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# 32. *The Ebino Earthquake Swarm and the Seismic Activity in the Kirisima Volcanoes, in 1968-1969, Part 2. Geographical Distribution of Initial Motion and Travel Time Curves along the Kirisima Volcanoes.*

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## 1. Introduction

In the previous paper, the writers studied the geographical distribution of the 1968 Ebino earthquake swarm as the first approximation based on the net of Ishimoto's acceleration seismograph. At the same time, they reported that the earthquake swarm in the Kakuto caldera had escaladed toward the south-east along the Kirisima volcano belt and a minor earthquake swarm of the *B* type shock occurred near the Simmoe and Takatiho cones.

In this paper, the same seismic activity, the localities of earthquakes and the propagating velocity of the *P* wave passing through under the Kirisima volcano group are investigated not only with the observation of former net, the fourth net, but also other three nets shown in Fig. 3 in the previous report.

The arrival times of the *P*-wave at 22 stations, which cover the Kirisima volcano group, were observed with high accuracy in order to get useful information regarding the structure of the covered area.

On the other hand, the geographical distribution of the initial motion of many earthquakes inside the Kakuto caldera was investigated by means of the seismograms which were obtained at a series of seismometrical stations in the Kirisima volcano group.

Since the epicentral positions of the Ebino earthquake swarm in the previous paper were determined by the fourth net with only the first approximation, they are examined in this paper by the arrival times of the initial motions observed by the second net which was set near the epicentral area.

## 2. Seismometrical nets covering the Kirisima volcano group

Although the writers already reported the geographical position of the permanent and temporary seismometrical nets covering the Kirisima volcano group, it is necessary to describe here the method and purpose of observation.

The first net covered the middle part of the Kirisima volcano group, the second the northern part including the southern part of the Kakuto caldera and the third its southern part including the dormant cones, Simmoe and Takatiho, respectively.

These three nets have recorder stations connected with a series of transducers by the transmission wire. Three recorder stations, which correspond to the nets, are as follows; the Kirisima Volcano Observatory for the first net, the Okamoto branch Observatory for the second and the Yunono Recorder Station for the third.

For continuous observation, the transducer at various places is connected with the pen galvanometer through the transistor amplifier which is usually adjusted to 15,000 in magnification on the smoked paper. The characteristics of the seismograph consist in the displacement type for earthquake motions whose vibration period is in a range from 0.3 sec to 1.0 sec. Time signal of every minute is recorded on the seismogram with a crystal clock of which the accuracy is within 0.1 sec per day, and the crystal clock is checked by the time signal from J. J. Y.

For temporary observation to get the arrival time precisely, the electro-magnetic oscillograph with 12 elements is used at each recorder station. The magnification on the oscillogram can be adjusted from 10,000 to 300,000. To get the arrival time of the seismic wave as precisely as possible, the second time signal from J. J. Y. was recorded directly on the oscillogram together with that from the crystal clock and the fifty cycles mark.

Since it is necessary to record clearly the initial motion of earthquake at each station, the writers used mainly the vertical component of transducers, because the horizontal component of the initial motion of the *P*-wave is not so conspicuous as the vertical one. Seismic observation of this kind was carried out every day for fifty minutes from 14h and 20h respectively in the three nets during the period from February to June, 1968. Besides the above observation at the fixed time, it was made whenever a strong earthquake took place. As a result, a lot of earthquakes originating from the Kakuto caldera were observed in the three nets. For example, the oscillograms obtained by three recorder stations are represented in Figs. 20 and 21. The arrival time observed by the above-mentioned method was carefully examined to 0.01 sec or at least 0.02 sec on the oscillogram.

## 3. Epicentral position given from the arrival time

Some of the earthquakes which were localized by the fourth seismometrical net were also caught on the oscillogram. In such a case, it is

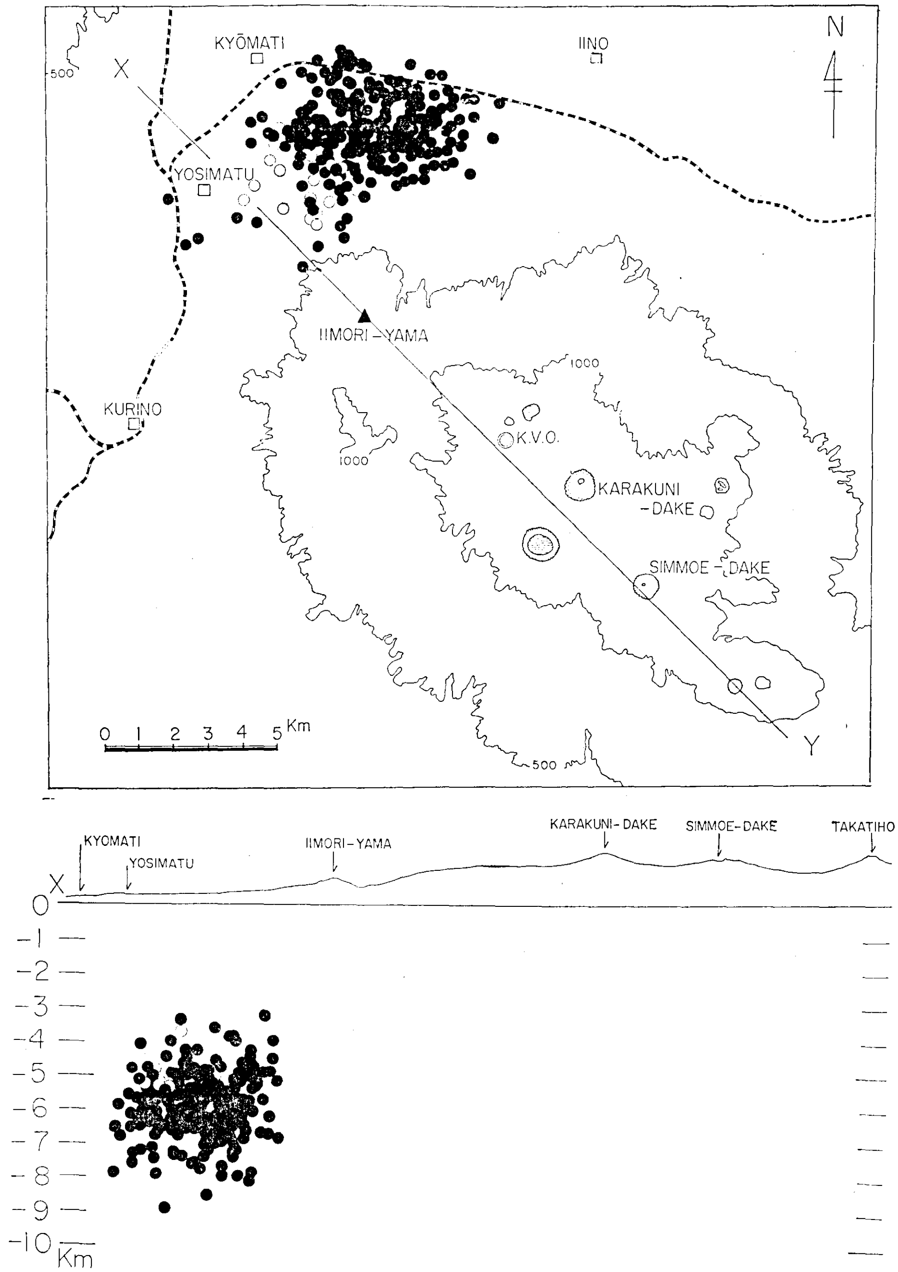


Fig. 1. Hypocentral distribution of the Ebino earthquake swarm (Feb. 11-Aug. 31, 1968).

Table 1. The arrival times and epicentral distances for 15 earthquakes of the 1968 Ebino earthquake swarm.

