BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 46 (1968), pp. 965-992

48. *The 1959 Eruption of Simmoe-dake and the 1961 Iimori-yama Earthquake Swarm.*

By Takeshi MINAKAMI, Daisuke SHIMOZURU, Tsutomu MIYAZAKI, Shiro HIRAGA and Masaru YAMAGUTI,

Earthquake Research Institute.

(Read Jun. 27, 1961, Mar. 22, 1966.—Received May 31, 1968.)

Contents

Abstract

Kirisima Volcano which is situated 50 km north of Sakura-zima Volcano has been studied from geophysical points of view, namely, seismic and geothermal observations which commenced after the phreatic eruption of Simmoe-dake in 1959. Kirisima Volcano consists of many cones the arrangement of which is roughly north-west and south-east. Seismic events during the period 1959–1966 are described based on observational facts. In March, 1964, Kirisima Volcano Observatory was established at Ebino. Since then, further extensive seismic, geothermal and geomagnetic surveys were conducted at Kirisima Volcano. Earthquakes which are originated from Kirisima Volcano have the focal depths of between 1 km and 10 km and no shallow earthquakes have been observed excepting at the time of the 1959 Simmoe-dake eruption. Measurements of underground temperature at Ebino clarified the gradual shift of high temperature region towards the west.

1. Introduction

Kirisima Volcano is situated 50 km north of Sakura-zima Volcano and 130 km south of Aso Volcano. In other words, Kirisima Volcano is situated between these two active volcanoes which are the most active in Japan. Kirisima Volcano was exempt from continuous geophysical observations before the eruption of Simmoe-dake in 1959 as a consequence of inactive volcanism in contrast to neighbouring volcanoes, namely, Sakura-zima and Aso.

In February, 1959, after a long quiescence, a sudden eruption took place from the summit crater and the upper part of the flank of Simmoe-dake. Shortly after this eruption, seismic and geothermal observations were initiated at Yunono and Ebino. In March, 1961, intense earthquake swarms occurred at the north-western extremity of Kirisima Volcano. These seismic events induced us, as well as the local residents, to establish a permanent volcano observatory for the purpose of fundamental research of Kirisima Volcano. Under these circumstances, a new volcano observatory was established at Ebino in March 1964. Since then, extensive seismic observations, geothermal and geomagnetic studies have been carried out covering the main part of Kirisima Volcano. This paper is a brief summary of geophysical work at Kirisima Volcano since 1959.

2. A brief description of Kirisima Volcano

Kirisima Volcano occupies a portion of the northern part of a long trough extending from Ata Caldera to Aira Caldera. This trough appears to be a sort of volcano-tectonic graben the northern extremity of which extends to Kakuto Basin, just north of Kirisima Volcano. Kakuto Basin is considered to be a caldera which is comparable in size to Ata and Aira caldera.

Kirisima Volcano is a composite volcano which occupies an area 30 km long and 20 km wide, with its major axis in a NW-SE direction. This direction is not parallel to the zone of volcanic belt running from Aso to Ryukyu. Direction of arrangement of volcanic cones at Kirisima Volcano is similar to those of Aso and also to those of vents of Sakura-zima Volcano.

The Main part of the volcano consists of a massive older, gentle-sloped shield volcano on which many younger steep cones are formed. These cones, almost 20 in number, are either shield or strato volcanoes or pyroclastic cones. Silhouette of Kirisima Volcano seen from NW direction is illustrated in Fig. 2, on which we can recognize the above mentioned general composition of Kirisima Volcano.

The rocks of Kirisima are olivine-pyroxene andesite or pyroxene andesite and belong to the hypersthene rock series.[1] The volcano is also characterized by several crater lakes (Onami-ike, Hudo-ike, Rokkannon-ike, Byakusi-ike) and maars (Ohata-ike, Mi-ike).

In and around Kirisima, many fumaroles and solfatara fields can be found among which Iwo-yama and Ebino, west of Karakuni-dake, are the most active. The fumaroles cluster also in many spots of the south western part of Kirisima Volcano.

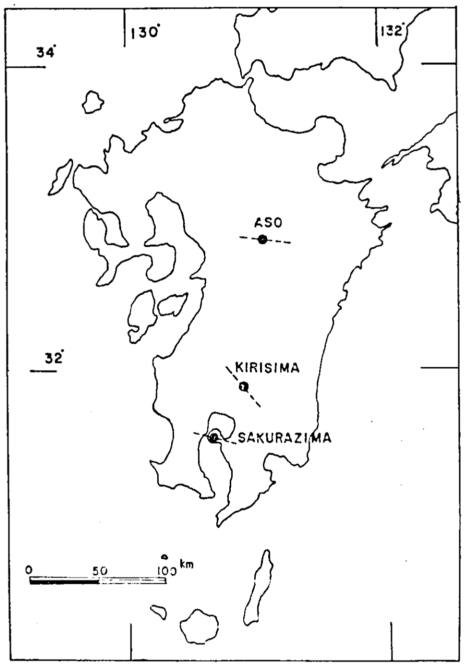

Fig. 1. Broken lines indicate the direction of arrangement of volcanic cones and fissures.

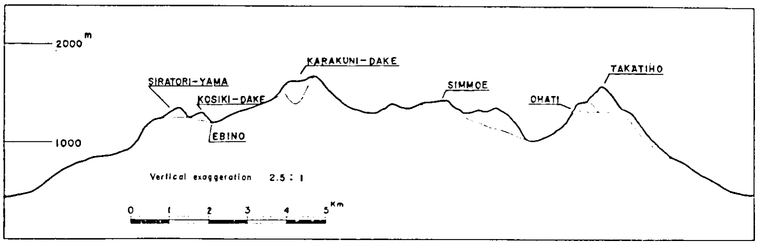

Fig. 2. Silhouette of Kirisima Volcano seen from west.

3. Historical sketch of eruptive and seismic events

The first record of the eruption of Kirisima Volcano appears as December 28, 742 A.D. The age of the first record is not exceptionally old. For instance, we have several volcanoes for which the first record

1) K. SAWAMURA and K. MATSUI, Explanatory Text of the Geological Map of Japan, "Kirisimayama", Geological Survey, Japan, 1957.

Table I. Sequence of eruptions of Kirisima Volcano.

742, Dec. 28	788, Apr. 18	837	843
857	858	945	1112, Mar. 9
1113	1167	1184, Feb. 7	1235, Jan. 25
1381	1524	1554	1566, Oct. 31 (†)
1574, Feb.-1578	1585	1587	1588, Apr. 7
1595	1598-1600	1613	1615
1617	1620	1628	1637

Takatiho	Simmoe
1659, Feb.-1661	
1662, Sep.-1664	
1667	
1678, Feb.-29	
1690	
1706, Jan. 28	
	1716, Mar. 11, Nov. 9 (†)
	1717, Feb. 7, 13 (†)
	1719
1768	
1769	
1771	
1772	
	1822, Jan. 20
	1832
1880, Sep.	
1887, May	
1888, Feb. 21, May 9	
1889, Dec. 10, 18	
1891, Jun. 19	
1894	
1895, Oct. 16 (†)	
1896, Mar. 15 (†)	
1897	
1898	
1899	
1900 (†)	
1903, Aug. 29, Nov. 25	
1913, Nov. 8, Dec. 9	
1914, Jan. 8, Nov. 8	
1923, Jul. (†)	
	1959, Feb. 17

(†) casualties.

of the eruption appears before the 8th Century, namely, Sakura-zima (708), Aso (796), Huzi (781), Asama (685) and O-sima (684 ?).

Sequence of eruptions of Kirisima Volcano is listed in Table I.

Up to the 1637 eruption, the location of the erupted crater had not been mentioned. After the 1659 eruption the name of the erupted crater is given as either Ohati or Simmoe-dake.

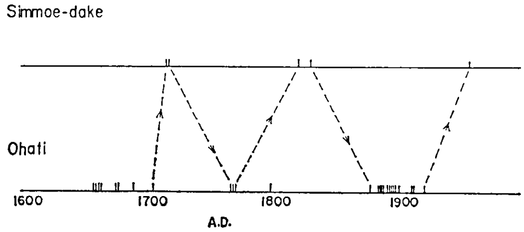

Fig. 3. Sequence of eruption of Kirisima Volcano since the 1659 eruption of Ohati.

Sequence of eruption after 1659 is illustrated for both Simmoe-dake and Ohati separately in Fig. 3. It seems that Simmoe-dake becomes active only during the period of quiscence of Takatiho (Ohati) or, rather say, that both volcanoes become active alternately.

During the historic period, the volcano erupted only scoria, lapilli and ashes while extrusion of lava does not appear to have taken place. These eruptions are considered as the so called phreatic type.

Next, we have to mention seismic events around Kirisima Volcano which seem to be relevant to volcanic activity.

There are at least three remarkable seismic episodes at the Kirisima area, namely, in 1913 (Masaki earthquake swarm), 1915 (Kurino earthquake swarm) and in 1961 (Iimori-yama earthquake swarm). The earthquake swarm in 1913 was followed by a minor eruption of Ohati while no eruptive activity is reported in case of the latter two earthquake swarms. The first two seismic events were reported by F. Omori[2] and the earthquake swarm in 1961 was studied seismometrically by the present authors.

Masaki earthquake swarm took place on 19th May, 1913 and continued almost six months. The Epicentral area of these earthquakes was presumed by Omori to be the region of Masaki. Just immediately after this earthquake swarm, Ohati erupted in Nov. 8, Dec. 9, 1913 and in Jan. 8 and 13, 1914. This eruptive activity of Kirisima Volcano is followed by the gigantic eruption of Sakura-zima in Jan. 12. 1914.

In July, 1915, an earthquake swarm occurred at the north western part of Kirisima Volcano and continued about one month. Based on the direction of initial motion and $S-P$ time interval of seismograph

2) F. OMORI, *Bull. Imp. Earthq. Invest. Comm.*, 92 (1920), 49-52.

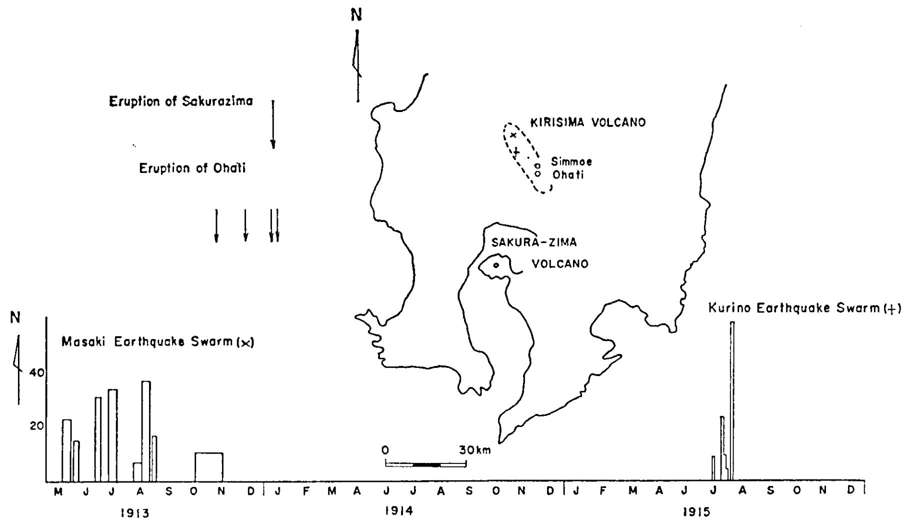

Fig. 4. Eruptive and seismic events in southern Kyushu during 1913-1915.

at Kagosima, F. Omori located the epicenters as 2 km north of Kurino-dake SPA. Intensity of this earthquake swarm was stronger than the Masaki earthquakes, however, no eruptive activity of Kirisima Volcano has been reported.

Sequence of seismic and eruptive episodes just mentioned above are illustrated in Fig. 4 together with the epicenter of major earthquakes of two earthquake swarms. Omori mentioned the significance of the position of epicentral regions which are located on the major axis of volcanic cones of Kirisima Volcano.

