

33. *The Ebino Earthquake Swarm and the Seismic Activity
in the Kirisima Volcanoes, in 1968-1969, Part 3.*
*Crustal Deformation inside the Kakuto Caldera Relating
to the 1968 Ebino Earthquakes.*

By Tsutomu MIYAZAKI, Shiro HIRAGA,
and
Takeshi MINAKAMI,

Earthquake Research Institute, University of Tokyo.
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1. Introduction

For more than one year from the beginning of February, 1968, the Kirisima volcanic region, especially the Kakuto caldera, was visited by a series of strong shocks which caused serious damage to dwelling houses and the landslides in many places in the caldera.

The history of the seismic activity in this region gives a clue to prediction of its occurrence. Usually, in its epicentral region, the strong earthquake is followed by deformation of the earth's surface. Therefore, the writers set a net of short levelling route in two places in the Kirisima region in November, 1966, of which the one covers Okamoto village located at the southern part of the Kakuto caldera and the other at Ebino Koogen near the Kirisima Volcano Observatory.

Since the first levelling survey had been carried out in March, 1967, one year before the occurrence of the present Ebino earthquake swarm, the crustal deformation which accompanied the earthquakes near their epicentral area was made clear to some extent by re-surveys. The paper deals mainly with the result of levellings along the above-mentioned routes.

2. Levelling surveys along the newly set routes

In order to observe anomalous deformation of the earth's surface, the levelling survey should be frequently carried out as soon as possible along the same route.

As it was not easy to make a levelling survey along the long distant route, the writers selected a narrow but flat area which may be important for detecting the deformation of the earth's surface.

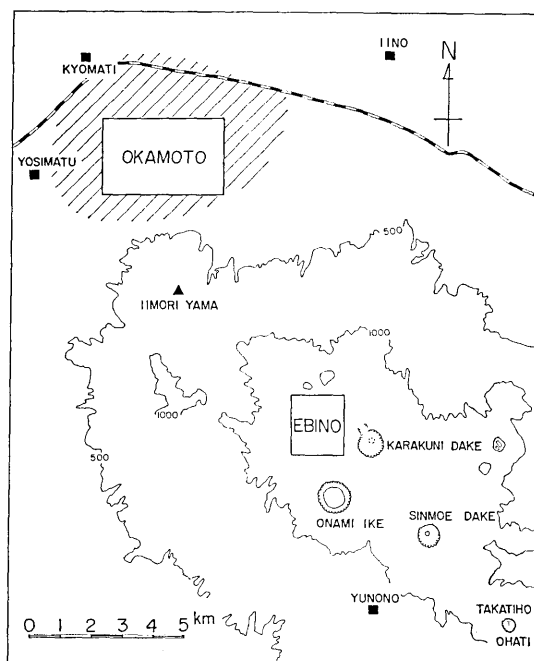


Fig. 1. Location of the Okamoto and Ebino Koogen levelling nets. Hatched area: epicentral area of the 1968 Ebino earthquakes.

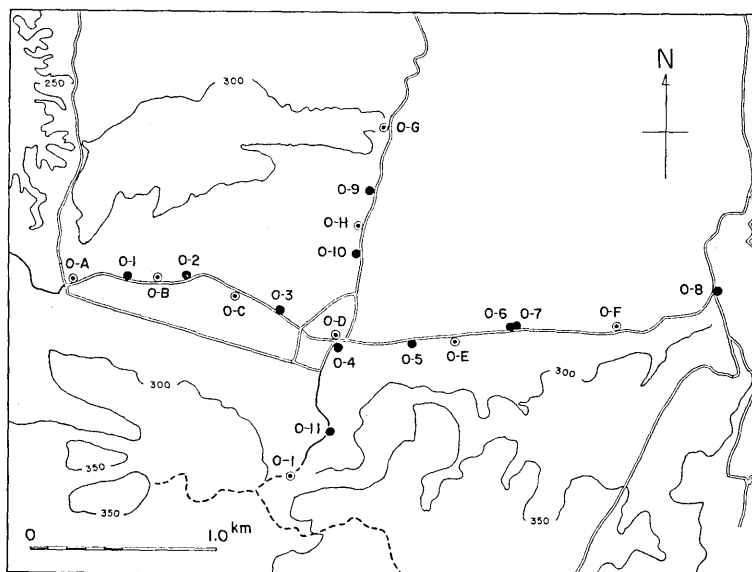


Fig. 2. The levelling route in Okamoto.