Eqk. No. 1. Mar. 24, '68. 20h 37m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 47.39sec | 2.60km |
| 7 | 〃.40 | 2.93 |
| 15 | 〃.43 | 3.30 |
| 8 | 〃.45 | 3.40 |
| 12 | 〃.53 | 4.15 |
| 13 | 〃.56 | 4.21 |
| 14 | 〃.69 | 4.80 |
| 10 | 〃.87 | 6.30 |
| 1 | 48.47 | 11.15 |
| 6 | 〃.41 | 11.80 |
| 3 | 〃.87 | 13.70 |
| 5 | 49.12 | 15.71 |
| 21 | 〃.24 | 16.70 |
| 20 | 〃.32 | 17.40 |
| 18 | 〃.50 | 17.53 |
| 19 | 〃.46 | 17.70 |
| 16 | 〃.53 | 18.05 |
| 17 | 〃.61 | 18.35 |
| 22 | 〃.71 | 19.46 |

Eqk. No. 2. Mar. 25, '68. 14h 40m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 38.16sec | 2.12km |
| 8 | 〃.23 | 2.73 |
| 12 | 〃.22 | 2.78 |
| 15 | 〃.35 | 3.63 |
| 13 | 〃.36 | 3.68 |
| 7 | 〃.48 | 3.99 |
| 14 | 〃.59 | 4.78 |
| 10 | 〃.84 | 5.28 |
| 26 | 39.68 | 10.70 |
| 1 | 〃.77 | 12.08 |
| 6 | 〃.85 | 13.18 |
| 3 | 40.17 | 14.50 |
| 5 | 〃.52 | 16.83 |

Eqk. No. 3. Mar. 25, '68. 15h 04m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 32.04sec | 0.38km |
| 8 | 〃.10 | 0.88 |
| 12 | 〃.09 | 1.43 |
| 13 | 〃.21 | 1.83 |
| 15 | 〃.18 | 1.85 |
| 7 | 〃.31 | 2.50 |
| 14 | 〃.40 | 2.90 |
| 26 | 33.27 | 8.85 |
| 1 | 〃.29 | 10.25 |
| 6 | 〃.36 | 11.40 |
| 3 | 〃.64 | 12.65 |
| 5 | 〃.97 | 15.05 |
| 21 | 34.11 | 15.85 |
| 20 | 〃.19 | 16.44 |
| 18 | 〃.31 | 16.50 |
| 19 | 〃.28 | 16.94 |
| 16 | 〃.35 | 17.13 |
| 17 | 〃.43 | 17.45 |
| 22 | 〃.58 | 18.89 |

Eqk. No. 4. Mar. 25, '68. 15h 28m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 51.55sec | 1.82km |
| 12 | 〃.56 | 2.27 |
| 8 | 52.00 | 2.28 |
| 13 | 〃.14 | 3.25 |
| 15 | 〃.13 | 3.35 |
| 7 | 〃.23 | 3.83 |
| 14 | 〃.37 | 4.37 |
| 10 | 〃.37 | 4.79 |
| 26 | 53.43 | 10.30 |
| 1 | 〃.50 | 11.77 |
| 6 | 〃.58 | 12.96 |
| 3 | 〃.82 | 14.18 |
| 5 | 54.26 | 16.58 |
| 21 | 〃.38 | 17.38 |
| 20 | 〃.45 | 17.98 |
| 18 | 〃.58 | 18.05 |
| 19 | 〃.59 | 18.48 |
| 16 | 〃.64 | 18.69 |
| 17 | 〃.72 | 18.98 |
| 22 | 〃.86 | 20.44 |

(to be continued)

Table 1. (continued)

Eqk. No. 5. Mar. 25, '68. 15h 51m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 12 | 8.52sec | 0.83km |
| 8 | 〃.56 | 1.56 |
| 11 | 〃.62 | 1.82 |
| 13 | 〃.62 | 2.20 |
| 15 | 〃.73 | 2.98 |
| 10 | 〃.74 | 3.25 |
| 14 | 〃.81 | 3.31 |
| 7 | 〃.88 | 3.83 |
| 26 | 9.67 | 9.05 |
| 1 | 〃.85 | 11.00 |
| 6 | 10.03 | 12.45 |
| 3 | 〃.20 | 13.29 |
| 5 | 〃.72 | 15.83 |
| 21 | 〃.69 | 16.50 |
| 18 | 〃.87 | 17.11 |
| 20 | 〃.89 | 17.20 |
| 19 | 〃.95 | 17.70 |
| 16 | 〃.96 | 17.74 |
| 17 | 11.11 | 18.25 |
| 22 | 〃.36 | 19.68 |

Eqk. No. 6. Mar. 25, '68. 20h 33m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 49.32sec | 0.83km |
| 8 | 〃.33 | 1.72 |
| 15 | 〃.36 | 2.10 |
| 7 | 〃.41 | 2.33 |
| 12 | 〃.40 | 2.40 |
| 13 | 〃.45 | 2.60 |
| 14 | 〃.57 | 3.53 |
| 10 | 〃.69 | 4.60 |
| 26 | 〃.51 | 9.45 |
| 1 | 50.47 | 10.50 |
| 6 | 〃.49 | 11.53 |
| 3 | 〃.89 | 12.98 |
| 5 | 51.15 | 15.25 |
| 21 | 〃.27 | 16.08 |
| 20 | 〃.34 | 16.63 |
| 18 | 〃.48 | 16.83 |
| 19 | 〃.48 | 17.20 |
| 16 | 〃.51 | 17.40 |
| 17 | 〃.60 | 17.70 |
| 22 | 〃.73 | 19.03 |

Eqk. No. 7. Mar. 25, '68. 21h 29m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 12 | 15.85sec | 0.82km |
| 8 | 〃.91 | 2.00 |
| 11 | 〃.95 | 2.26 |
| 13 | 〃.98 | 2.56 |
| 10 | 16.11 | 3.30 |
| 15 | 〃.08 | 3.42 |
| 14 | 〃.18 | 3.63 |
| 7 | 〃.22 | 4.33 |
| 26 | 17.17 | 9.20 |
| 1 | 〃.33 | 11.36 |
| 6 | 〃.54 | 12.88 |
| 3 | 〃.72 | 13.55 |
| 21 | 18.30 | 16.85 |
| 18 | 〃.34 | 17.40 |
| 19 | 〃.41 | 18.00 |
| 16 | 〃.43 | 18.05 |
| 17 | 〃.49 | 18.38 |
| 22 | 〃.72 | 20.00 |

Eqk. No. 8. Mar. 25, '68. 16h 46m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 12 | 5.82sec | 2.23km |
| 8 | 〃.92 | 3.18 |
| 11 | 〃.98 | 3.45 |
| 13 | 〃.98 | 3.65 |
| 10 | 6.01 | 3.82 |
| 15 | 〃.10 | 4.63 |
| 14 | 〃.15 | 4.65 |
| 7 | 〃.27 | 5.75 |
| 26 | 7.00 | 9.96 |
| 1 | 〃.28 | 12.31 |
| 6 | 〃.51 | 13.98 |
| 3 | 〃.63 | 14.50 |
| 5 | 8.07 | 17.16 |
| 21 | 〃.10 | 17.75 |
| 18 | 〃.24 | 18.30 |
| 20 | 〃.22 | 18.75 |
| 19 | 〃.34 | 18.95 |
| 16 | 〃.32 | 18.96 |
| 17 | 〃.34 | 19.25 |
| 22 | 〃.63 | 21.00 |

(to be continued)

Table 1. (continued)

Eqk. No. 9. Mar. 26, '68. 14h 28m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 7.29sec | 0.42km |
| 8 | 〃.31 | 1.30 |
| 12 | 〃.34 | 1.73 |
| 15 | 〃.36 | 1.73 |
| 7 | 〃.40 | 2.10 |
| 13 | 〃.40 | 2.15 |
| 14 | 〃.53 | 3.10 |
| 10 | 〃.68 | 4.20 |
| 2 | 〃.65 | 5.50 |
| 26 | 8.53 | 9.00 |
| 1 | 〃.55 | 10.18 |
| 6 | 〃.61 | 11.25 |
| 3 | 〃.94 | 12.63 |
| 5 | 9.21 | 14.95 |
| 21 | 〃.37 | 15.75 |
| 20 | 〃.46 | 16.28 |
| 18 | 〃.58 | 16.50 |
| 19 | 〃.57 | 16.85 |
| 16 | 〃.64 | 17.08 |
| 17 | 〃.68 | 17.39 |
| 22 | 〃.81 | 18.74 |

Eqk. No. 10. Mar. 26, '68. 14h 59m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 11.25sec | 0.25km |
| 8 | 〃.25 | 0.78 |
| 15 | 〃.33 | 1.33 |
| 13 | 〃.35 | 1.63 |
| 12 | 〃.29 | 1.75 |
| 7 | 〃.37 | 1.95 |
| 14 | 〃.50 | 2.25 |
| 10 | 〃.67 | 3.70 |
| 26 | 12.43 | 8.48 |
| 1 | 〃.45 | 9.78 |
| 6 | 〃.50 | 10.95 |
| 3 | 〃.82 | 12.20 |
| 5 | 13.15 | 14.55 |
| 21 | 〃.22 | 15.35 |
| 20 | 〃.33 | 15.93 |
| 18 | 〃.47 | 16.04 |
| 19 | 〃.49 | 16.45 |
| 16 | 〃.53 | 16.64 |
| 17 | 〃.59 | 16.95 |
| 22 | 〃.70 | 18.35 |