4. Eruption of Simmoe-dake in 1959

After a mild activity of Simmoe-dake in 1832, the center of activity moved to Ohati which had erupted on nearly twenty occasions during 40 years. The repose period of Simmoe-dake, namely, 127 years, ended with the eruption in Feb. 17, 1959. On that day, the summit of Simmoe-dake was covered by rainy cloud and, hence, no body recongized the accurate time of the eruption nor the eruptive site. At around 14 h 50 m, residents of the eastern and southern part of the volcano heard volcanic rumbling. In particular, considerable air shock was felt at the office of the Forest Reserve at Ohata-ike and Sin-yu. However, no explosion earthquake was recorded at the Seismographic Station at

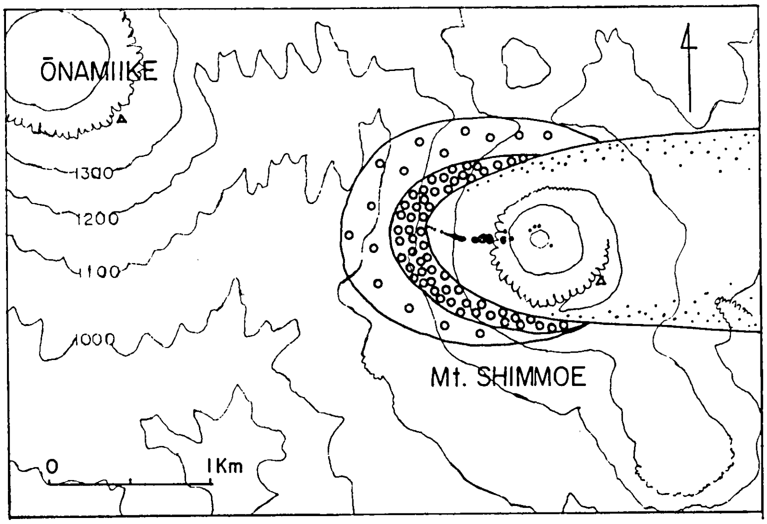

Fig. 5. Distribution of fragmental ejecta and ash deposit by the 1959 eruption of Simmoe-dake.

Kagosima and at Miyazaki, nor was the air wave detected by the micro-barograph at Kagosima.

According to our survey, eruption took place from newly opened craterlets ranging from the north-western part of the inner crater wall to the outer slope of Simmoe in the direction of N 65°W. The eruption

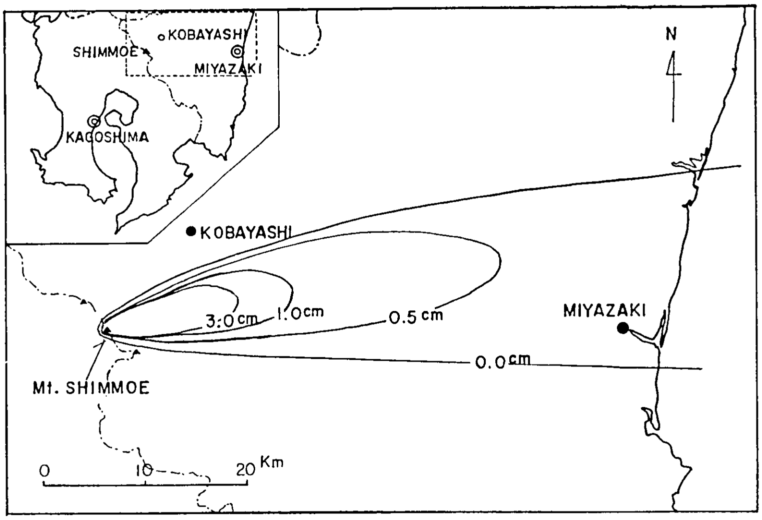

Fig. 6. Distribution of ash fall deposit by the 1959 eruption of Simmoe-dake.

is a typical fissure eruption of which the newly opened fissure is shown in Fig. 5 as well as the distribution of fragmental ejecta and ashes.

Projection of fragmental ejecta is only limited to the western part of the crater while ash deposit extends widely towards the east. Distribution of ash fall is shown in Fig. 6. The eruption is phreatic type and no juvenile materials were ejected. Even at the crater, no trace of burning of plants could be found. This is one reason for believing that the temperature of ejected materials might have been low.

Kinetic energy of the present eruption was estimated as 10^{19} ergs based on the total amount of ejected material and calculated initial velocity of volcanic bomb.

After the eruption, fumarolic activity continued from fissures and gradually decreased its activity.

5. Seismic studies from 1959 through 1961

Immediately after the eruption of Simmoe-dake in Feb. 1959, seismic observation was carried out from March 1 to 31 at Yunono, at the southern foot of Simmoe-dake. Three horizontal 1 c/s seismometers, P_1, P_2, and P_3 were located as shown in Fig. 7. Seismic signals transmitted by cables were recorded by electro-magnetic oscillograph with the paper speeds of 1 mm/s or 3 mm/s. Magnification of seismograph was 4,000. Daily frequency of earthquakes which took place at Kirisima Volcano is shown in Fig. 8, as well as the tremor amplitude recorded at Station 1. Earthquake occurrence decreased sharply after March 5. Most of these earthquakes were found to have occurred at a depth of 1–3 km below Simmoe-dake and Naka-dake. Beside these volcanic earthquakes, volcanic tremor of harmonic type has been

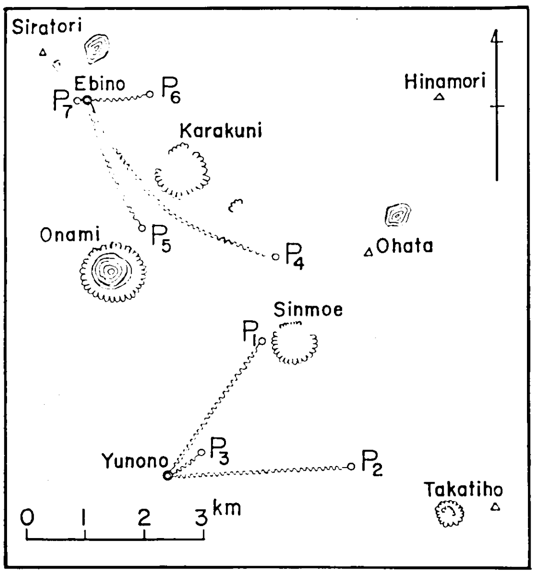

Fig. 7. Location of seismometers at Kirisima Volcano.

recorded the source of which seemed to be located at the newly opened crater.

The Predominating period of volcanic tremor recorded at Station I, the nearest seismometer to Simmoe-dake, was 0.25 sec. Amplitude and period relation of volcanic tremor at two seismic stations is shown in Fig. 9. Decrease of tremor amplitude with distance from Simmoe-dake is found to be large from which the source of tremor is presumed to be shallow.

It is interesting to find from Fig. 8 that, on March 2nd, volcanic tremor disappeared while occurrence of volcanic earthquakes showed maximum frequency.

There has been no seismological observation made so far at Kirisima Volcano. Hence, ordinary seismic activity in this area has not been known. In order to investigate the seismic activity which has close relation to volcanic activity, seismometers were transferred to Ebino where a small observatory has been constructed by the courtesy of Miyazaki Prefecture. Four seismometers, P_4, P_5, P_6, and P_7 were placed as shown in Fig. 7 during the period April 21-28. From this observation,

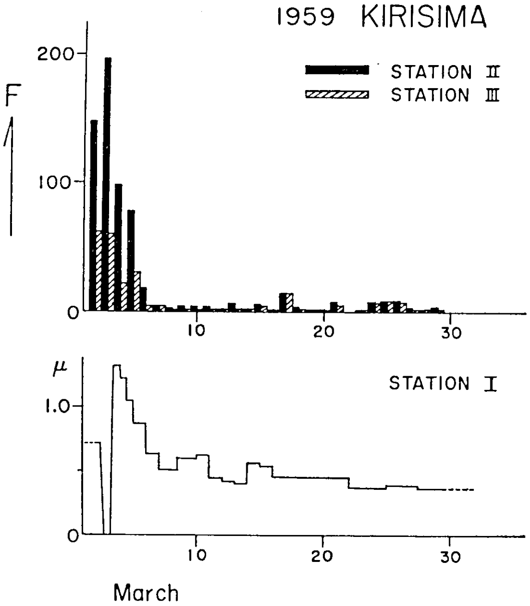

Fig. 8. Upper figure shows the daily frequency of earthquakes accompanying the 1959 eruption. Lower figure is the tremor amplitude recorded by the seismometer nearest to Simmoe-dake.

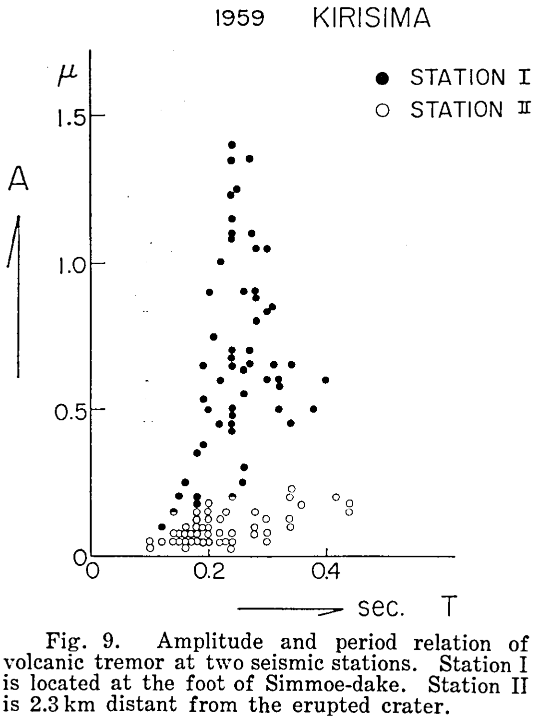

Fig. 9. Amplitude and period relation of volcanic tremor at two seismic stations. Station I is located at the foot of Simmoe-dake. Station II is 2.3 km distant from the erupted crater.

though short in period, a few earthquakes were found to be originated at a shallow depth beneath the area of Ebino and Karakuni. It can be said that, accompanying the eruption of Simmoe-dake, earthquakes occurred not only beneath the erupted crater, but also beneath the wider area which belongs to the major axis of the arrangement of cones of Kirisima Volcano.

For the purpose of precautionary measures for future eruptive activity, one seismometer, P_7, continued to be operated up to July 20, 1964 with the reduced magnification of 2,000.

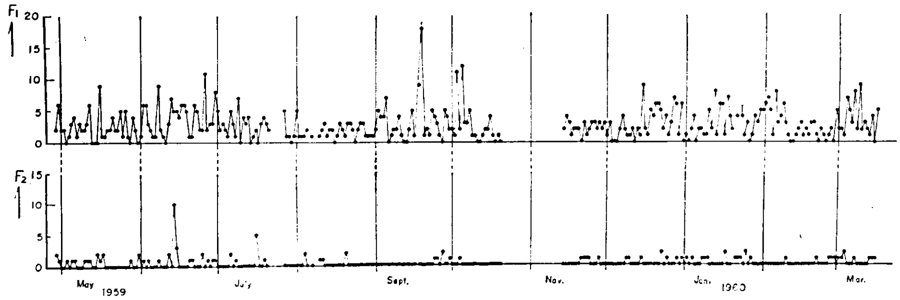

Fig. 10. Daily frequency of earthquakes recorded at Ebino. F_1 is the total number and F_2 is the number of earthquakes of which $S-P$ is less than 5 sec.

Number of earthquakes recorded at Ebino with the above seismometer is shown in Fig. 10. Usual daily number of earthquakes which occurred at Kirisima Volcano ($S-P<5.0$ sec.) is less than 2. Slightly high seismic activity is seen on June 12–15 when Simmoe-dake showed more intense fumarolic activity than usual.

