かく，観測期間中の地震頻度を以って，直ちに平常の状態であるのか否かの判定は困難であった．今後機会を得て，観測を繰り返すことが望ましい．

(以上の火山調査は，主として文部省の特定研究“噴火予知の研究”に対する研究費による.)

なお，本報告中のコロンビア国，ソタラ火山の調査は，その方法，目的等上記の他の火山と同じであるのでここに記載した．(ソタラ火山の調査は海外技術協力事業団の海外技術協力事業費による)．