Table 1 (a). The result of the 1967-1969 levellings at the Okamoto area.

B.M.	H_1	H_2	H_3	H_4	ΔH_{2-1}	ΔH_{3-2}	ΔH_{4-3}	ΔH_{4-1}
O-A	—	—	+7.0261 m	+7.0272 m	—	—	+0.11 cm	—
O-1	+0.5358 m	+0.5214 m	-0.0765	-0.0758	-1.44 cm	+0.02 cm	+0.07	-1.35 cm
O-B	—	—	+0.2034	+0.2034	—	—	0.00	—
O-2	+0.8622	+0.8682	+0.2727	+0.2730	+0.60	+0.26	+0.03	+0.89
O-C	—	—	+0.6144	+0.6136	—	—	-0.08	—
O-3	-0.5249	-0.5203	-1.1164	-1.1160	+0.46	+0.21	+0.03	+0.70
O-4	0.0000	0.0000	-0.5986	—	0.00	0.00	0.00	0.00
O-D	—	—	0.0000	0.0000	—	—	—	—
O-5	+3.3940	+3.3954	+2.7964	+2.7966	+0.14	-0.09	+0.02	+0.07
O-E	—	—	+2.5736	+2.5720	—	—	-0.16	—
O-6	+6.4164	+6.4179	+5.8177	—	+0.15	-0.21	-0.19	—
O-7	—	—	+6.0619	+6.0600	—	-0.15	—	—
O-F	—	—	+4.7048	+4.7020	—	—	-0.28	—
O-8	—	—	+6.0156	+6.0101	—	+0.25	-0.55	—
O-G	—	+6.6112	+12.6148	+12.6168	—	—	+0.20	—
O-9	+4.2433	+4.2395	+3.6298	+3.6293	-0.38	-1.16	-0.05	-1.59
O-H	—	—	-0.9679	-0.9689	—	—	-0.10	—
O-10	+0.0307	+0.0340	-0.5644	-0.5647	+0.33	-0.03	-0.03	+0.27
O-D	—	—	0.0000	0.0000	—	—	—	—
O-4	0.0000	0.0000	-0.5981	—	0.00	0.00	0.00	0.00
O-11	+0.8497	+0.8518	+0.2517	+0.2524	+0.21	-0.20	+0.07	+0.08
O-I	—	—	+3.1094	+3.1096	—	—	+0.02	—

As a result, two levelling routes available for detecting the crustal deformation, or at least, tilt of ground were set at Okamoto and Ebino-Koogen whose localities are illustrated on the map of Fig. 1. A series of bench marks at both places are set on the two lines which intersect almost crosswise as can be seen on the map, so that we may measure the tilt of the earth's surface covered by the nets. The bench marks O-1, O-2, ... O-11 were set at Okamoto in November, 1966, and, similarly, bench marks O-A, O-B, ..., O-I were added along the same route in

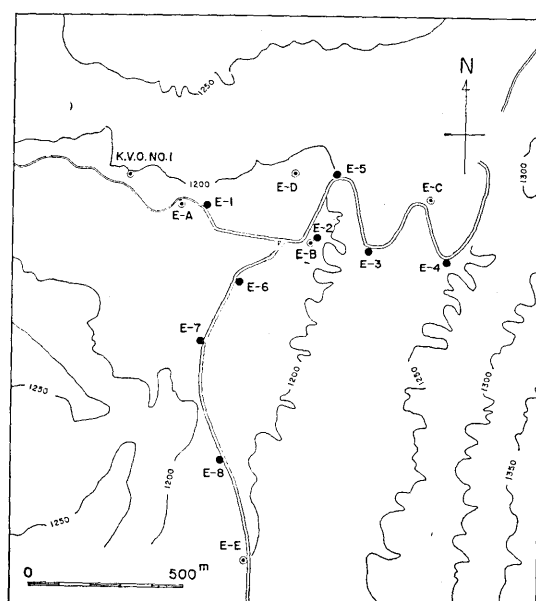


Fig. 3. The levelling route in Ebino Koogen.

Table 1 (b). The horizontal distance between the successive two bench marks situated in the Okamoto area.