Eqk. No. 11. Mar. 26, '68. 15h 00m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 29.69sec | 0.25km |
| 8 | 〃.73 | 0.67 |
| 15 | 〃.78 | 1.45 |
| 12 | 〃.75 | 1.53 |
| 13 | 〃.81 | 1.55 |
| 7 | 〃.83 | 2.15 |
| 14 | 〃.97 | 2.55 |
| 10 | 30.08 | 3.55 |
| 26 | 〃.82 | 8.50 |
| 1 | 〃.82 | 9.88 |
| 6 | 〃.86 | 11.11 |
| 3 | 31.23 | 12.28 |
| 5 | 〃.48 | 14.68 |
| 21 | 〃.65 | 15.48 |
| 20 | 〃.73 | 16.05 |
| 18 | 〃.86 | 16.15 |
| 19 | 〃.85 | 16.55 |
| 16 | 〃.92 | 16.77 |
| 17 | 〃.99 | 17.08 |
| 22 | 32.14 | 18.50 |

Eqk. No. 12. Apr. 5, '68. 13h 06m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 43.99sec | 1.20km |
| 7 | 44.02 | 1.65 |
| 15 | 〃.00 | 1.75 |
| 8 | 〃.01 | 2.20 |
| 13 | 〃.08 | 2.70 |
| 12 | 〃.05 | 2.90 |
| 14 | 〃.18 | 3.44 |
| 26 | 45.06 | 9.15 |
| 1 | 44.95 | 9.95 |
| 6 | 〃.98 | 10.85 |
| 3 | 45.30 | 12.46 |
| 5 | 〃.59 | 14.65 |
| 21 | 〃.72 | 15.55 |
| 20 | 〃.79 | 16.00 |
| 18 | 〃.96 | 16.33 |
| 19 | 〃.93 | 16.59 |
| 16 | 46.01 | 16.89 |
| 17 | 〃.07 | 17.18 |
| 22 | 〃.16 | 18.35 |

(to be continued)

Table 1. (continued)

Eqk. No. 13. Apr. 5, '68. 13h 58m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 45.07sec | 1.30km |
| 15 | 〃 .15 | 1.85 |
| 8 | 〃 .16 | 1.95 |
| 13 | 〃 .28 | 2.64 |
| 12 | 〃 .23 | 2.74 |
| 14 | 〃 .42 | 3.46 |
| 2 | 〃 .44 | 5.27 |
| 26 | 46.49 | 9.23 |
| 1 | 〃 .46 | 10.20 |
| 6 | 〃 .44 | 11.05 |
| 3 | 〃 .86 | 12.60 |
| 5 | 47.15 | 14.80 |
| 21 | 〃 .27 | 15.71 |
| 20 | 〃 .34 | 16.17 |
| 18 | 〃 .50 | 16.47 |
| 19 | 〃 .50 | 16.75 |
| 17 | 〃 .62 | 17.36 |
| 22 | 〃 .72 | 18.59 |

Eqk. No. 14. Apr. 5, '68. 14h 52m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 9.25sec | 0.43km |
| 8 | 〃 .33 | 1.31 |
| 15 | 〃 .35 | 1.59 |
| 7 | 〃 .45 | 1.93 |
| 13 | 〃 .44 | 2.13 |
| 12 | 〃 .37 | 2.14 |
| 14 | 〃 .56 | 3.03 |
| 10 | 〃 .83 | 4.20 |
| 26 | 10.40 | 8.90 |
| 1 | 〃 .42 | 10.25 |
| 6 | 〃 .41 | 11.10 |
| 3 | 〃 .74 | 12.50 |
| 5 | 11.05 | 14.80 |
| 21 | 〃 .18 | 15.62 |
| 20 | 〃 .33 | 16.14 |
| 18 | 〃 .41 | 16.35 |
| 19 | 〃 .39 | 16.69 |
| 17 | 〃 .50 | 17.24 |
| 22 | 〃 .64 | 18.60 |

Eqk. No. 15. Apr. 15, '68. 14h 16m.

| Station No. | Arrival time | Epi. dist. |
|---|---|---|
| 11 | 10.51sec | 1.23km |
| 15 | 〃 .57 | 1.64 |
| 8 | 〃 .58 | 2.00 |
| 13 | 〃 .67 | 2.60 |
| 12 | 〃 .65 | 2.93 |
| 14 | 〃 .82 | 3.31 |
| 2 | 〃 .65 | 4.88 |
| 26 | 11.78 | 9.01 |
| 1 | 〃 .74 | 9.78 |
| 6 | 〃 .71 | 10.65 |
| 3 | 12.06 | 12.28 |
| 5 | 〃 .38 | 14.45 |
| 21 | 〃 .56 | 15.30 |
| 20 | 〃 .61 | 15.80 |
| 18 | 〃 .79 | 16.11 |
| 19 | 〃 .77 | 16.38 |
| 16 | 〃 .82 | 16.68 |
| 17 | 〃 .91 | 17.00 |
| 22 | 13.00 | 18.25 |

easy and necessary to correct its hypocentral position which was already determined by *S-P* at the four stations belonging to the fourth net. It is especially easy to correct the epicentral position by the arrival time of the *P*-wave at the stations situated near the epicenter. Therefore, the writers adopted the result of observation made in the second net which was set on the Kakuto caldera.

Since the hypocentral depth given by *S-P* in the four stations was not so accurate, the writers re-determined it from the arrival time of the initial wave at the series of stations in the same net after the epicentral position was corrected by the above method.

The epicentral position of the present earthquake swarm is situated within 6–7 km from each transducer station belonging to the second net,

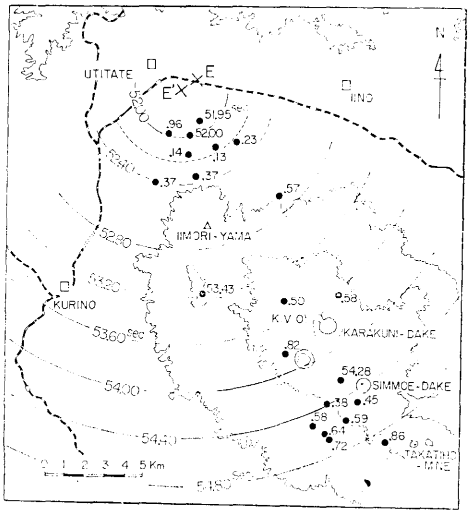


Fig. 2. The coseismal lines of the earthquake at 15h 28m 51s on March 25, 1968.
E: epicenter given by S-P
E′: epicenter given by P arrival times

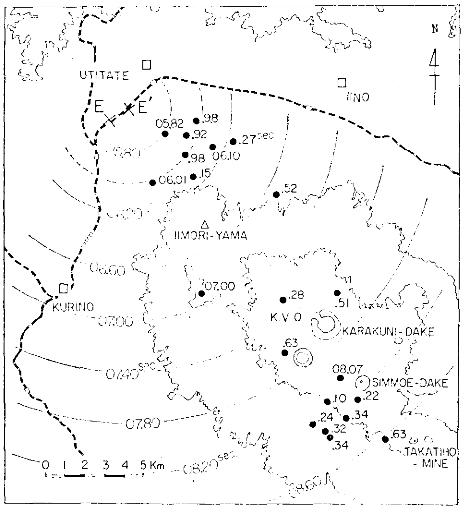


Fig. 3. The coseismal lines of the earthquake at 16h 46m 05s on March 25, 1968.
E: epicenter given by S-P
E′: epicenter given by P arrival times

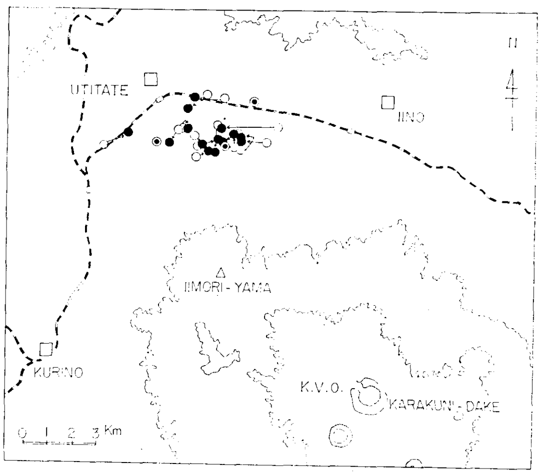


Fig. 4. The comparison of the epicentral positions given by S-P and the P arrival times.
opened circle: from S-P
closed circle: from P arrival times

and the hypocentral position of the earthquake is estimated to be in a range from 3–4 km to 8–9 km and mostly 4–7 km though it is given from the first approximation. Consequently, it is reasonably assumed that the initial wave observed by the second net is the wave directly propagated from the origin to each station and the upper part of the crust near the earth's surface, covered by the second net, has no remarkable heterogeneity with respect to the propagation of the *P*-wave.