On 27th of February, 1961, just two years after the 1959 Simmoe-dake eruption, the Hyuganada earthquake occurred 50 km off the coast of Miyazaki ($\lambda=131.9°$ E, $\varphi=31.6°$ N, $M=7.0$). The eastern coast of Kyushu was attacked by minor tsunami and several casualties were reported at Miyazaki. The earthquake was followed by many aftershocks till early in April.

Simultaneously with the occurrence of the main shock, the seismograph at Ebino began to record earthquakes originating from the Kirisima Volcano area. The Daily number of earthquakes originating from Hyuganada and from Kirisima are shown in Fig. 11 separately as (1) and (2). The Number of felt earthquakes at Ebino is shown as (3) in the above figure.

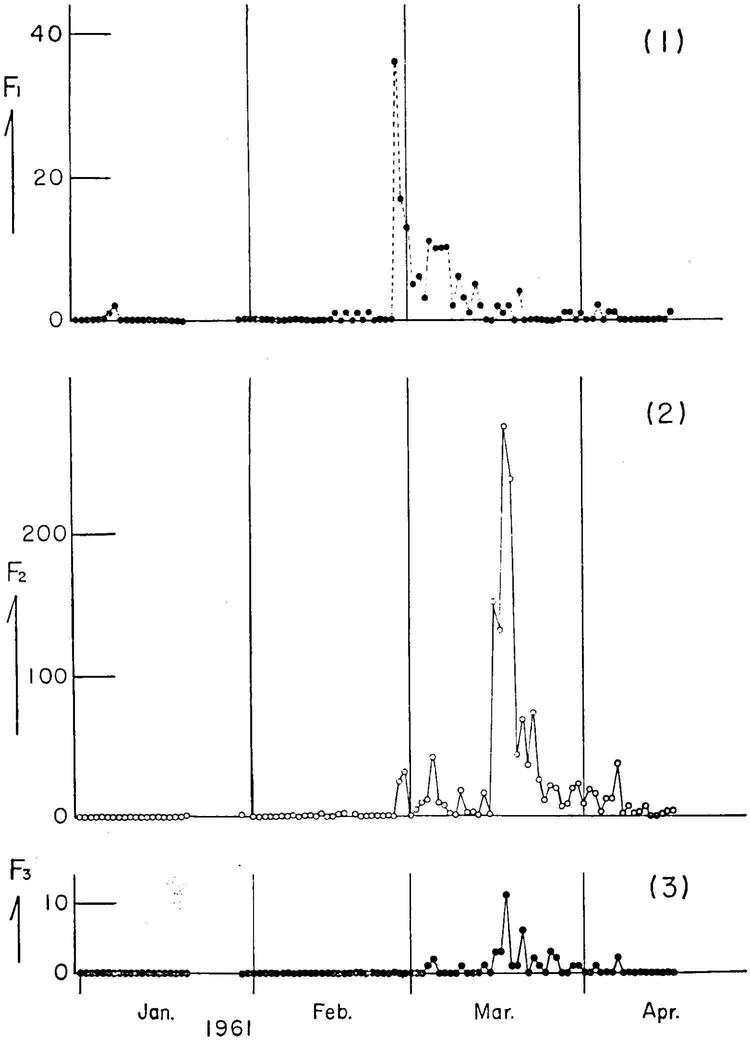

Fig. 11. (1) Daily number of earthquakes originating from Hyuganada, (2) daily number of earthquakes originating from Kirisima Volcano, (3) number of felt earthquakes at Ebino.

Kirisima Volcano is about 100 km west of the epicentral region of the Hyuganada earthquake. It is quite interesting to find in Fig. 11 that the pattern of sequence of earthquake occurrence for both earthquakes is quite similar and, further, the earthquakes of Kirisima Volcano began to occur with the phase delay of 17 days.

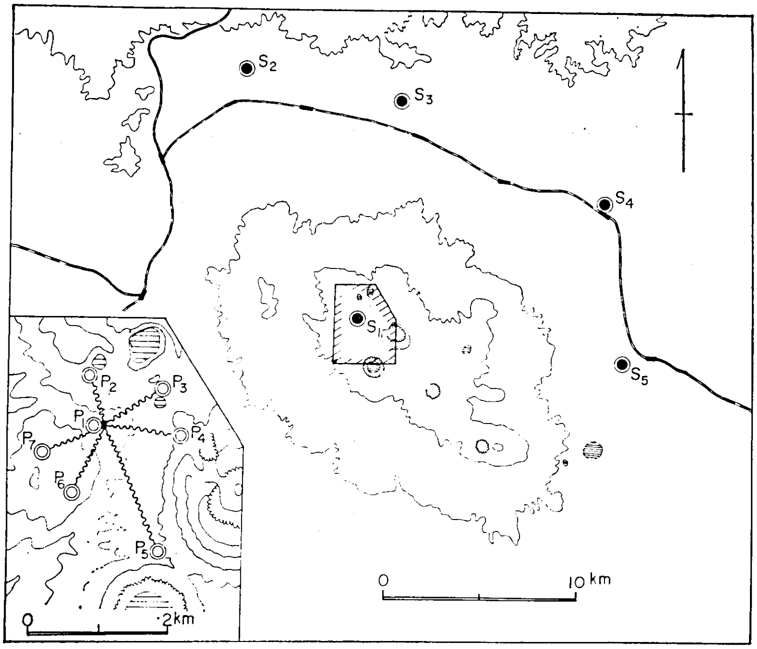

Fig. 12. Location of seismometers of seismic reconnaissance for Iimori-yama earthquake swarm in 1961. S_i, P_i indicate acceleration seismograph and moving coil type transducer, respectively.

As described in Chapter 3, a similar earthquake swarm in 1913 (Masaki earthquake swarm) was followed by a minor eruption of Ohati. Recalling this historic episode, local residents feared any future eruption or the occurrence of a destructive earthquake. Local authorities and the Office of the National Park required urgent precautionary measures to be taken for preventing disasters from volcanic activity.

Table II. Seismographs located at Kirisima Volcano during March 23—April 17, 1961.

Notation in Fig. 10	Seismograph	Number	Magnification
S_1 ~	Accelaration	1 vertical and	200
S_5	Seismograph	2 horizonal in each	
P_1	Moving coil transducer(1c/s)+ Oscillograph	1 vertical and 2 horizontal	3000
P_2	〃	1 vertical	〃
P_7	〃	〃	〃

In these circumstances, and also from purely academic reasons, seismic observation was carried out from March 23 to April 17. Seismometers were placed as shown in Fig. 12. Transducers were directly connected with the oscillograph through cables without amplifier.

Relatively large earthquakes were recorded by at least four acceleration seismographs by which their hypocenters were determined from $S-P$.

In principle, time duration of $S-P$ is proportinal to the focal distance. This proportionality coefficient (K) is called "Omori's constant" which varies with focal depth and elastic constants of the medium concerned. In other words, K is the velocity of hypothetical ($P-S$) wave. K was determined through geometrical drawing by use of at least four $S-P$ recorded by acceleration seismograph as 6.5–6.8 km/sec.

On the other hand, apparent velocities and direction of approach of seismic waves are obtained from the first arrival of seven seismometers located as shown in Fig. 12. Let one pair of seismometers be P_p and P_q of which arrival time is t_p and t_q and horizontal distance of the two seismometers is l_{pq}. Let θ and φ be the angle of the direction of approach of seismic waves and that of the direction of l_{pq} measured from the north clockwise as shown in Fig. 13. If we assume the seismic waves to be plane waves with the apparent phase velocity of $\bar{V}_p$, we have

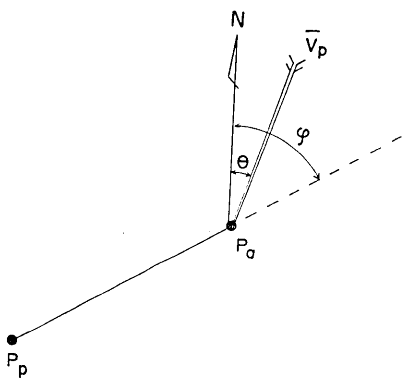

Fig. 13. $\bar{V}$, θ indicate the apparent P velocity and direction of approach of seismic waves.

$$\cos(\varphi-\theta)\cdot l_{pq}/(t_p-t_q)=\bar{V}_p\,.$$

Hence,

$$(\cos\varphi\cdot\cos\theta+\sin\varphi\cdot\sin\theta)l_{pq}/(t_p-t_q)=\bar{V}_p\,.$$

Thus, we have

$$\frac{\cos\varphi\cdot\cos\theta}{\bar{V}_p}+\frac{\sin\varphi\cdot\sin\theta}{\bar{V}_p}=\frac{t_p-t_q}{l_{pq}}\,.$$

Putting,

$$\cos\theta/\bar{V}_p = X, \quad \sin\theta/\bar{V}_p = Y ,$$

we have

$$X\cdot\cos\varphi + Y\cdot\sin\varphi = (t_p - t_q)/l_{pq} , \tag{1}$$

where

$$X^2 + Y^2 = 1/\bar{V}_p^2 \quad \text{and} \quad Y/X = \tan\theta . \tag{2}$$

Therefore, if we can determine X and Y from a possible combination of seismometers, we obtain apparent phase velocity $\bar{V}_p$ and direction of approach θ from equation (2).

If the equation (1) is divided by $\cos\varphi$, we have

$$X + Y\tan\varphi - \frac{t_p - t_q}{l_{pq}}\sec\varphi = 0 .$$

Therefore, normal equation of X and Y are

$$nX + Y\sum\tan\varphi_i - \sum\frac{t_p - t_q}{l_{pq}}\sec\varphi_i = 0 ,$$

$$X\sum\tan\varphi_i + Y\sum\tan^2\varphi_i - \sum\frac{t_p - t_q}{l_{pq}}\sec\varphi_i\tan\varphi_i = 0 .$$

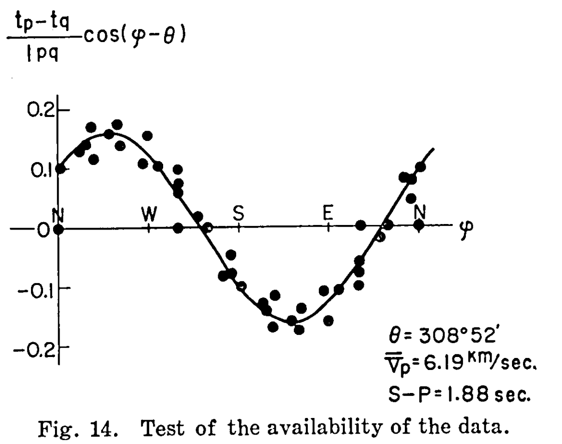

Fig. 14. Test of the availability of the data.

From seven seismometers, we have 21 combinations as a maximum. Fig. 14 is an example of the plot of equation $\cos(\varphi-\theta) = \bar{V}_p(t_p - t_q)/l_{pq}$ for one earthquake. If the first arrival of any seismometer is poor because of local conditions or misreading of the time of onset, plotted values for seimometers combined with this inadequate seismometer may be deviated largely from the curve of circular function. In this case, such combinations are withdrawn and X and Y have to be recalculated from the combination of remaining seismometers.

Table III. List of parameters of observed earthquakes. θ, v, $s-p$ and Z denote the azimuth of direction of approach, apparent velocity, $s-p$ time duration and focal depth respectively.