B.M.	Distance	B.M.	Distance
O-A ~ O-1	0.320 km	O-6 ~ O-7	0.020 km
O-1 ~ O-B	0.140	O-7 ~ O-F	0.570
O-B ~ O-2	0.190	O-F ~ O-8	0.510
O-2 ~ O-C	0.220	O-G ~ O-9	0.315
O-C ~ O-3	0.270	O-9 ~ O-H	0.220
O-3 ~ O-4	0.340	O-H ~ O-10	0.125
O-4 ~ O-D	0.008	O-10 ~ O-D	0.500
O-D ~ O-5	0.440	O-D ~ O-4	0.008
O-5 ~ O-E	0.200	O-4 ~ O-11	0.480
O-E ~ O-6	0.350	O-11 ~ O-I	0.260

Table 2 (a). The result of the 1967-1969 levellings in Ebino Koogen.

B.M.	H_1	H_2	H_3	H_4	ΔH_{2-1}	ΔH_{3-2}	ΔH_{4-3}	ΔH_{4-1}
K.V.O. No. 1	—	—	-1.0826 m	-1.0861	—	+0.22 cm	-0.35 cm	—
E-A	—	—	-21.0304	-21.0334	—	—	-0.30	—
E-1	-18.0323 m	-18.0349 m	-18.0325	-18.0325	-0.26 cm	+0.24	-0.26	-0.28 cm
E-2	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00
E-B	—	—	-1.1459	-1.1463	—	—	-0.04	—
E-3	+14.0288	+14.0249	+14.0233	+14.0210	-0.39	-0.16	-0.23	-0.78
E-C	—	—	+34.3117	+34.3114	—	—	-0.03	—
E-4	+33.8054	+33.7963	+33.7882	+33.7870	-0.91	-0.81	-0.12	-1.84
E-5	+5.2480	+5.4272	+5.4286	+5.4287	-0.08	+0.14	+0.01	+0.07
E-D	—	—	-3.8138	-3.8124	—	—	+0.14	—
E-2	0.0000	0.0000	0.0000	0.0000	0.00	0.00	0.00	0.00
E-B	—	—	-1.1459	-1.1463	—	—	-0.04	—
E-6	-16.8526	-16.8546	-16.8534	-16.8556	-0.20	+0.12	-0.22	-0.30
E-7	-18.8522	-18.8510	-18.8509	-18.8527	+0.12	+0.01	-0.18	-0.05
E-8	—	—	-3.1364	-3.1378	—	+0.12	-0.14	-0.02
E-E	—	—	+0.1426	+0.1427	—	—	+0.01	—

March, 1968. Another series of bench marks E-1, E-2, ..., E-8 were newly set at Ebino Koogen near the Kirisima Volcano Observatory in November, 1966, and the bench marks E-A, E-B, ..., E-E, added alike in March, 1968.

Since the 1966 bench marks were made of stainless metal and were not serviceable over a long period, the 1968 ones were made of granite pile.

In Table 1 (a), H_1 , H_2 , H_3 and H indicate the relative height of the respective bench marks, assuming that the height of the bench mark O-4 in the first and second levellings and that of O-D in the third and fourth ones are zero. In Table 2 (a), the relative height H_1-H is referred to that of the bench mark E-2. In Tables 1 (a) and 2 (a), the relative subsidence and upheaval of the respective bench marks during the period of those two surveys are shown by ΔH_{2-1} , ΔH_{3-2} on the assumption that the bench marks O-4, O-D and E-2 did not move during that period.

It must be added here that the height of bench mark K.V.O. No. 1 in Table 2 (a) was 1195.809 m according to the 1968 levelling referred to the bench mark No. 221-033 which belongs to the Geographical Survey Institute of Japan. Tables 1 (b) and 2 (b) show the horizontal distance between the adjoining two bench marks.

Table 2 (b). Horizontal distance between the successive two bench marks situated in Ebino Koogen.

B.M.	Distance	B.M.	Distance
K.V.O. No. 1 ~ E-A	0.140 km	E-5 ~ E-D	0.145 km
E-A ~ E-1	0.090	E-D ~ E-2	0.150
E-1 ~ E-2	0.360	E-2 ~ E-B	0.025
E-2 ~ E-B	0.025	E-B ~ E-6	0.240
E-B ~ E-3	0.240	E-6 ~ E-7	0.215
E-3 ~ E-C	0.240	E-7 ~ E-8	0.430
E-C ~ E-4	0.160	E-8 ~ E-E	0.350

3. The crustal deformation of the Kakuto caldera relating to the 1968 Ebino earthquakes

The Okamoto levelling route covers not only the southern part of the Kakuto caldera, but also the southern part of the epicentral area of the 1968 Ebino earthquake swarm. Since the first, second and third levelling surveys were carried out during the periods from March 7 to 10, 1967, from March 11 to 15, 1968, and from November 3 to 5, 1968, the crustal deformation which is related to the Ebino earthquakes will be made

clear from the comparison of these three surveys.