According to above assumption, the epicentral position was determined on the basis of the arrival times of the *P*-wave of the second net. It is, however, important for determining the epicentral position by the above assumption that the propagating velocity of the *P*-wave should be fixed at the same time and show nearly constant value in the series of Ebino earthquakes.

In Table 1, the arrival times of 15 earthquakes observed by the station Nos. 7∼14 in the second net are listed. On the map of Fig. 4, the epicentral position of fifteen earthquakes given from the fourth net and corrected by the arrival times in the second net are shown.

## 4. Geographical distribution of the initial motion of the Ebino earthquakes

The problem of whether the earthquakes originating from the volcanic districts, especially those of *A* type occurring on and near the active and dormant volcanoes like the present Ebino earthquake swarm, have any different character from the earthquakes in tectonic origins in respect of the mechanism of the generation of the seismic wave is important but not yet solved in the field of volcano geophysics.

In the present seismometrical investigation, the writers devoted special attention not only to the type of development of the seismic activity in the Kakuto caldera but also to the shift of the seismic localities along the volcanic belt in order to get any instructive information. However, it is the most useful and proper way to study the problem as to the pattern of the geographical distribution of the initial motion of earthquakes. For this purpose, the seismograph and transducer

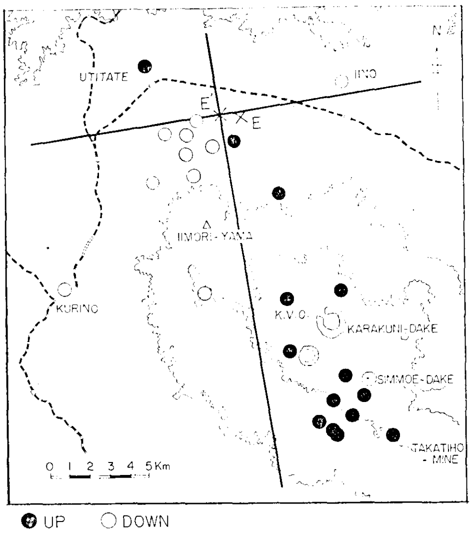


Fig. 5. The locality of the epicenter of the Ebino Earthquake at 13h 58m 45s on April 5, 1968.
E: epicenter given by S-P
E′: epicenter given by P arrival times

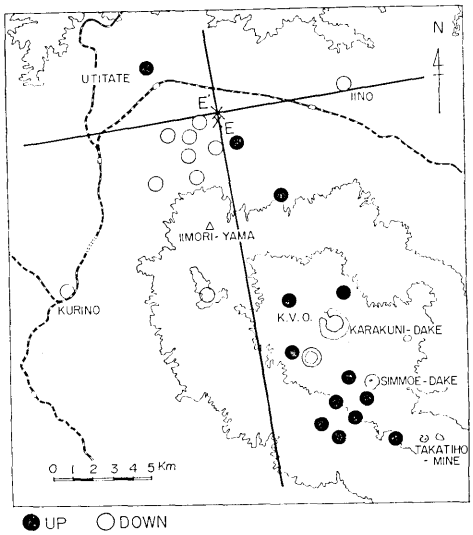


Fig. 6. The locality of the epicenter of the Ebino Earthquake at 14h 16m 10s on April 15, 1968.
E: epicenter given by S-P
E′: epicenter given by P arrival times

were set at 26 stations in and around the epicentral region in which 20 stations were equipped with the vertical component of the instruments as are shown in Table 2 in Part 1.

Since a series of earthquakes was recorded in the four nets which consist of 26 stations, not only the geographical distribution of the initial motion but also the locality of the hypocentral position of the great number of earthquakes could be made clear.

It must be noted that the pattern of the geographical distribution of the initial motion of two earthquakes shown in Figs. 5 and 6 is the typical one in the present Ebino earthquake swarm and almost 90% of the earthquakes showed the same pattern. In other words, the up and down initial motions are separated by two nodal lines which intersect nearly rectangularily at the epicenter. The one nodal line passes from north or north-west to south or south-east and the other forms nearly a rectangle to the other at the epicenter. Therefore, no nodal line passed on and near the summit part or central part of the Kirisima volcano group which was in the domain of strong upward motion.

The earthquakes of February 21, at 8h and 10h, and of March 25, at 0h were so strong that the initial motion of these earthquakes was recorded in a series of Wiechert's seismograph covering the south-western part of Japan. According to the result of the observation, the geographical distribution of the initial motion showed the same pattern in the broad area as mentioned above. As examples, the distribution of the initial motion in the broad area, those of the earthquakes of February 21, at 8h and 10h, are illustrated based on the report of the Japan Meteorological Agency. However, the direction of the initial motion of the February 21 earthquake which was observed at Kumamoto and Muroto did not harmonize with that of other stations. Since the Ebino earthquakes were quite shallow, their initial motions were not clearly recorded at distant places.

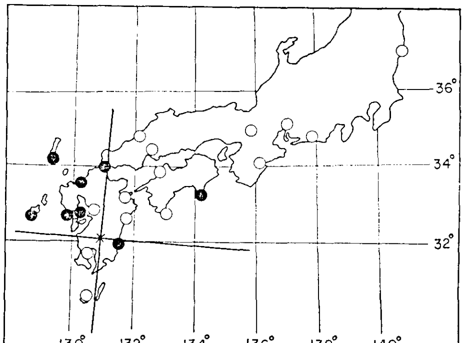

Fig. 7. The geographical distribution of the initial motion of the earthquake at 10h 44m, February 21, 1968.
closed circle: up or push
opened circle: down or pull
(After Japan Meteorological Agency)

The initial motion of less than ten percent of the Ebino earthquakes showed downward only at the stations of the four nets and no upward initial motion appeared at all as in the case of the earthquakes of April 5, 1968, at 12h 39m, and of March 25, 1968, at

15h 51m. As the example, the particular pattern of the distribution of the initial motion is illustrated on the map of Figs. 8 and 9 with respect to the earthquakes of March 25 and April 5. The pattern of the geographical distribution of the initial motions which shows downward in all directions from the epicenter suggests a negative single source at the hypocenter. It is indeed worthy of note that some of the Ebino earthquakes, which took place at the central part of the Kakuto caldera, originated certainly from the negative single source.

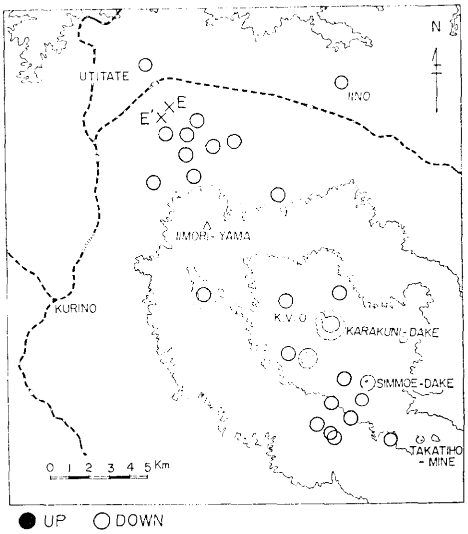


Fig. 8. The locality of the epicenter of the earthquake at 15h 51m 08s on March 25, 1968.
E: epicenter given by S-P
E′: epicenter by P arrival times

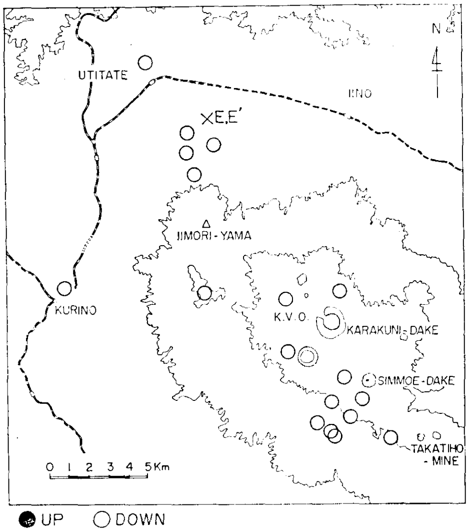


Fig. 9. The locality of the epicenter of the earthquake at 12h 39m 09s on April 5, 1968.
E: epicenter given by S-P
E′: epicenter given by P arrival times

It should be added with respect to the normal pattern of the initial motion that the trend of the summits of the cones in the Kirisima volcanic belt is running from nearly north 45° west to south 45° east and therefore intersects with an angle of 45° to both of the nodal lines. On the other hand, it is usual that one of the nodal lines coincides with the locality of the fault line of the big earthquake of tectonic origin if it is newly formed, and that the ground at both sides of the fault plane moved parallel with the fault plane and in the opposite direction sliding along the fault plane.