No.	θ	v	$s-p$	Z
	N W	km/sec	sec	km
1	59°55′	6.59	1.60	8.1
2	26°14′	4.84	1.30	4.0
3	10°56′	5.25	1.31	5.1
4	17°47′	4.40	1.45	2.1
5	27°32′	5.68	1.86	8.1
6	52°39′	4.98	1.81	6.2
7	51°08′	6.19	1.88	9.0
8	50°22′	5.48	1.90	7.8
9	48°39′	6.17	2.07	9.9
10	54°36′	6.32	1.58	7.7
11	46°30′	6.48	1.68	8.4
12	28°02′	5.27	1.38	5.3
13	25°14′	5.75	1.42	6.4
14	45°32′	5.19	1.67	6.3
15	2°42′	6.74	1.37	7.1
16	25°50′	5.76	1.40	6.3
17	40°06′	5.29	1.50	5.9

If we assume the mean true velocity of P waves (V_p) as 4.5 km/s for the upper layer of the concerned crust, emergent angle (e) is calculated from observed $\bar{V}_p$ for each earthquake. Thus, epicentral distance (Δ) and focal depth (h) are calculated by the following equations,

$$\Delta_i = K(S-P)_i \sin e_i \ ,$$

$$h_i = K(S-P)_i \cos e_i \ .$$

Table III is a list of earthquakes determined by the above procedure of which epicenters and hypocenters are plotted as solid circles, in Fig. 15. In this figure, double circles are the earthquake foci determined by $(S-P)$ of acceleration seismographs. Shaded area is the epicentral and hypocentral area of earthquakes which occurred at the time of the 1959 Simmoe-dake Eruption. Earthquakes have been found to occur at a depth of 4-8 km beneath the border of towns of Masaki and Yosimatu, i.e., very near Iimori-yama, one of the volcanic cones which is old and extinct. Epicentral area, in other words, is located on the axis of the arrangement of volcanic cones. The Northern part of Kirisima

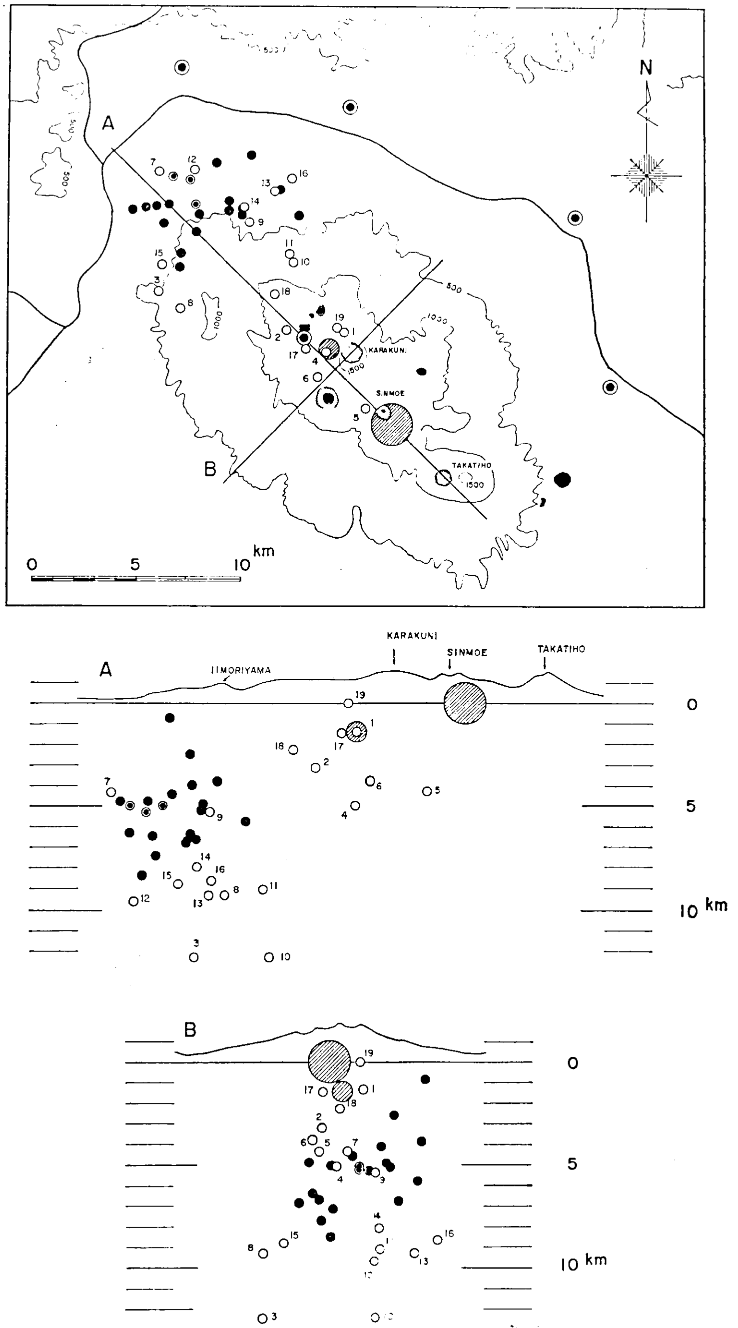

Fig. 15. Epicenters and hypocenters of earthquakes originating from Kirisima Volcano. Solid circles indicate those of Iimori-yama earthquake swarm, open circles are those of A type earthquakes. Small double circles were determined by $S-P$ of acceleration seismograph which are indicated by double circles in the upper figure.

Volcano is joined to the Kakuto Basin and the earthquake swarm took place at the northern extremity of volcano-tectonic graben.

The Iimori-yama earthquake swarm was almost over on April 17. Considering the location of hypocenters of the present earthquakes, though we could observe no remarkable surface activity of Kirisima Volcano, the Iimoriyama earthquakes can be presumed to be related to volcanic process under ground. All earthquakes which have been recorded in the present observation have the epicentral area just mentioned above, and no earthquake has been recorded which occurred at a shallow depth beneath active cones. Thus, we believed that we had no indication of eruptive activity in the near future.

6. Establishment of Kirisima Volcano Observatory

In view of the eruptive and seismic episodes of Kirisima Volcano in recent times as mentioned earlier, continuous geophysical observations

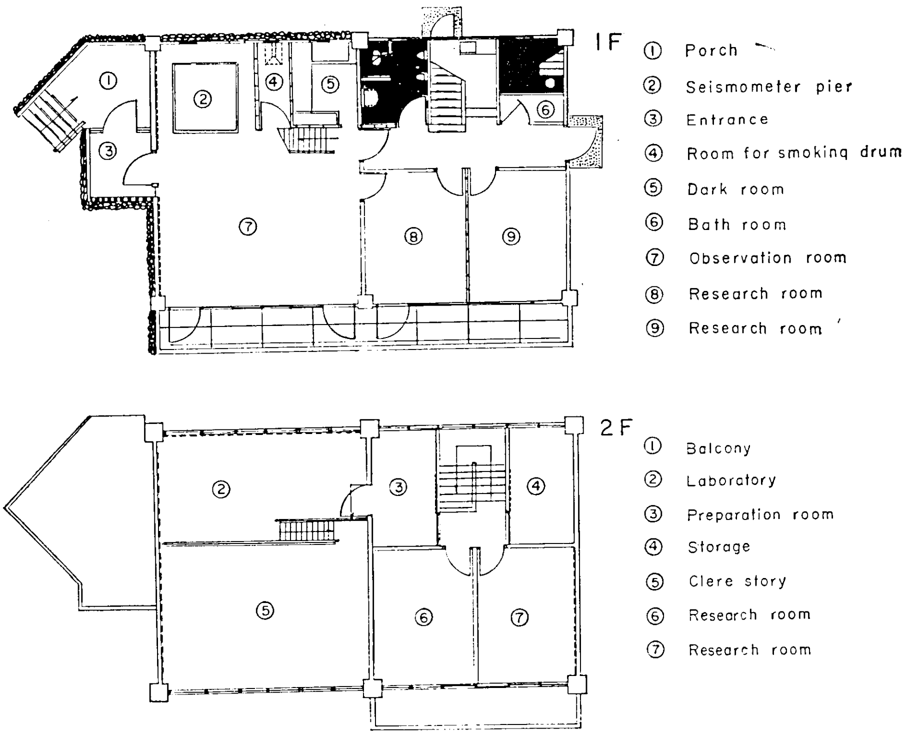

Fig. 16. Plan of the Kirisima Volcano Observatory.

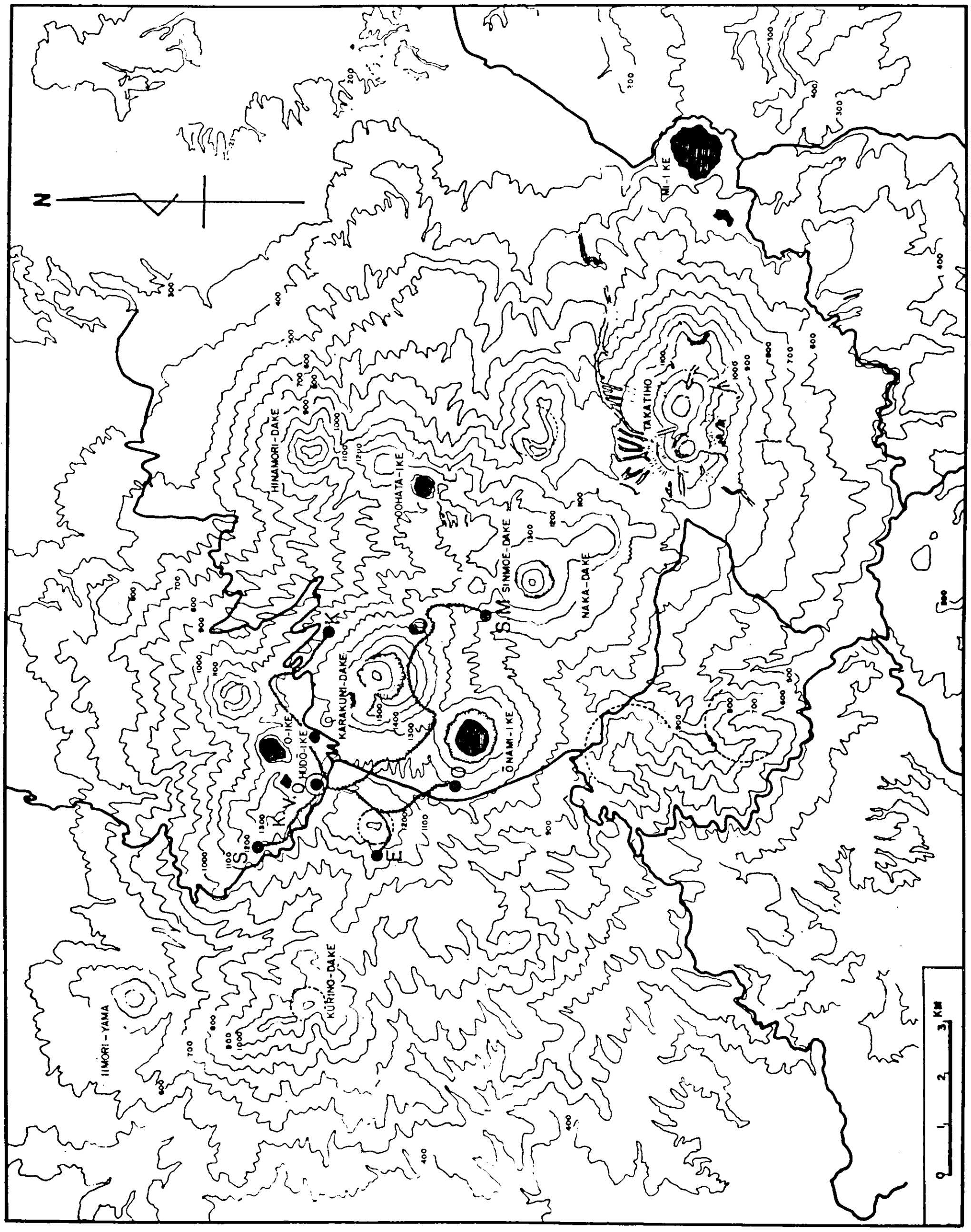

Fig. 17. Location of seismometers for routine observation.

of a permanent character have been considered to be necessary. Furthermore, the geothermal field of the Kirisima Volcano area, such as, Ebino and Yunono, is worth studying for future exploitation of geothermal energy as well as to gain knowledge about the form of heat output from a volcanic area.