From the comparison of the first and second levelling, the crustal deformation along the bench marks O-1, O-2 and O-3, located on the east route, was very remarkable and especially the bench mark O-1 subsided by 2.0 cm relatively as compared with the bench mark O-2, notwithstanding that the former is located only 320 m west of the latter. It must be noted that the catastrophic earthquakes took place at 8 h and 10 h on February 21, 1968, about 1.5 km north-west of the bench mark O-1, and that the second levelling covered the epicentral area soon after the above earthquakes.

From the comparison of the second and third levelling it was made clear that a remarkable deformation appeared on the northern route of the junction point, and especially the bench mark O-9, located at the end of the northern route, subsided by 1.2 cm relatively as compared with the adjoining bench mark O-10, which is situated only 350 m south of the O-9.

It may be necessary to remark that the Ebino seismic activity still lasted in the Kakuto caldera since the second levelling survey, but their epicenters shifted toward the east or the north of the bench mark O-9, as was reported in part I of this report.

The present earthquake swarm got weak after August, 1968, though ten or twenty earthquakes were daily observed by the seismometrical nets of the Kirisima Volcano Observatory even at the end of March, 1969.

From the comparison of the results of the third and fourth levelling surveys, no marked crustal deformation was found, which is rather natural because it can be said that most of the Ebino earthquake swarm had already passed before the third levelling survey.

4. The result of the levelling at the Ebino Koogen route

We must here touch on the results of the levelling surveys at the Ebino Koogen route which is located about 12 km south-east of the route mentioned in the previous chapter. The levelling survey was taken four times as in the former route. As is seen in Table 2 (a), no remarkable change along the route except at the bench marks E-3 and E-4 appeared during the period from the first survey to the fourth. A series of bench marks E-1, E-3, E-4 and E-6 in Table 2 (a) systematically showed the relative subsidence to the other bench marks and especially the relative subsidence of the bench marks E-4 and E-3, this being 1.84 cm and 0.78 cm respectively, compared with that of bench mark E-2. Since the horizontal distances from the bench mark E-2 to the E-4 and E-3 are only 440 m and 220 m respectively, the tilt in the area including these

bench marks was remarkable during the occurrence of the present Ebino earthquake swarm in spite of the quite long distance from the epicentral area.

5. The crustal deformation of the Okamoto and Ebino Koogen areas and the 1968-1969 Ebino earthquake swarm

Although the relative upheaval and subsidence at the nets of the bench marks in the Okamoto and Ebino Koogen areas were made clear, these two levelling nets cover only narrow areas. It is, therefore, reasonable that the crustal deformation of the present case is studied from the view point of the space differential quantities of deformation or in a form of the tilt of the earth's surface.

Examining the result of levelling surveys at the Okamoto route, it seems that the movement of the Okamoto area is separated into two blocks (A and B), of which one includes the bench marks O-A, O-1, O-B, O-2, O-G, O-9, O-H, O-10, and the other consists of the rest of the series of bench marks in the Okamoto levelling net. The values of the tilt and the direction of the above two blocks are given as the result of the four levelling surveys in Table 3 and Figs. 4~6.

Table 3. The tilting of the A and B blocks in the Okamoto area.

A block		B block		Period
Amount of tilt	Direction of tilt	Amount of tilt	Direction of tilt	
65.7×10^{-6}	35°	4.0×10^{-6}	240°	Mar. 1967-Mar. 1968
37.8×10^{-6}	6°	4.0×10^{-6}	240°	Mar. 1968-Nov. 1968
1.6×10^{-6}	290°	1.0×10^{-6}	290°	Nov. 1968-Mar. 1969

(Direction of tilt was measured counter-clockwise from north)

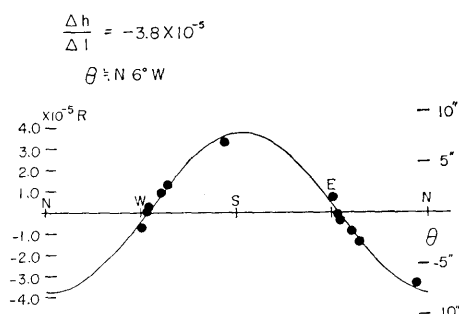


Fig. 4. The tilt movement of the A block in Okamoto in the period of March, 1968, through November, 1968.