On the contrary, the displacement of ground on the occasion of an eruption from a newly formed fissure was not parallel to the fissure line but rectangular to the trend of fissure which made the fissure open.

Seeing the different mode of the crustal deformation in the tectonic earthquake and the fissure eruption, it will be natural that one of the nodal lines is not identical with the trend of the cones and craters in the Kirisima volcano group.

As described above, judging from the formation of the caldera, it is very important that some earthquakes inside the Kakuto caldera originated from the negative single source.

On the other hand, according to the levelling survey covering the southern part of the caldera which will be reported in the coming report, it seems that the central part of the epicentral area in the caldera subsided during the development of the present earthquake swarm.

Although the epicentral positions of the Ebino earthquakes based on S-P in the fourth net were checked and corrected by the arrival times of the P-wave of the second net, they were also checked by the geographical distribution of the initial motion of the earthquake which was separated into two nodal lines. As a result, the epicentral position corrected by the arrival time agrees almost perfectly with that given by the latter method, as is seen in Figs. 5 and 6.

In the 1968 Ebino earthquakes, it is the most remarkable feature that the two kinds of pattern in the geographical distribution of the initial motion were observed, which indicate two different mechanisms with respect to the outbreak of earthquake.

## 5. Propagating velocity of the P-wave under the Kirisima volcano group

Since the epicentral positions of the present earthquakes were precisely studied with respect not only to the S-P observed at the fourth net, but also to the *P* arrival time at the second net and the initial motion just mentioned above, the travel time curves of P-wave were studied in a lot of earthquakes.

Seeing the travel time curves in some of the Ebino earthquakes, the writers found a slight but systematic anomaly of the arrival time at one or two stations, such as, station No. 6, located at the north-east of Karakuni-dake.

Judging from the circumstances, it seems that they originated from an extremely local structure near the station, which is rather usual in the volcanic region. As the first step to studying the propagating velocity of the P-wave and the structure of the Kirisima volcanoes, it is necessary to obtain the value of anomaly of the arrival time which is caused by the local structure near the earth's surface. Therefore, the value of the correction for the arrival time was given by the following method. As is seen in Figs. 10~12, the arrival times at station

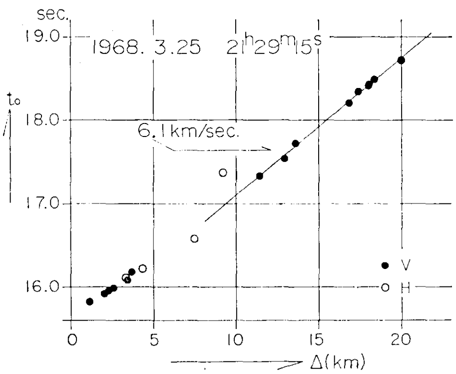


Fig. 10. The travel time curve of the earthquake at 21h 29m 15s on March 25, 1968.

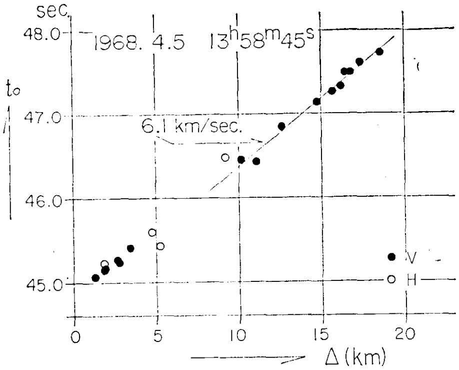


Fig. 11. The travel time curve of the earthquake at 13h 58m 45s on April 5, 1968.

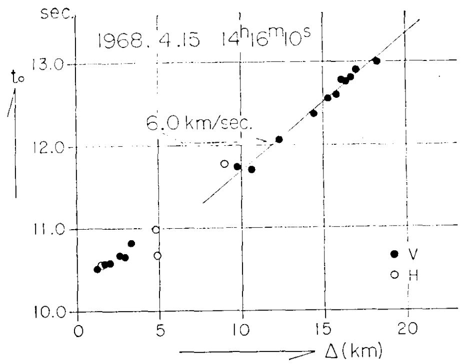


Fig. 12. The travel time curve of the earthquake at 14h 16m 10s on April 15, 1968.

No. 1 and the stations situated at epicentral distance longer than at the station No. 1, are nearly on a linear travel time curve. Such linear travel curve was obtained in the respective earthquakes by the least square. The value of the local anomaly for the arrival time is defined by the deviation from the above linear travel time curve. It will be needless to mention that the apparent velocity, or the velocity along the earth's surface, of the initial wave, which supply useful information regarding the propagating velocity under the Kirisima volcanoes, can be given by the above procedure.
The values of the local anomaly and their square mean errors at the stations of the first and third nets are shown in Table 2.

In the present investigation of the travel time, the result obtained by the horizontal transducer is excluded, because its record was not always clear as compared with that by the vertical one.

After the arrival time of the eleven stations was corrected by the values in Table 2, the travel time curves of these 15 earthquakes were made, using the improved epicenter, and the apparent velocities were calculated again.

On the other hand, the altitudes of the eleven stations are not so different from each other except in the case of No. 5, and the series of volcanic cones of the Kirisima volcano group are comparably the

Table 2. Local anomaly of the $P$ arrival time at the stations in the first and third seismometrical nets.

| Stn. No. | Place | Anomaly of arrival time and square mean error |
|---|---|---|
| 1 | Kirisima V. O. (1) | 0.04±0.03sec |
| 3 | Oonami-ike W. | 0.03±0.04 |
| 4 | Kurino-dake. | 0.22±0.06 |
| 5 | Simmoe crattr N. | −0.01±0.04 |
| 6 | Karakuni-dake NE. | −0.06±0.03 |
| 16 | Yunono | 0.02±0.02 |
| 17 | Yunono-ura | 0.04±0.02 |
| 18 | Ebosi-dake | 0.06±0.03 |
| 19 | Simmoe-Nake-dake | 0.01±0.02 |
| 20 | Simmoe crater S | −0.04±0.03 |
| 21 | Oonami-ike S. | −0.03±0.03 |
| 22 | Takatiho | −0.04±0.02 |

(Positive, delayed time: negative, advanced time)

same, not only in their volume, but also in the thickness of the volcanic ejecta covering them. However, as the first approximation, the anomaly, caused by difference of the altitude of the station and other extreme local circumstances, was corrected by the above method. Therefore it is reasonably assumed that at any place in the Kirisima volcanoes the propagating velocity of the P wave between the earth's surface and the sea-level is not so different.

As is shown in Table 4 the apparent velocities of the 15 earthquakes given from the series of the stations located more distant than station No. 1, or 10–20 km, in the epicentral distance are in a range from 5.7 km/sec to 6.4 km/sec, while those of the 12 earthquakes are in a range from 6.1 km/sec to 6.4 km/sec. In addition, total mean value of apparent velocities is 6.1 km/sec.

As the first approximation it is general that the analysis of the above travel time curves in the Ebino earthquakes is made on the basis of the assumption of the horizontal layers with respect to the propagating velocity of the seismic wave. In the present case, the problem dealt with will be the homogeneous model in the horizontal direction. Since the problem is dealt with on the above assumption, the epicentral position is given from the series of the arrival times of the initial seismic wave independent of the determination of the hypocentral depth.

On the other hand, the epicentral positions given from the S–P at the four stations of the fourth net were re-determined, as is shown in Fig. 4, by the P-arrival times of the stations of the second net which were located very near to these epicentral positions. Therefore, it can be said that the epicentral positions of these earthquakes are precisely determined within a range of error of 0.3 km.

The hypocentral depths given from S-P at the four stations were mostly in a range between 4 km and 8km, and 313 earthquakes out of 337 are in a range from 4 km to 8 km in depth, though these hypocentral

Table 3. Frequency distribution of hypocentral depth and distance coefficient given from S-P at the four stations of the fourth net.

(Feb. 11-Aug. 31, 1968)

| Hypocentral depth | Frequency | Distance coefficient | Frequency |
|---|---|---|---|
| 2.0—2.9 km | 4 | 5.3—5.4 | 1 |
| 3.0—3.9 | 18 | 5.5—5.6 | 9 |
| 4.0—4.9 | 66 | 5.7—5.8 | 31 |
| 5.0—5.9 | 116 | 5.9—6.0 | 257 |
| 6.0—6.9 | 101 | 6.1—6.2 | 18 |
| 7.0—7.9 | 30 | 6.3—6.4 | 14 |
| 8.0—8.9 | 2 | 6.5—6.6 | 6 |

depths based on the S-P at the four stations are usually not so accurate and are expected to have an error of $\pm 2$ or $\pm 3$ km.

