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ON THE PECULIAR MODE OF CRUSTAL MOVEMENTS ACCOMPANIED WITH THE ACTIVITIES OF SHALLOW EARTHQUAKES[1]

By

Tokio ICHINOHE and Yutaka TANAKA

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Abstract

Since 1937 the continuous observations of the crustal movements with tiltmeters and extensometers have been carried out at twenty observing stations in Japan. From the results of tiltmetric observations it was found that the ground tilt relating to the occurrence of earthquakes proceeded generally through three stages. In the first stage, the ground tilt generally proceeded in the direction of operation of geotectonic force which caused the horizontal displacement of the ground at the observing station. In the second stage, it was prominent in the direction towards the epicentral region. In the third stage, just before the occurrence of earthquakes, the ground tilt generally increased its speed or reversed the sense of its direction.

1. Introduction

Since 1937 the continuous observations of the crustal movements with tiltmeters and extensometers have been carried out at twenty observing stations in Japan. In these observing stations, about fifty tiltmeters and thirteen extensometers are in operation at present. During about thirty years from 1937 to the present, there occurred scores of remarkable earthquakes and innumerable moderate and small earthquakes in and near Japan. Some of these remarkable earthquakes were accompanied with characteristic crustal movements before and after the occurrence of earthquakes.

The late Professor Nishimura who was our teacher has published many papers on the crustal movements forerunning the occurrence of earthquakes. But he didn't come to find the general law existing between the forerunning crustal movements and earthquakes. Thereafter we succeeded to his study and promoted it. According to our studies, it seems that the forerunning crustal movements proceed generally through three stages so far as shallow earthquakes in

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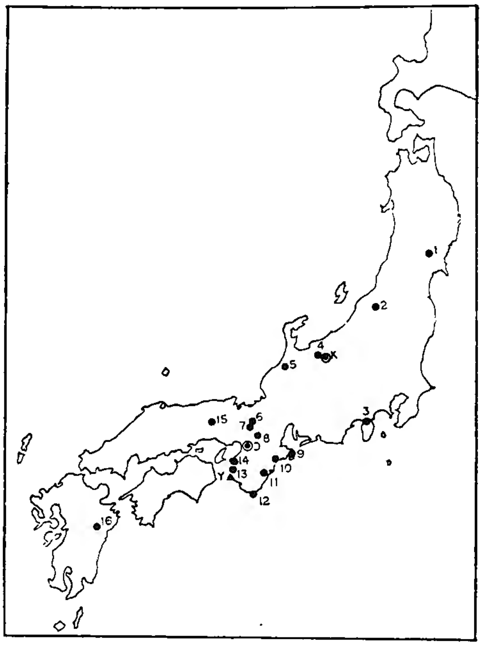

Fig. 1. Location of the observing stations.

some regions are concerned.

Fig. 1 shows the distribution of our observing stations. In this paper some observational results obtained mainly at Makimine, Kamioka and Ogoya stations (Nos. 16, 4 and 5) will be reported.

2. Characteristic ground tilt at Makimine station

Fig. 2 is the vectorial representation of secular change of ground tilt at Makimine station during the period from 1958 to 1963. Fig. 3 shows the same ground tilt, resolving it into the six components in the directions

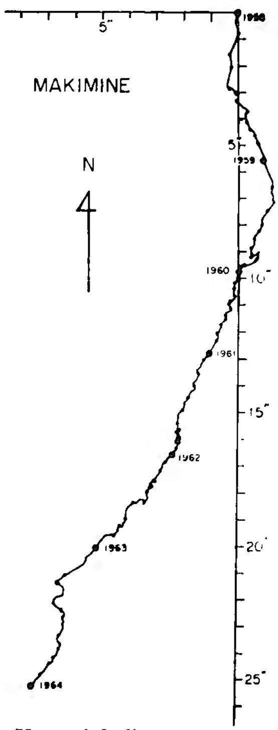

Fig. 2. Vectorial diagram of the ground tilt at Makimine station.