In Table 3, the tilts of the A and B blocks are given according to three periods which correspond to three stages of the activity of the Ebino earthquake swarm.

The first stage of the 1968-1969 Ebino earthquake swarm includes not only two catastrophic earthquakes on February 21, and a great number of shocks up to March, 1968, but also a series of forerunning

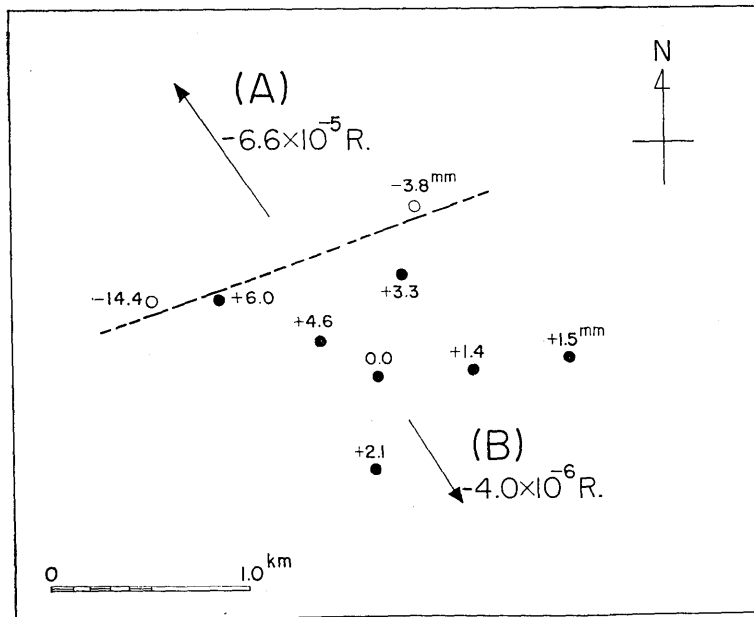


Fig. 5. The crustal deformation at Okamoto in March, 1967, through March, 1968.

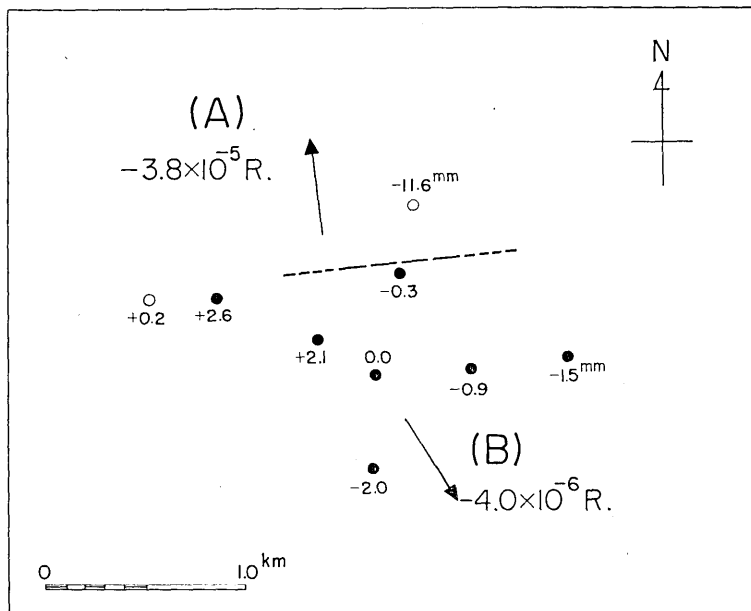


Fig. 6. The crustal deformation at Okamoto in March through November, 1968.

earthquakes during the period from February 1 to 21, 1968.

The crustal deformation for the above period was observed by the first and second levelling surveys.

The second stage of the Ebino earthquake swarm covers its most active period in seismic frequency including the strong earthquake on March 25, 1968. The crustal deformation of the second stage was caught by the second and third levelling surveys.