With respect to the precise determination of the hypocentral depth, the writers will discuss afterward. Needless to say, the distance coefficients for the Ebino earthquakes were obtained at the same time their hypocenters were determined on the basis of S-P at the fourth net. The distance coefficients are represented in Table 3 together with the frequency distribution of the hypocentral depth.

On the other hand, it is natural to expect that the propagating velocity of the P wave at the surface of the Kirisima volcanoes, on which the present seismometrical net is set, will be exceedingly smaller than 6.1—6.4 km/sec which is suggested from the apparent velocity. Judging from the value of the distance coefficient, 6.0, the propagating velocity of the P-wave near the upper part of the region will be in a range from 4.0 km/sec to 4.5 km/sec as the mean velocity of the surface layer from the earth's surface to 5 or 6 km deep. The above value for the P wave will be reasonable according to the experiments concerning the seismic velocity at volcanic region.

The result of the observations of the present Ebino earthquakes will be summarized as the seismic features of Kirisima volcanoes as follows.

1) So long as the parallel structure in the velocity distribution is assumed in the present case, the discontinuity with respect to the propagating velocity will be reasonably expected at the depth of 5 km or 6 km from the earth's surface.

2) The propagating velocity of the P wave will be in a range from

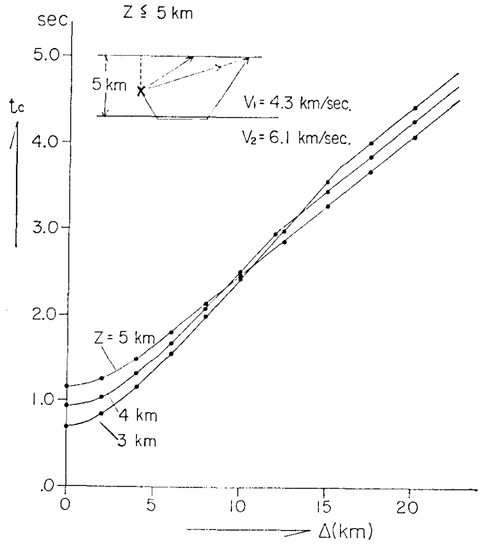


Fig. 13-a. The travel time curves calculated on the basis of the above model structure.

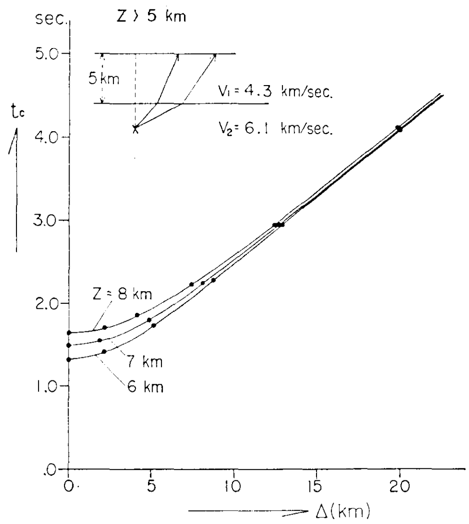


Fig. 13-b. The travel time curves calculated on the basis of the above model structure.

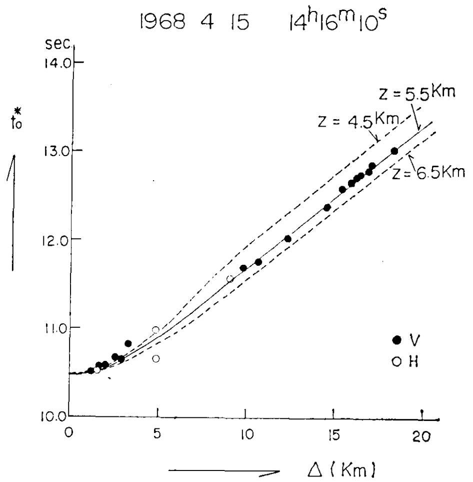


Fig. 14. The travel time curve for the arrival times corrected by the local anomaly of each station and those calculated on the basis of the model structure.

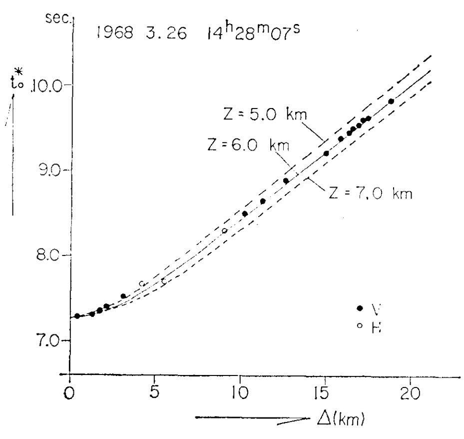


Fig. 15. The travel time curve for the arrival times corrected by the local anomaly of each station and those calculated on the basis of the model structure.

4.0 to 4.5 km/sec in the surface layer and in the part deeper than the discontinuity in a range from 6.0 to 6.3 km/sec.

The above results include three ranges of values, or two ranges concerning the propagating velocity of the P wave of which one is for the thickness of the surface layer. Since the above ranges are limited respectively, the most suitable value was found on the basis of the travel time curves of 15 earthquakes.

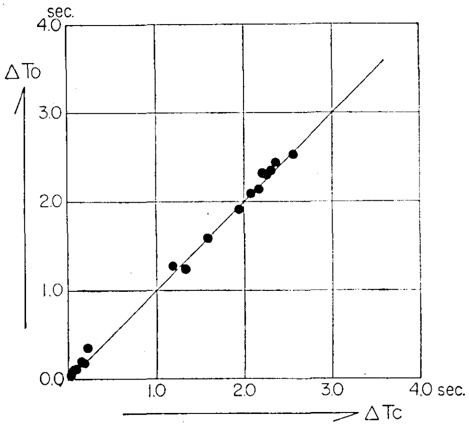


Fig. 16. Comparison of the observed travel time of the earthquake at 14h 16m on April 15, 1968 with that calculated on the basis of the model structure.
(hypocentral depth: 5.5km)

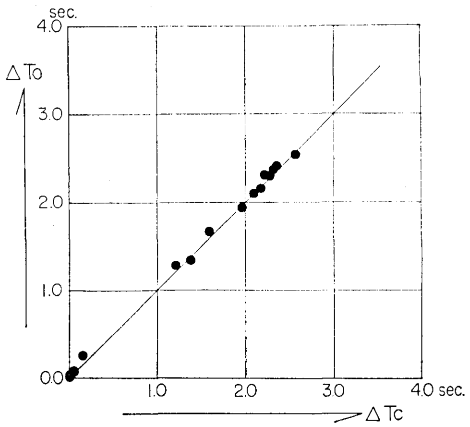


Fig. 17. Comparison of the observed travel time of the earthquake at 14h 28m on March 26, 1968 with that calculated on the basis of the model structure.
(hypocentral depth: 6.0km)

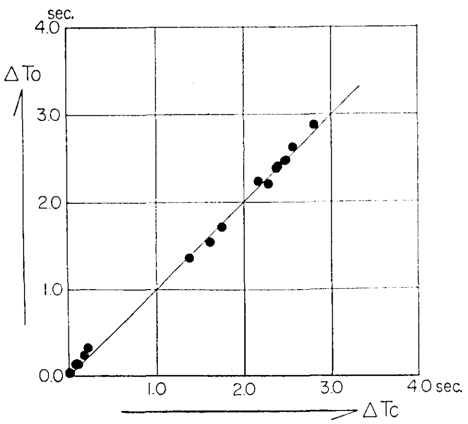


Fig. 18. Comparison of the observed travel time of the earthquake at 15h 51m on March 25, 1968 with that calculated on the basis of the model structure.
(hypocentral depth: 5.5km)

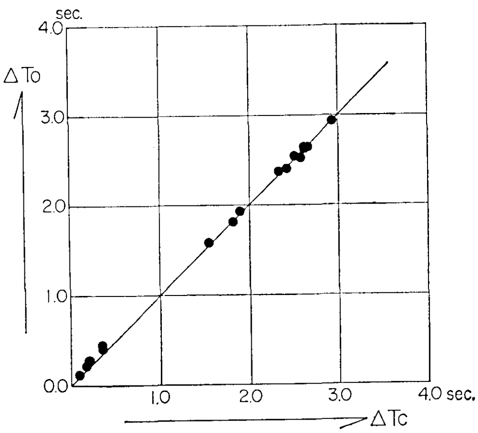


Fig. 19. Comparison of the observed travel time of the earthquake at 16h 46m on March 26, 1968 with that calculated on the basis of the model structure.
(hypocentral depth: 6.0km)

As a result, the propagating velocities and the thickness of the surface layer are obtained as 4.3 km/sec, 6.1 km/sec and 5 km/sec, respectively.