In these circumstances, in March, 1964, the Kirisima Volcano Observatory was established at Ebino with the floor area of 162.5 m^2.

The building is two storied with reinforced concrete construction.

Seismometers are located as shown in Fig. 17 and are connected to the transistorized amplifiers in the observatory through cables. Three component acceleration seismographs are installed on the seismometer pier in the observatory. The crystal clock generates accurate 50 c/s A.C. which is amplified and supplied to the synchronous motor of the recording drums so as to maintain uniform rotation of the drum.

As is usual in a volcanic area, there are heavy thunderstorms with lightning, especially in summer, when excessively high voltage may occur between telemetering line, transducer coils, amplifier and the ground. This high voltage may damage amplifiers, transducers and cables, which thus must be protected, in order to prevent interruption of telemetered seismic and geothermal observations. For this purpose, three arrester tubes were attached to the input of each amplifier for which earth resistances are less than 20 ohms.

Since the establishment of the observatory in 1964, installation of seismographs, measurements of underground temperature at many spots in Ebino and geomagnetic survey were done by the staff of the observatory. In the following chapters, seismic and geothermic works are described separately.

7. Seismic studies after 1964

There were no remarkable seismic events during 1964 and 1965. Daily frequency of earthquakes is shown in Fig. 18.

Daily number of recorded earthquakes and that of earthquakes originated from Kirisima Volcano are shown separately. At the end of February, 1965, we had frequent occurrences of small volcanic earthquakes. Judging from arrival time of seismometers and from $S-P$, these earthquakes were found to be originated from the region almost the same as that of the Iimoriyama earthquake swarm in 1961. Frequency distribution of $S-P$ time intervals during the period Apr. 19, 1964-Dec.

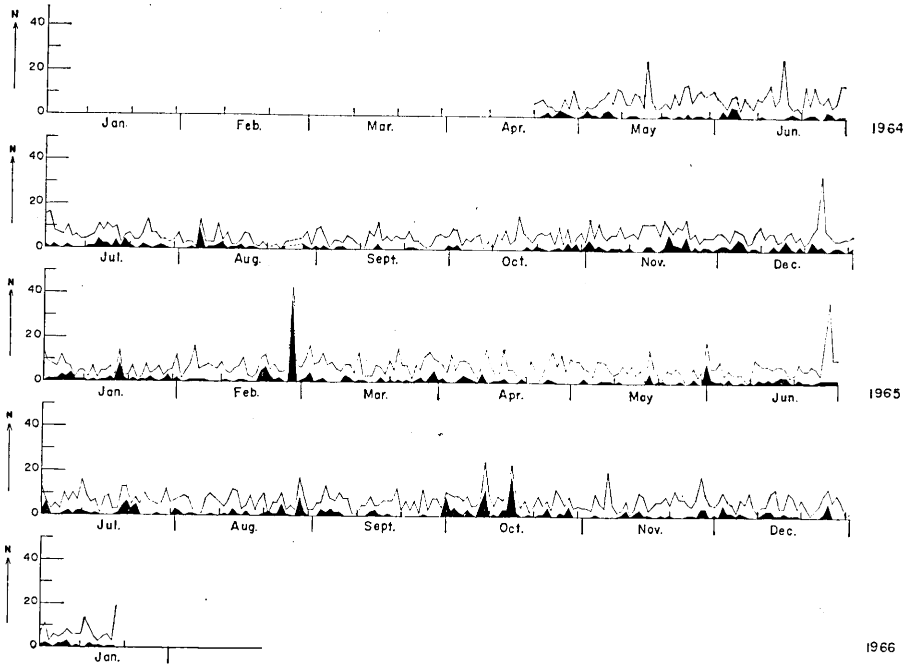

Fig. 18. Daily frequency of earthquakes observed at the Observatory seismograph (magnification: 15,000). Black area is the frequency of earthquakes originating from Kirisima Volcano.

31, 1965, recorded by the Observatory seismograph is shown in Fig. 19. The histogram is separated into two parts, i.e., one for $S-P$ being less than 3.0 sec. and the other is 12.0–16.0 sec. Epicentral area of most of the earthquakes belonging to the latter is off the coast of Miyazaki

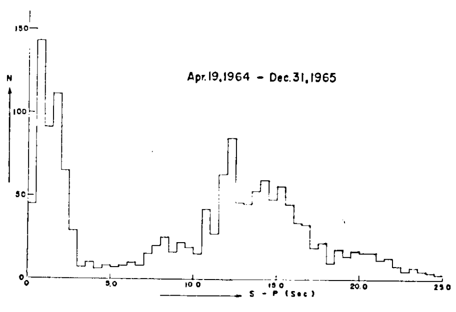

Fig. 19. Histogram of $(S-P)$ of earthquakes rocorded at the Observatory seimograph.

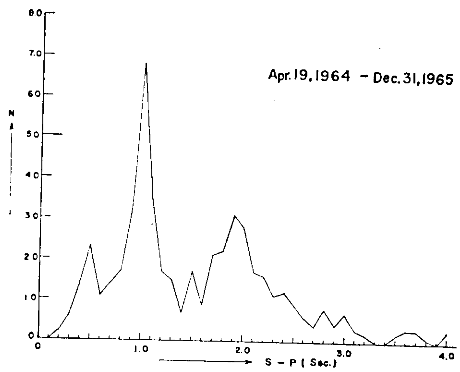

Fig. 20. Histogram of $(S-P)$ less than 4 seconds.

which is one of the high seismic regions in Kyushu. These earthquakes occur with the focal depth of less than 60 km. The fine structure of $S-P$ less than 4.0 sec. is shown in Fig. 20.

There are noticeable two peaks in $(S-P)$, that is, 1.0 sec. and 2.0 sec. These earthquakes are with no doubt of volcanic origin. Very sharp P and S implies the focal depth as not very shallow. Earthquakes with 1.0 sec. in $S-P$ originate beneath the region of Karakuni-dake, Ebino and Shiratori-yama, whereas those with 2.0 sec. in $S-P$ occur beneath the region of Iimori-yama. Examples of hypocenters and epicenters of these earthquakes are plotted in Fig. 15 as open circles together with those of Iimori-yama earthquake swarm in 1961 (solid circles). Shaded circles are the epicentral and hypocentral area of earthquakes which occurred immediately after the Simmoe-dake Eruption of 1959. We have, thus, three categories in spatial distribution of hypocenters originating from Kirisima Volcano. They are the earthquakes which take place at extremely shallow depth of active cone, Simmoe-dake, earthquakes beneath Karakuni-dake and Ebino with focal depth of less than 5 km. and earthquakes beneath Iimori-yama with the focal depth from several kilometers to 10 km.

It seems that there is no seismic activity just beneath the active crater, Simmoe-dake and Ohati, excepting the extremely shallow one. Focal depth increases as we go to the north-west of these cones which is parallel to the axis of the arrangement of the cones of Kirisima Volcano.

Routine seismic observation, results of which are mentioned above, is done usually with the magnification of 15,000 in displacement. However, the noise level of Kirisima Volcano is comparatively lower than that of other active volcanoes in Japan. In good atmospheric conditions, the noise level is less than 0.02 microns. Therefore, observations with high magnification seismographs were greatly needed for the purpose of obtaining more detailed seismicity of Kirisima Volcano.

In July, 1965, in this connection, seismic observation with high magnification has been carried out during July 9–July 29. Short span tripartite seismic net was set up as a reference station at Ebino with 3 c/s vertical transducers. Seismic signals were amplified and recorded by oscillograph at the Observatory. Another mobile tripartite net with a data-recorder was set up at Shubasho, Mi-ike, Obeno and at Takatiho-gawara successively. Four- or five-night observations were carried out at each mobile station. Apparent velocities and direction of approach of observed earthquakes have been determined independently at the Observatory and at the mobile seismic station.

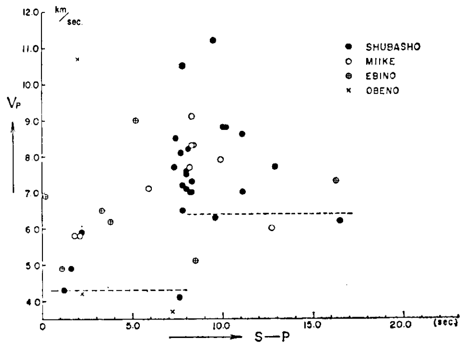

Fig. 21. Plot of apparent velocity (V_p) against ($S-P$).

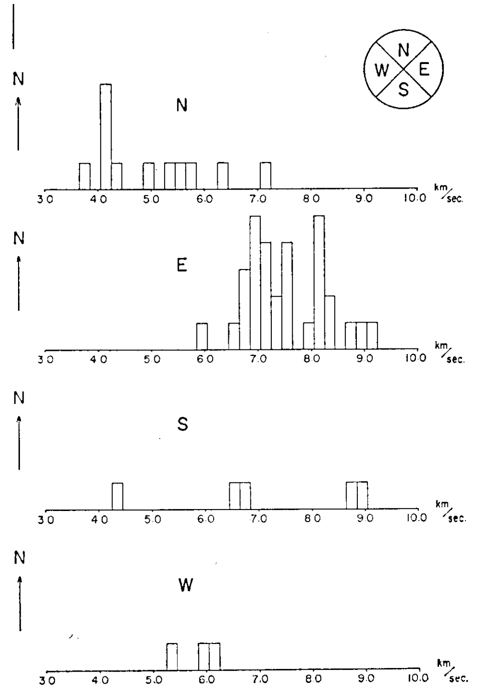

Fig. 22. Frequency of apparent velocities separated by the direction of approach.

Apparent velocities and $S-P$ observed at these tripartite nets is plotted in Fig. 21. Earthquakes with $S-P$ less than 5 seconds have apparent velocities 4–7 km/sec whereas those with $S-P$ larger than 5 seconds have apparent velocities 6–9 km/sec. It is, thus, likely that P velocity in the upper part of Kirisima Volcano is about 4.3 km/sec and that of the lower layer about 6.5 km/sec.

As can be seen in Fig. 22, earthquakes with relatively large apparent velocities mostly occur eastward, namely, at the coastal region of Miyazaki.

During three week's observation, the seismic activity of Kirisima Volcano was quite low. Direction of approach and apparent velocities are shown as vectors in Fig. 23 at each seismic station. Despite the longer period of observation at Ebino than at other seismic stations, the number of observed earthquakes is small which is the consequence of lower magnification of seismographs than at other stations resulting from relatively high noise level at Ebino. Earthquakes of No. 3, 6 and 7 in Fig. 23 were commonly observed at Ebino and another mobile station. Epicenters of these earthquakes can be determined from combined tripartite nets as they occurred north-west of Kirisima Volcano.