The third and final stage will be covered from November, 1968, to the time when the usual level of seismic frequency at the Kakuto caldera is regained. However, at present, April 20, 1969, the seismic activity at that area still keeps a high level, though it is gradually getting weak.

Judging from the result of the third and fourth levelling surveys, crustal movement at the Okamoto area during that period was smaller than that of the earlier stage.

As is seen in Table 3, the A block tilted to the west and slightly to the north by 6.6×10^{-5} or 13.7 seconds of arc at the first stage, in which a lot of earthquakes took place mainly at the west area of the Okamoto levelling net. At the second stage, however, the A block tilted to north by 3.8×10^{-5} radian or 7.4 seconds of arc, in which the center of the epicentral area shifted to north of the A block.

On the contrary, the B block tilted by 4.0×10^{-6} radian or 0.8 second of arc at the first stage and by 4.0×10^{-6} radian or 0.8 second of arc at the second stage. In both stages, it tilted to the south-east direction.

Since the values of tilt of the A block are outstandingly of large scale in both first and second stages, it would be interesting to investigate whether any dislocation like a fault appeared at the boundary between the A and B blocks or not. According to the field investigations at the Okamoto area, the writers found a lot of small fissure and local depression on the cultivated land and roads which were made mainly on the occasion of the strong earthquakes at the first and early second stages. Although no evident earthquake fault was found on the earth's surface, it might hide around the boundary between A and B blocks.

If one of the dislocations should exist at the boundary between A and B blocks, the direction of the dislocation line would agree with that of the one nodal line in the geographical distribution of the initial motion for the majority of the Ebino earthquakes.

The Ebino Koogen area is situated at the northern foot of Karakuni-dake, an extinct cone, and its circumference is surrounded by a series of low hills. The area is topographically flat and has a lot of fumarole and hot springs, and the geothermal temperature near the earth's surface is abnormally high. The levelling net covers the main part of the Ebino Koogen area. The level of underground water and the geothermal