Since the structure relating to the velocity distribution of the

Table 4. Apparent velocities ($V_0$) for the observed arrival times, the ones ($V_0^*$) corrected by the local anomaly and the apparent velocity ($V_c$) calculated on the basis of the model, at the epicentral distances from 10 km to 20 km.

| Eqk No. | $V_0$ | $V_0^*$ | $V_c$ |
|---|---|---|---|
| 1 | 6.2km/sec | 6.2km/sec | 6.3km/sec |
| 2 | 6.1 〃 | 5.9 〃 | 6.1 〃 |
| 3 | 6.3 〃 | 6.3 〃 | 6.2 〃 |
| 4 | 5.9 〃 | 5.9 〃 | 6.1 〃 |
| 5 | 5.7 〃 | 5.7 〃 | 6.1 〃 |
| 6 | 6.3 〃 | 6.3 〃 | 6.3 〃 |
| 7 | 6.1 〃 | 6.1 〃 | 6.1 〃 |
| 8 | 6.4 〃 | 6.4 〃 | 6.2 〃 |
| 9 | 6.3 〃 | 6.3 〃 | 6.2 〃 |
| 10 | 6.3 〃 | 6.3 〃 | 6.2 〃 |
| 11 | 6.1 〃 | 6.1 〃 | 6.2 〃 |
| 12 | 6.4 〃 | 6.4 〃 | 6.2 〃 |
| 13 | 6.1 〃 | 6.1 〃 | 6.1 〃 |
| 14 | 6.3 〃 | 6.2 〃 | 6.2 〃 |
| 15 | 6.0 〃 | 6.1 〃 | 6.1 〃 |

seismic wave was determined, the travel time curve for various hypocentral depths was calculated in the epicentral distance of from 0 to 25 km. The result of calculation is given in Figs. 13-a, b, and the calculated travel time curves are compared with those of the observed ones for determining precisely their hypocentral depth.

From the comparison of the observed and calculated traveltime curves and the hypocentral depths were re-determined in the respective earthquakes, the accuracy of the hypocentral depth was exceedingly improved. As a result, the hypocentral depths which were already given from the S−P at the four stations were changed in a range of $\pm 0.2 \sim 0.5$ km, based on the calculated travel time curves of the mentioned model.

In order to show how the adopted model harmonizes with the present observation the following examinations are made for the improved hypocentral depth. First of all, the time differences between

Table 5. The comparison of the hypocentral depth given by S−P with that obtained by a series of the P arrival time, the arrival times at the epicenter and occurrence times at the hypocenter.

*Z* : Hypocentral depth given from S−P
*Z**: Hypocentral depth given from P arrival time
*T* : P arrival time at the epicenter
*T**: Occurrence time (origin time) at the hypocenter

| Eqk. No. | *Z* | *Z** | *T* | *T** |
|---|---|---|---|---|
| 1 | 4km | 7.5km | Mar. 24, 20h 37m 47.28s | 〃 45.71s |
| 2 | 6 | 4.5 | 〃 25, 14h 40m 38.00s | 〃 36.95s |
| 3 | 5 | 6.0 | 〃 〃 15h 04m 32.02s | 〃 30.70s |
| 4 | 6 | 5.0 | 〃 〃 15h 28m 51.80s | 〃 50.64s |
| 5 | 4 | 5.5 | 〃 〃 15h 51m 08.48s | 〃 07.23s |
| 6 | 6 | 7.0 | 〃 〃 20h 33m 49.28s | 〃 47.79s |
| 7 | 6 | 5.0 | 〃 〃 21h 29m 15.76s | 〃 14.71s |
| 8 | 3 | 6.0 | 〃 〃 16h 46m 05.70s | 〃 04.38s |
| 9 | 6 | 6.0 | 〃 26, 14h 28m 07.27s | 〃 05.95s |
| 10 | 5 | 6.0 | 〃 〃 14h 59m 11.24s | 〃 09.92s |
| 11 | 6 | 6.5 | 〃 〃 15h 00m 29.69s | 〃 28.28s |
| 12 | 5 | 8.0 | Apr. 5, 13h 06m 43.92s | 〃 42.35s |
| 13 | 4 | 4.5 | 〃 〃 13h 58m 44.96s | 〃 43.91s |
| 14 | 4 | 6.5 | 〃 〃 14h 52m 09.25s | 〃 07.84s |
| 15 | 6 | 5.5 | 〃 15, 14h 16m 10.47s | 〃 09.22s |

the arrival time at the epicenter and that of the respective stations are compared with the time differences calculated in the above model and the improved origin in Figs. 16∼19.

On the other hand, the apparent seismic velocities are obtained from the observed travel time curves at the epicentral distances of between 10 km and 20 km, and compared with those calculated in the model and the improved hypocentral position in Table 4. As are seen in Figs. 16∼19 the observed traveltime curves harmonize well with those calculated in respect to their travel times and apparent velocity of the initial wave.

Therefore, it will be reasonable that the proposed model will be accepted as the reliable structure of the Kirisima volcanoes in respect of the propagating velocity distribution of the P wave.

## 6. Conclusion

One of the writers had been conceiving for quite a long time a plan that, besides the seismic blast, the structure of volcano relating to the velocity distribution of the elastic wave could be studied in a lot of earthquakes which take place near the volcano.

It was fortunate to get a chance to put the plan into practice to some extent in the 1968 Ebino earthquake swarm.

In the present paper, the writers deal with the geographical distribution of the initial motion of the Ebino earthquakes, the structure of the Kirisima volcanoes relating to the velocity distribution of the seismic P wave and, at the same time, the re-determination of the