Kirisima Volcano, in general, is characterized by relatively low seismic activity as clarified by seismic observation made by the present

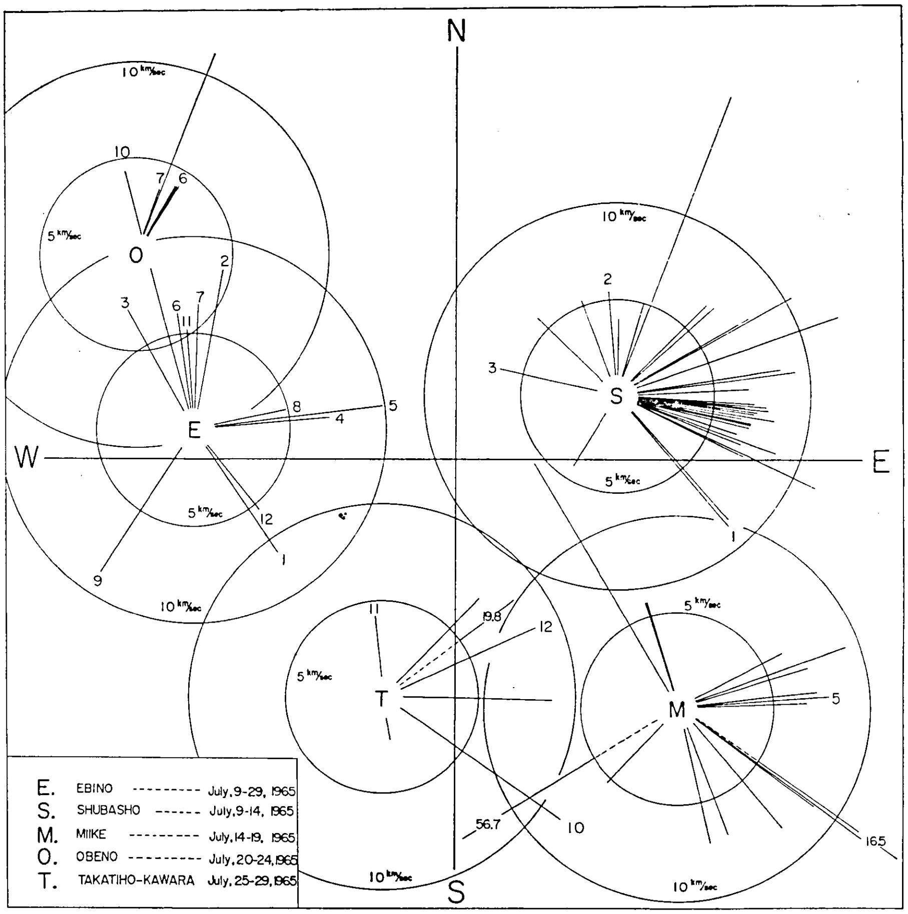

Fig. 23. Direction of approach and apparent velocities of seismic wave observed during July 9-29, 1965.

authors in the past several years. Most of the earthquakes originating from Kirisima Volcano have the focal depth of 1–10 km which are the so called A type earthquakes. Spatial distribution of hypocenters of these earthquakes is roughly arranged in the plane dipping to north-west direction. Focal depth is deep at the north-western extremity of Kirisima Volcano and becomes shallow beneath the active craters. Kirisima Volcano is situated at the northern extremity of the volcano-tectonic graben, as previously mentioned. It is characteristic that relatively deep A type earthquakes occur beneath the area where the volcano-tectonic graben disappears into the Kakuto Basin. Based on geological studies, the north-western part of Kirisima Volcano seems to be older than the south-eastern part in which active craters are involved. We have, however, little knowledge to judge whether these earthquakes are directly related to magmatic processes or not.

If we consider the general seismicity of southern Kyushu, major earthquakes are found to occur at the depth of 100–200 km beneath the volcanic belt. It is also said that the outside of the volcanic belt is characterized by the concentration of seismicity at shallow depth, namely, less than 60 km[5].

8. Geothermal studies

There are several geothermal fields in Kirisima Volcano, such as, Ebino, Yunono, Siratori and others. Hot springs are supplied to the hotels and steam is utilized to supply hot water to them. One of the remarkable features of the geothermal field at Ebino is the gradual shift of steaming spots. This is recognized from both the distribution of dead plants and the present steaming area. This movement of steaming spots has given rise to the future plan of the development of the National Park.

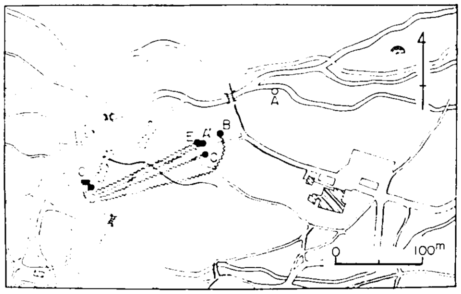

Fig. 24. Location of thermistor thermometers for the continuous measurement of underground temperature.

In order to know the present distribution of actual underground temperature as well as its time variation, four thermistor thermometers have been put at 1 meter depth at four spots, A, B, C and D as shown in Fig. 24 in November, 1959. Temperatures were continuously recorded at the seismic station at Ebino. Underground temperature at 1 meter depth shows only seasonal variation and diurnal variation mostly disappears. 5-day running mean

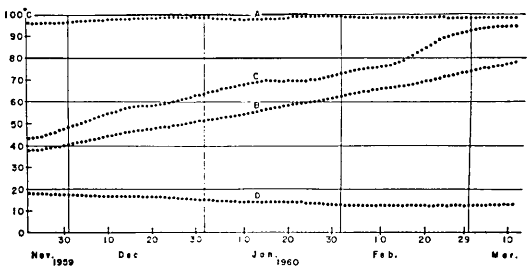

Fig. 25. Daily temperature at 1 meter depth.

5) D. SHIMOZURU, *Bull. Volcanologique*, 26 (1963), 181–195.

of daily temperatures are plotted in Fig. 25 in which the temperature at B and C shows gradual increase with the velocity of 0.4°C/day and 0.6°C/day, respectively. Temperature at A is almost constant at 97°C which is nearly the boiling point at the altitude of this area. Slight decrease of temperature at D is no doubt the seasonal variation.

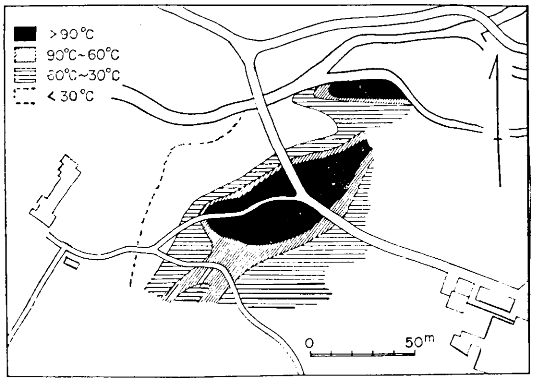

Fig. 26. Distribution of underground temperature at 1 meter depth at Ebino.

On 8th and 9th of October, 1960, temperatures were measured by mercury thermometer at 1 meter depth at each grid point which divides the area of 100 m² into equal squares of 10 m edge length.

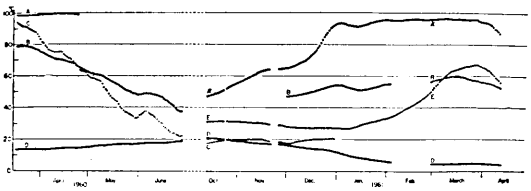
Fig. 27. Variation of underground temperature at Ebino.

As shown in Fig. 26, high temperature region extends towars the west in a tongue shape. On October 9, 1960, measurement at spot A was transfered to a new hole A′. Thus, temperature measurements began at five spots, A′, B, C, D and E. Daily mean temperature for these holes are plotted in Figs. 27 and 28.

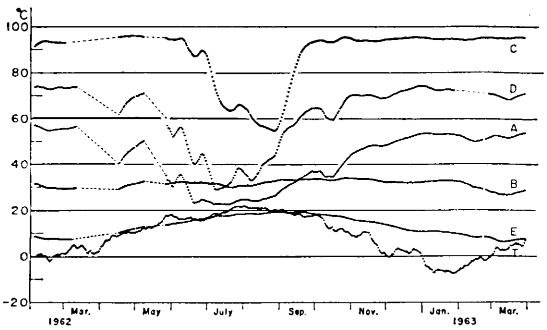

Fig. 28. Variation of underground temperature at Ebino.

Underground temperature at B and C show marked decrease from March, 1960. Temperature decrease in summer can be attributed to the increase of ground water resulting from heavy rain falls. This effect is more remarkable for the holes of high temperature than those of low temperature. Before establishment of a new volcano observatory, distribution of underground temperature has been measured for selecting the site of the building. Fig. 29 is a temperature distribution

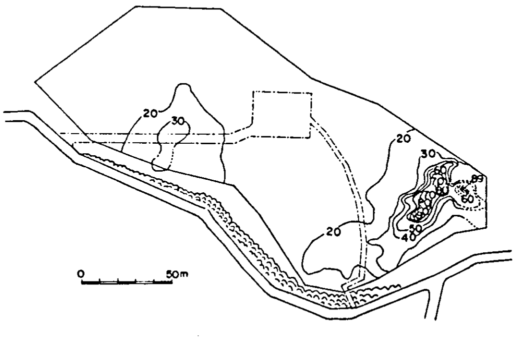

Fig. 29. Distribution of underground temperature at the leased torritory.

at 1 meter depth measured during the period October 31–November, 7, 1942. Only the eastern border of the leased territory (19,000 m^2) showed high temperature. Therefore, the proposed site of the observatory was the center of the territory as indicated by chain line in Fig. 29.

After establishment of the Kirisima Volcano Observatory, further extensive work has been initiated by drilling many holes at Ebino geothermal area. Temperatures at 1 meter depth have been continuously recorded by use of thermistor thermometers at spots No. 1–11 in Fig. 30. Temperatures at other spots as shown by solid circles in Fig. 30 have been measured once a month. Temperatures of continuous recording at

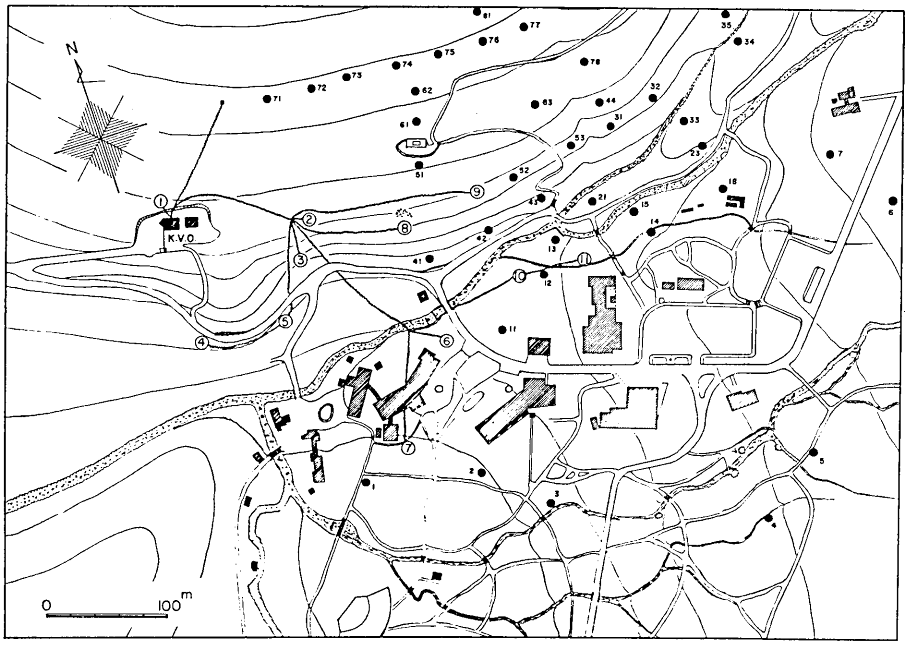

Fig. 30. Distribution of holes (1 meter depth) at Ebino for the measurement of underground temperature. Open circles for holes for continuous recording and solid circles are those for the measurements once a month.