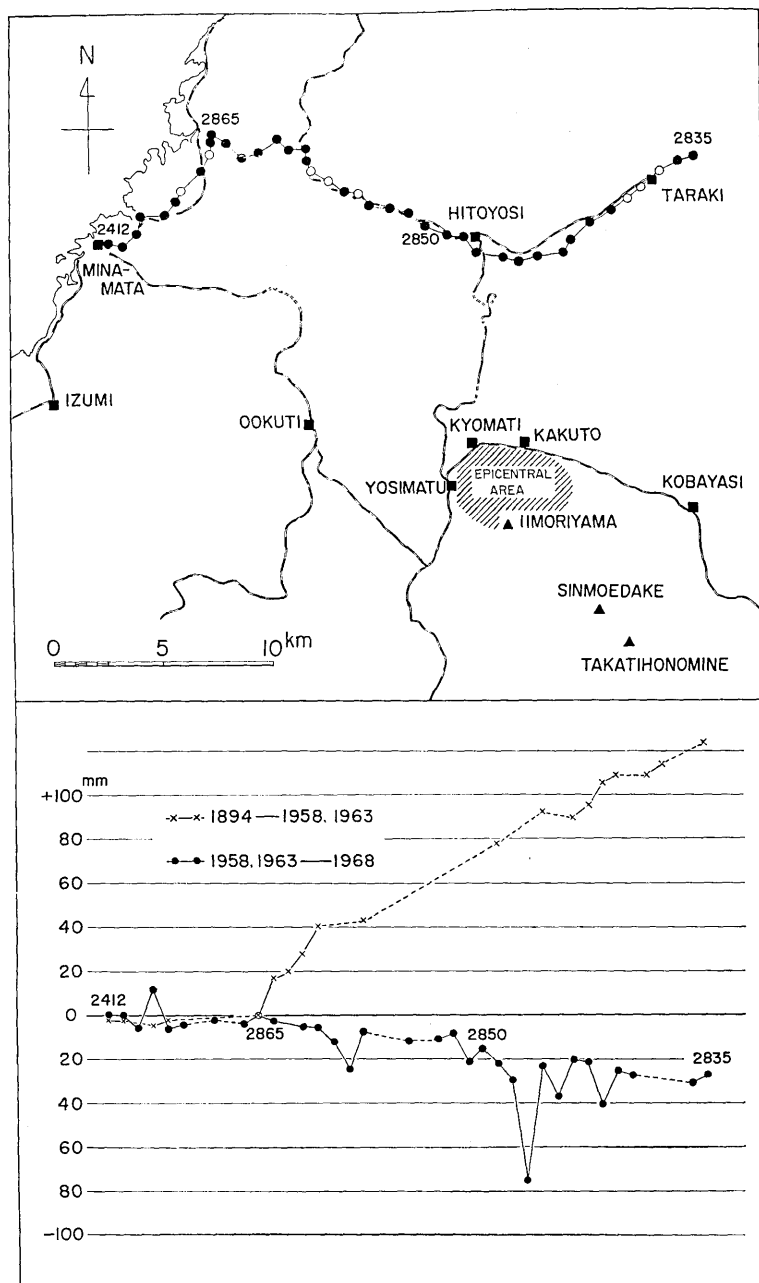


Fig. 7. Result of levelling surveys made by Geographical Survey Institute.

temperature change remarkably according to the season and the annual rain fall. It can be said, therefore, that as the nature of the ground at Ebino Koogen is unstable and has an adverse effect on the obser-

vation, the results of the levelling surveys should be discussed after investigation of the changes of the water level and geothermal temperature.

On the other hand, the Geographical Survey Institute of Japan made the levelling survey soon after the outbreak of the Ebino earthquakes along the western levelling route of Kyusyu Island which runs about 25 km north of the Ebino epicentral region. The comparison of the 1968 survey with the 1961 one made clear the crustal deformation along the route during the last seven years. The result of the 1968 levelling and the locality of the levelling route are illustrated in Fig. 7 with the comparison of the 1968 levelling with that of 1958 and 1963.

6. Conclusion

The writers reported in this paper the results of the levelling surveys at Okamoto situated inside the Kakuto caldera and at Ebino Koogen located near the central part of the Kirisima volcano group.

The first levelling surveys at these levelling nets were carried out one year before the outbreak of the Ebino earthquake swarm, and a series of the levelling surveys made clear the crustal movement relating to the earthquake swarm. Since both Okamoto and Ebino Koogen levelling nets cover only limited areas, the results of these surveys dealt with a form of tilt of the earth's surface. The Okamoto area was divided into two blocks based on the type of movement; the one tilted almost by 10^{-4} radian, and the other by 10^{-5} radian. Judging from such big tilts, it may be reasonable to assume that a dislocation like an earthquake fault of small scale lies hidden from our sight near the boundary between the two blocks.

On the other hand, the gravity survey taken by the Japan Geological Survey made it clear that the Kakuto caldera area showed the negative gravity anomaly.

As already reported in Part 2, the writers found that among the great number of Ebino earthquakes, a few of them show the downward initial motion in all directions from the epicenter, which suggests the existence of the earthquake caused by a negative single source.

The tilt at the Okamoto area and the southern part of the Kakuto caldera which is related to the Ebino earthquakes, directed toward the north-west and the north, or the central part of the caldera. However, it is not always certain whether the central part of the caldera, which almost coincides with the epicentral area of the Ebino earthquakes, subsided subsequently as the result of the present earthquake swarm or not. So far as the direction of the tilt at Okamoto is concerned, the central part of the caldera subsides as the result of the Ebino earthquakes.

If it should be true, it could be said that the Ebino earthquakes afford an important key, not only to solution of the structure of the Kakuto caldera, but also to the study of the geographical distribution of the initial motion of the earthquakes originating from the negative single source and of the negative gravity anomaly inside the caldera.

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33. 1968-1969 年のえびの地震群及び霧島火山群の地震活動 (第 3 報)

加久藤カルデラ内岡元地区及びえびの高原に於ける水準測量結果

地震研究所 { 宮 崎 務
平 賀 士 郎
水 上 武

1966 年岡元地区に地震観測網を新設すると同時に、狭い地域ではあるが水準点を十字状に配列して、同地域の傾斜変動の検出に便利な水準路線をつくつた。同様の水準路線をえびの高原に新設した(霧島火山観測所の水準点を含む)。

第一回目の水準測量は 1967 年 3 月に実施したが、それはえびの地震群の発生する約一年前である。第二回は地震群が発生して間もなくの 1968 年 3 月、第三回は同年 11 月、第四回は 1969 年 3 月に行なつた。本報告には以上の水準測量の結果と、えびの地震群に伴つたと推定される水準変化および傾動について記載した。