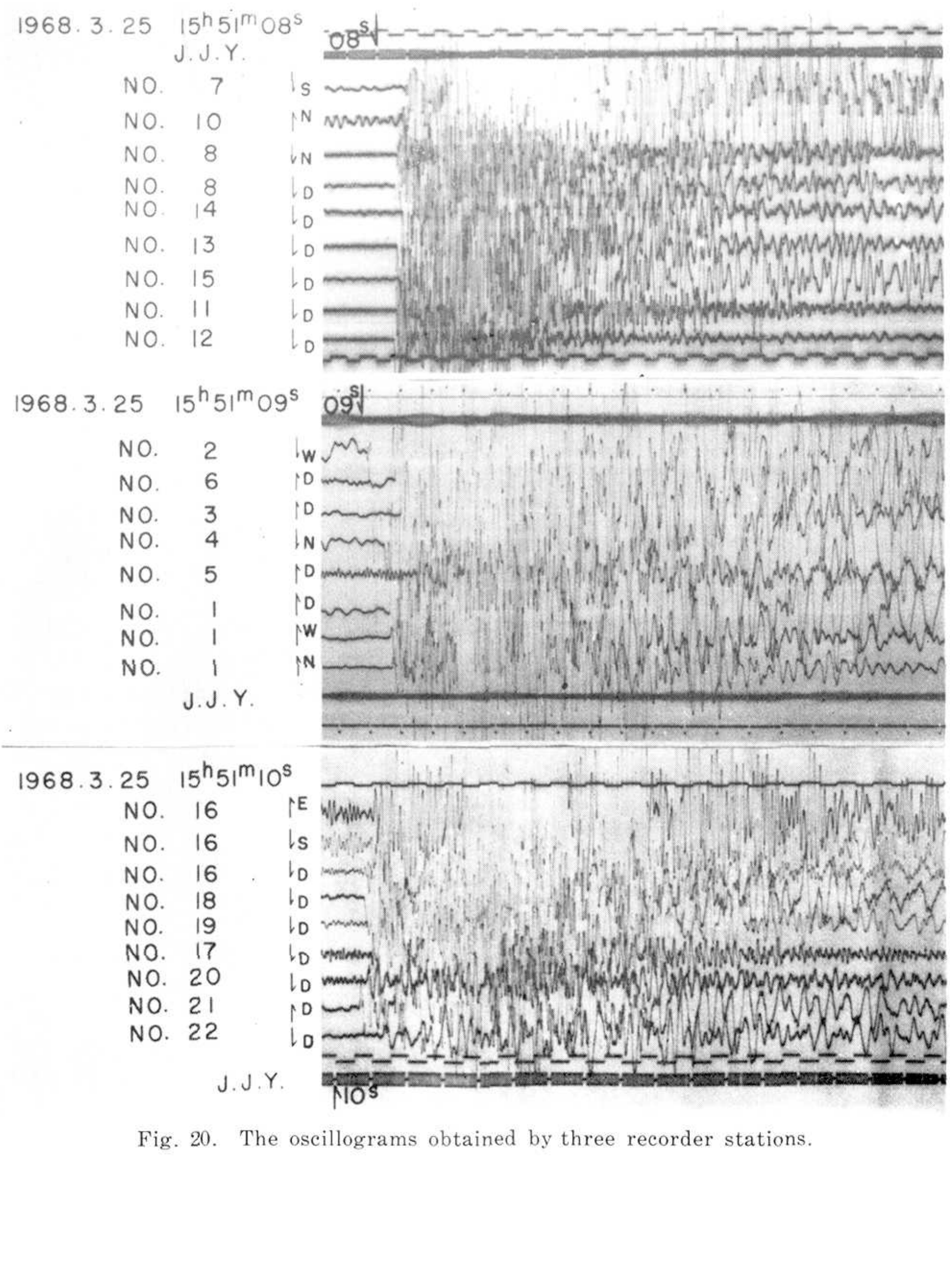


Fig. 20. The oscillograms obtained by three recorder stations.

hypocentral depth based on the travel time curves.

Although the geographical distribution of the initial motion for the great number of the Ebino earthquakes was of the ordinary type in which the upward and downward motions are separated into two straight lines passing the respective epicenters in the junction, a small percentage of the earthquakes showed the downward motion in all directions from the epicenter. The latter distribution indicates the

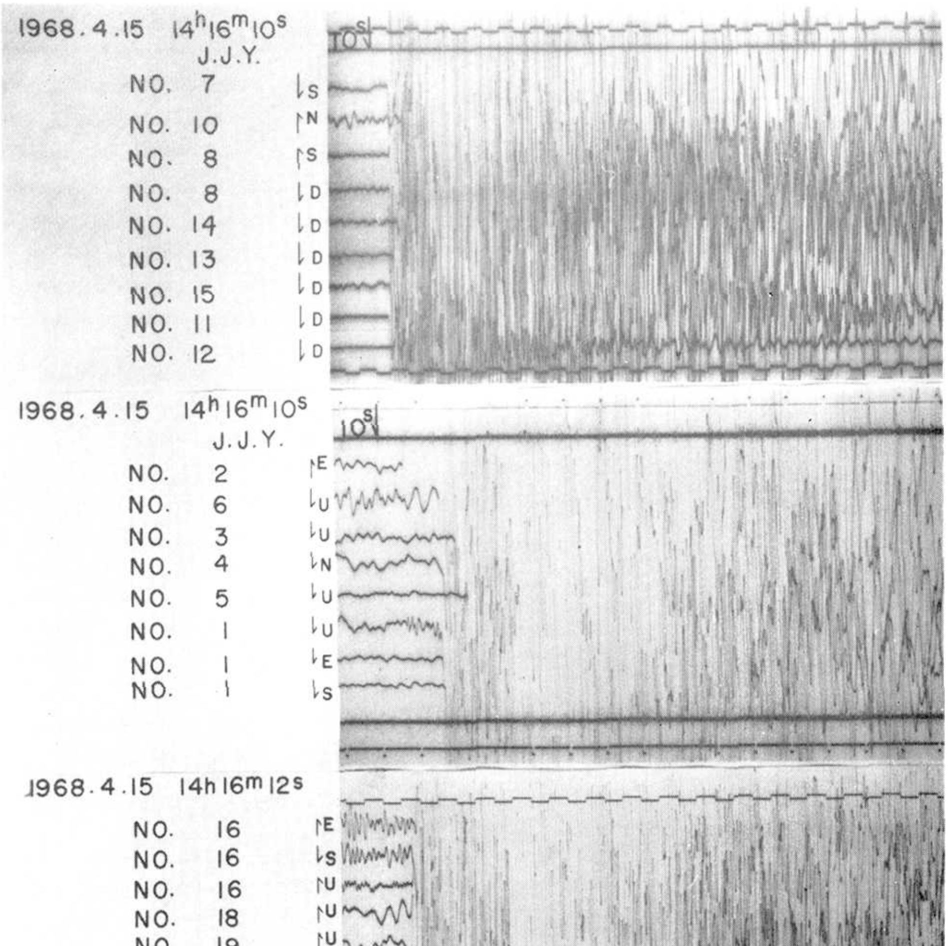


Fig. 21. The oscillograms obtained by three recorder stations.

mechanism of a negative single source in the appearance of the seismic wave at the hypocenter which was located inside the Kakuto caldera. Since the phenomenon is interesting and important for the caldera formation, it will be necessary to study further from the geological and geophysical point of view.

On the basis of the seismometrical observations at stations which are set on the Kirisima volcanoes, the travel time curves were studied in detail and the velocity distribution of the P wave was made clear to some extent. As a result, the writers found the model of the parallel structure with respect to the velocity distribution of seismic wave under the Kirisima volcanoes.

In conclusion, the writers wish to express their thanks to Mr. S. Utibori and Mr. N. Gyoda for their help in the seismometrical observation in the 1968 Ebino earthquakes, and to Miss T. Utsunomiya, Miss K. Hirai and Mrs. T. Kinoshita for their help in preparation of this paper.

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## 32. 1968-1969 年のえびの地震群及び霧島火山群の地震活動 (第 2 報)

### 初動の地理的分布と霧島火山群に沿う走時曲線

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寺尾弘子

第 1 報においては，1968 年 2月初旬より発生したえびの地震群の経過及び地震観測網の大要を述べた．かつ 4 カ所の石本式加速度地震計より成る第 4 観測網を用いて，地震群の震源位置を定め，その結果について述べた．

本報告では，主として第 1，第 2 及び第 3 観測網によるオシログラフを用いた研究結果を記述してある．これら 3 つの観測網のそれぞれの記録観測点では，水晶時計及び，J. J. Y. の分秒時刻及び 50 サイクルのマークを記録に入れたので，100 分の 1 秒から 100 分の 2 秒の精度で，発震時を読み取つた．

1) 震央に近接した第 2 観測網の発震時から，さきに第 4 観測網の S—P で定めた震央の位置を補正した．

2) 24 ヵ所における初動の観測から，その地理的分布を調べたが，地震群の 90% は，震央で直交する 2 直線で初動の押し，引きが分けられる，極めて一般的な分布を示した．その節線の方向と霧島火山群の火口丘群の配列方向とは一致しないで，35°～45° 位の相違がみられた．10% 以下の数の地震ではあるが，震央から総ての方向で引きだけを示す地震が見つけられた．つまり負の震源の機構によつて発生する地震が存在することを意味する．特に地震発生地域が，加久藤カルデラ内部であり，カルデラの生成の機構とも関連する問題として注目すべき現象である．しかしこの問題は，上記の如き重要な問題を含むので，更に検討するつもりである．例えば，下記のように，同地域は，地震波の速度分布が，地表下，約 5 km にやや著しい不連続面が推定されるので，表層中に震源を持つ地震波が，この不連続面で屈折することによつて生ずる初動分布の逆転について，なお検討する余地が残されている．

3) 霧島火山群に沿つて，配置された 17 ヵ所の上下動成分の発震時を用いて，15 コの地震についての走時曲線を作つた．その際に用いた震央は，第 2 観測網の発震時によつて定めたが，先に S—P から定めた震央位置とは 1 km 前後の相異を示すものが多かつた．また上記の走時曲線の震央距離が，10 km から 20 km に亘つて存在する 11 コの観測点発震時から求められる，見掛上の速度は 5.9～6.5 km/sec，特に 15 コの中 4 コの地震は 6.1 km/sec を示した．また 4 点の S—P から震源位置を定めた際の $k$ の値は 6.0 のものが多かつた．S—P で定めた震源の深さは，4 km から 9 km の間に分布し，5～8 km の範囲のものが大部分であつた．以上の諸観測の結果を考慮に入れて，水平構造を仮定し，霧島火山群の地震波速度に関する構造として，5～6 km の厚さの水平の地表層で，上層の P 波の速度として，4.0～4.5 km/sec，下層の速度として，6.0～6.3 km/sec の model を考えた．以上 3 コの量は，上記の範囲をもつが，15 コの走時曲線を最もよく説明する値として，上層の P の速度 4.3 km/sec，下層の P の速度 6.1 km/sec，及び表層の厚さとして，5.0 km を得た．