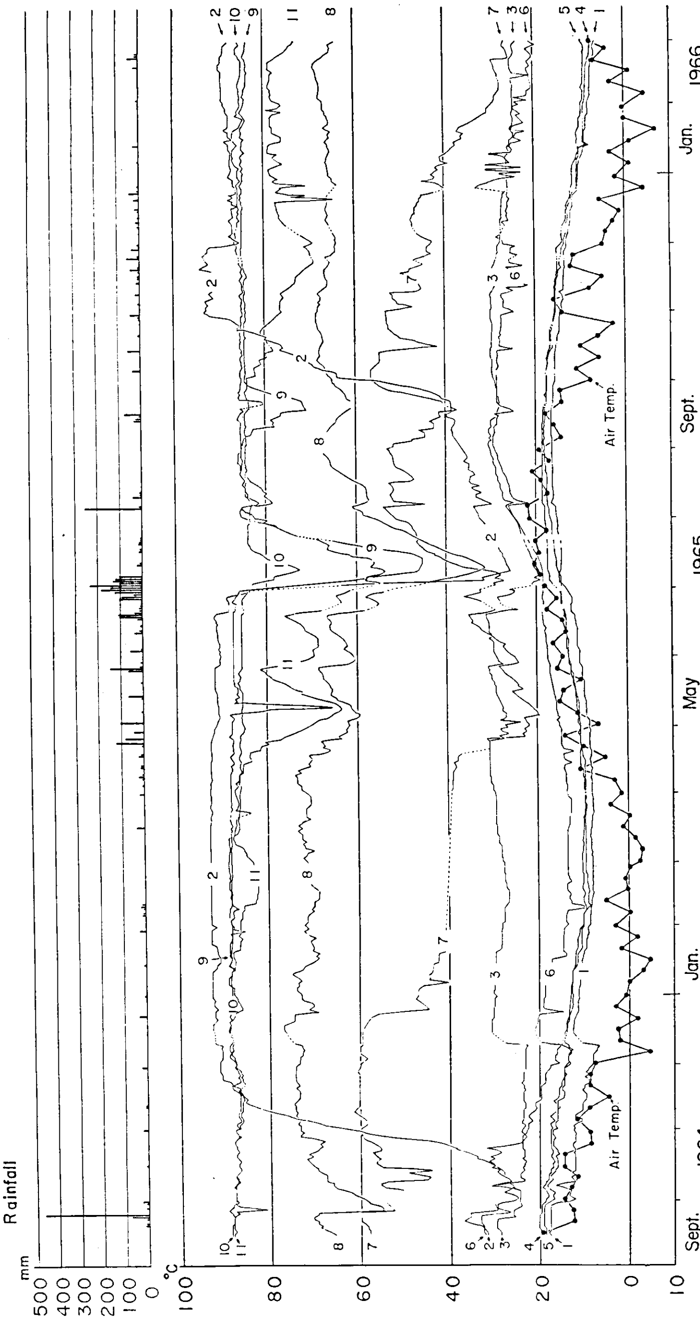

Fig. 31. Temperature variations for holes of continuous observation. 5 day running mean of air temperature is plotted as solid circles.

eleven holes are shown in Fig 31 together with the precipitation at Ebino and air temperature. Large decrease of temperature at the holes 2, 8, 9, 10 and 11 in summer is due to rain falls. Decrease of temperature is not remarkable for the holes of relatively low temperature such as, 1, 4 and 5, for which seasonal variation is clearly seen. Decrease of amplitude and time lag of the maxima and minima of temperature compared with the seasonal variation of air temperature reflects the law of heat conduction. There is also a time lag between rain falls and the temperature decrease which means the effect of seepage of ground water through porous ground.

9. Acknowledgment

The authors are largely indebted to the Governer and Officers of Miyazaki Prefecture for their kind cooperation in our initiation and continuation of geophysical work at Ebino. We are very grateful to the late Mr. K. Imamura and Mr. I. Sibata, manager of Ebino Kogen-so, who generously helped and permitted us to use their facilities.

---

48. 1959年の新燃岳の噴火および1961年の飯盛山群発地震

地震研究所 水上　武
下鶴大輔
宮崎　務
平賀士郎
山口　勝

1959年2月，霧島火山の新燃岳が長い静穏期に終りを告げて水蒸気爆発を行なつた．噴出物の調査によれば爆発の運動のエネルギーは 10^{19} エルグと推定された．爆発直後実施した地震観測によれば，火山性地震が新燃岳のごく浅い場所に発生していることが判つた．また新燃岳に最も近い地震計は最大1.5ミクロンに達する火山性脈動を記録した．

これを機会に，これまで未知であつた霧島火山の地震活動を知るため，湯之野における観測にひきつづいて，えびの高原において地震観測を開始した．1961年2月，日向灘地震が発生し，それと期を同じくして，霧島火山に有感地震が群発した．1913年，真幸地震発生後，高千穂の活動を見たので，今回も霧島火山の活動の可能性もあつたので，えびの高原を中心として多成分地震観測を行なつた．その結果によれば，群発地震の震源は，飯盛山を中心として，地下数 km に存在し，新燃岳や高千穂の地下浅い所には地震が発生していないことが判つた．従つて，群発地震の発生に関連して，噴火が起る可能性は無いであろうと推論された．

1964年3月に，えびの高原に霧島火山観測所が設置され，地震観測がルーチン化された．1966年の初めまでの期間には，霧島火山に震源を持つ火山性地震の発生頻度は極めて少なかつた．これらの地震のうち震源が決まつたものについて見ると，飯盛山附近の地下数 km に存在するものが多い．1961年の群発地震の例を見ても判るように，霧島火山に発生する火山性地震が，古い山体である飯盛山の地下に頻発することは霧島火山の活動に関連して極めて興味深いことである．

霧島火山にはえびの高原を中心として，地熱地帯が散在する．1m の深さの穴をえびの高原に多数堀り，そのうちの11点は観測所においてサーミスタ温度計による1m 深の地中温度連続観測を行ない，えびの高原の1m 深の温度分布が判つたが，これは季節により移動するように見られる．

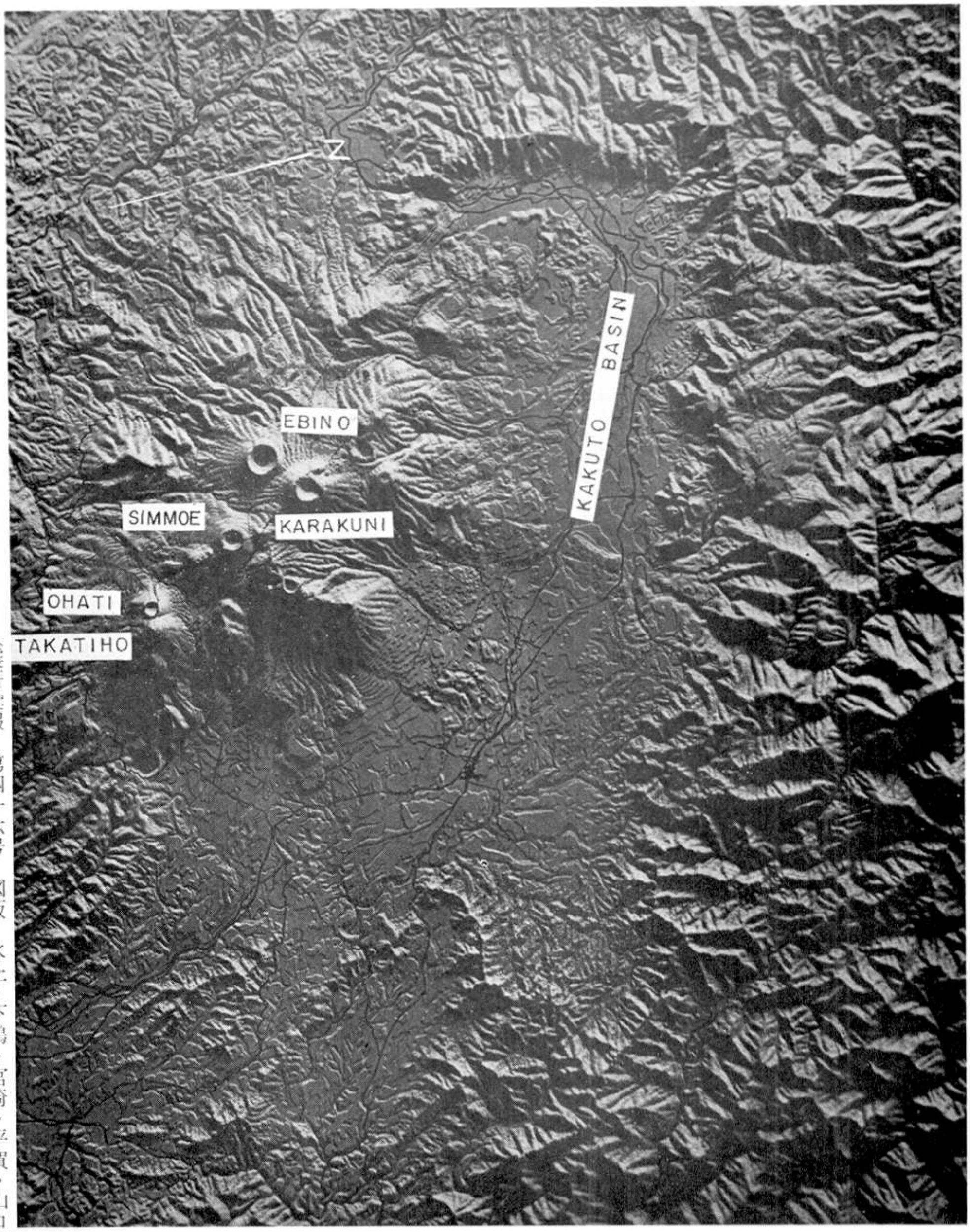

Fig. 32. Relief model of Kirisima Volcano and surrounding area.

Fig. 33. Aerial photograph of Kirisima Volcano.

(震研彙報 第四十六号 図版 水上・下鶴・宮崎・平賀・山口)

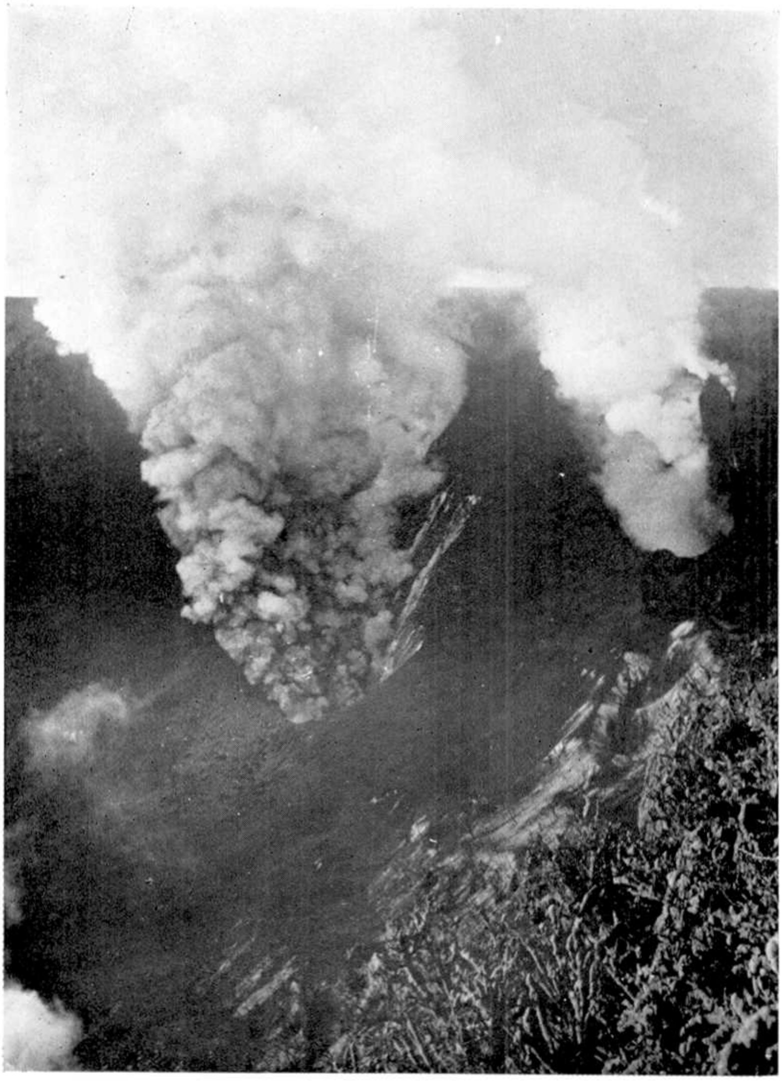

Fig. 34. Eruption of Simmoe-dake. Photograph was taken at 8 a.m., Feb. 17, 1959.

Fig. 35. View of the Kirisima Volcano Observatory.

(震研彙報 第四十六号 図版 水上・下鶴・宮崎 平賀・山口)

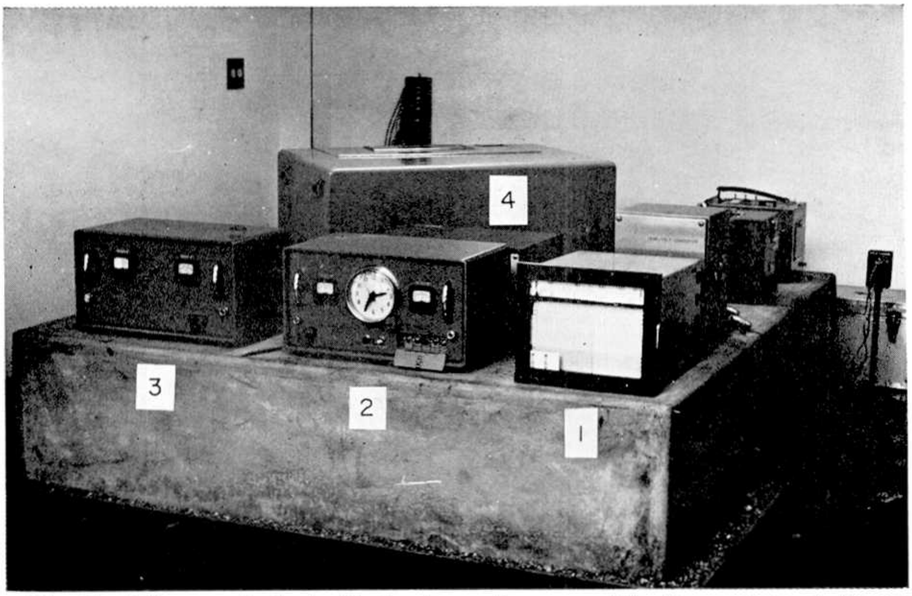

Fig. 36. Seismograph pier inside the observation room of the Observatory. 1. Temperature recorder of 12 channels. 2. Quartz crystal clock. 3. Amplifier of 50 c/s, supplying power to synchronous motor of recording drum of seismograph. 4. accelaration seismograph.

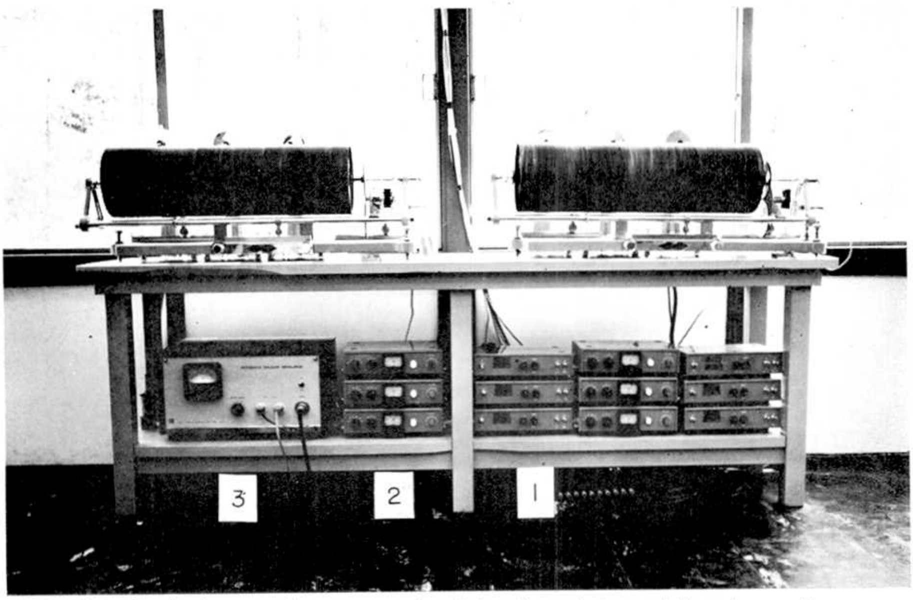

Fig. 37. Smoked paper drums are placed by the window of the observation room of the Observatory so that visitors can see from outside. 1. transistorized amplifier. 2. power supply for the amplifier. 3. stabilizer for the power.

（震研彙報 第四十六号 図版 水上・下鶴・宮崎・平賀・山口）

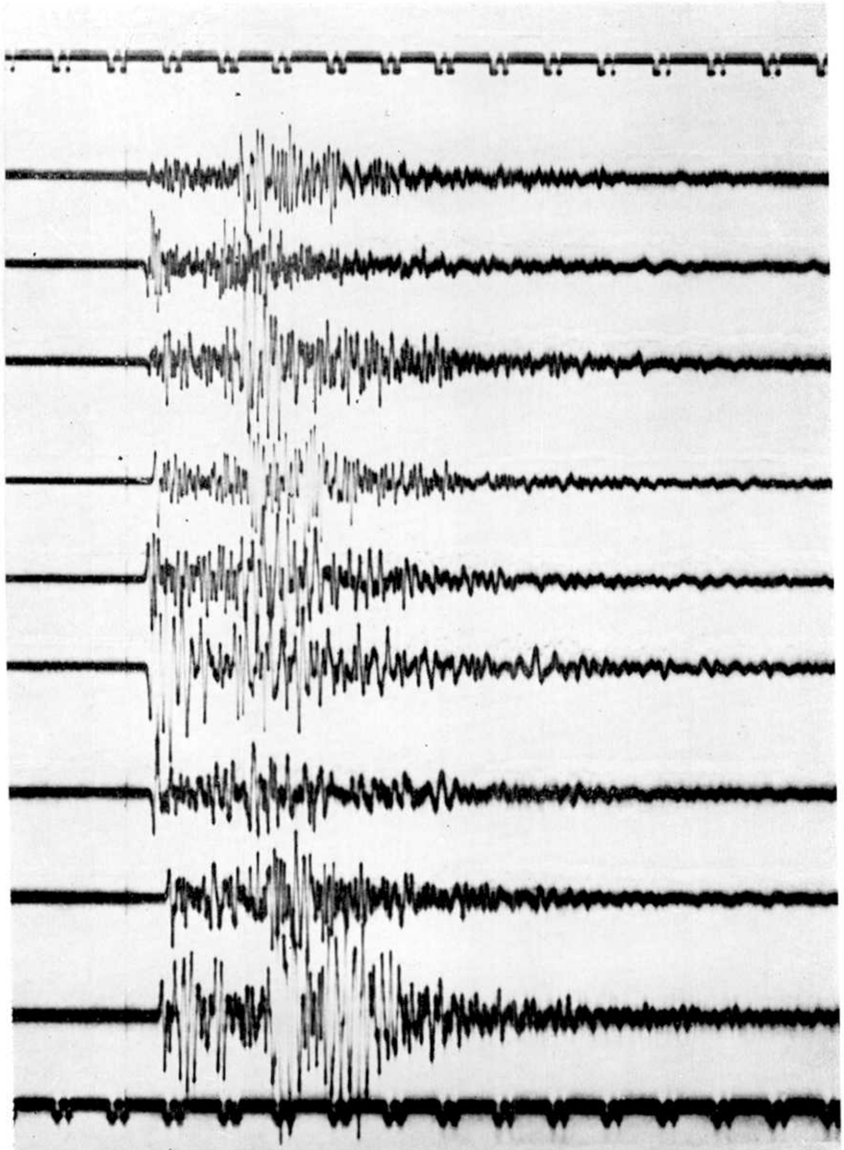

Fig. 38. An example of oscillogram recorded during Iimori-yama earthquake swarm.

（震研彙報 第四十六号 図版 水上・下鶴・宮崎・平賀・山口）

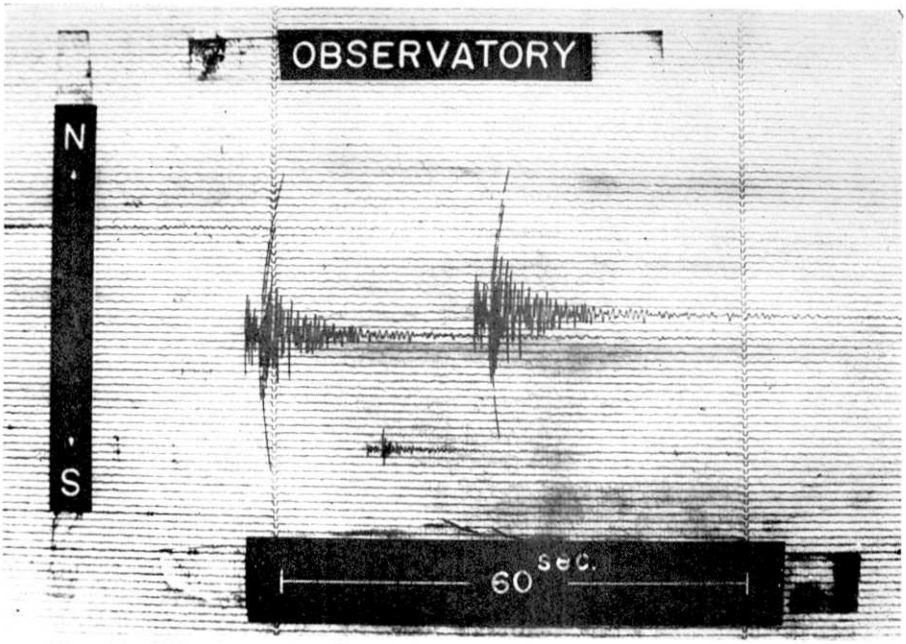

Fig. 39. Volcanic earthquake of A type originating from Kirisima Volcano.

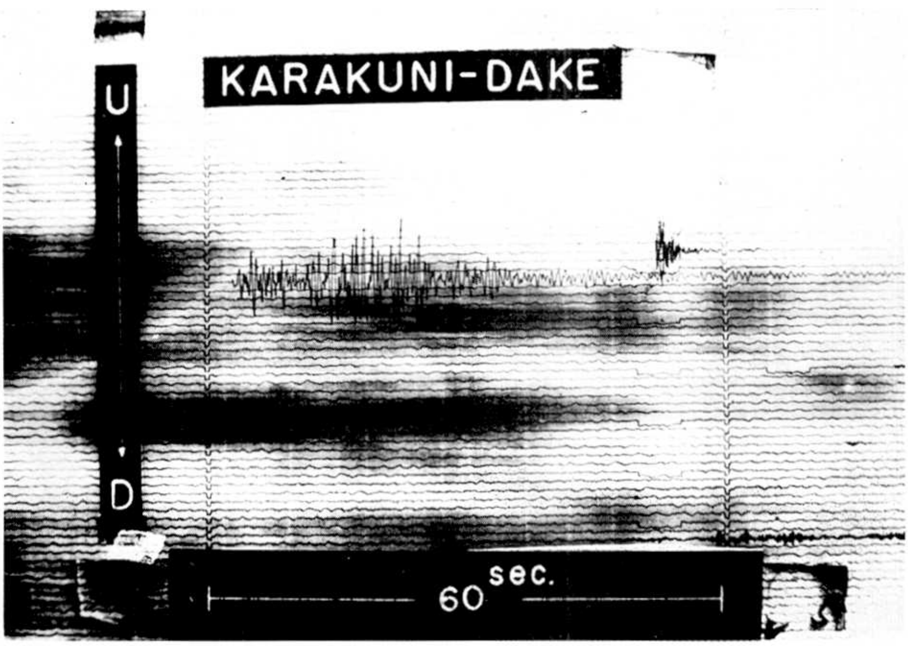

Fig. 40. Earthquakes which took place off the coast of Miyazaki and A type volcanic earthquake.