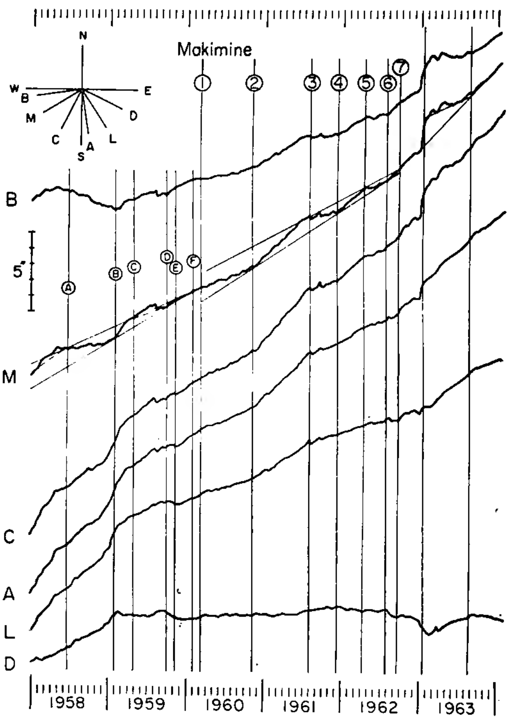

Fig. 3. Ground tilt at Makimine resolved into six components.

A, B, C, D, L and M, making an angle of 30 degrees to each other. The direction M and characteristic ground tilt in that direction should be especially remarked.

Fig. 4 shows the horizontal displacements of the triangulation points in the south-western part of Japan during recent several decades, which was published by E. Inoue of the Geographical Survey Institute of Japan. The direction M in the former figure correctly coincides with the direction of horizontal displacement of the ground at Makimine station, and further accidentally or not, it also coincides with the direction of the Median dislocation line which is one of the typical geotectonic lines in Japan.

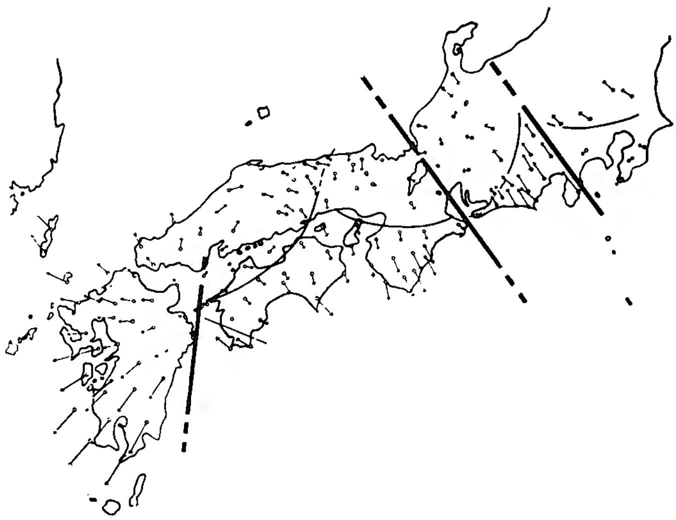

Fig. 4. Horizontal displacement of the triangulation points in the south-western part of Japan.

Fig. 5 is the enlargement of a section of the ground tilt in the direction M. In this figure we can see that the mean velocity of the ground tilt has changed twice, namely at epochs ② and ③. In the period involved in this figure, there occurred many shallow earthquakes and three deep earthquakes. Broken lines show the times of earthquake occurrences. The middle shows the Hyuganada earthquake, and ②, ③ and ④ show deep earthquakes. Fig. 6 shows the distribution of epicentres of shallow earthquakes, being divided into three groups ⓐ, ⓑ and ⓒ.

In Fig. 5, the 1st period (from the beginning to ②) corresponds to the activity of earthquakes of the group ⓐ, the 2nd period (from ② to ③) to the group ⓑ, and the 3rd period (from ③ to the end) to the group ⓒ. In this figure, we can see that in the 1st period the shallow earthquakes occurred at

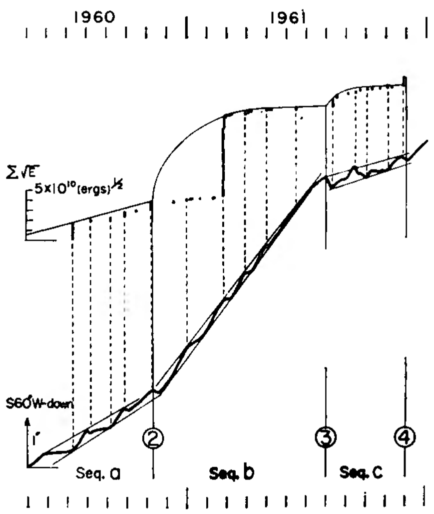

Fig. 5. Ground tilt of Makimine in the direction M.

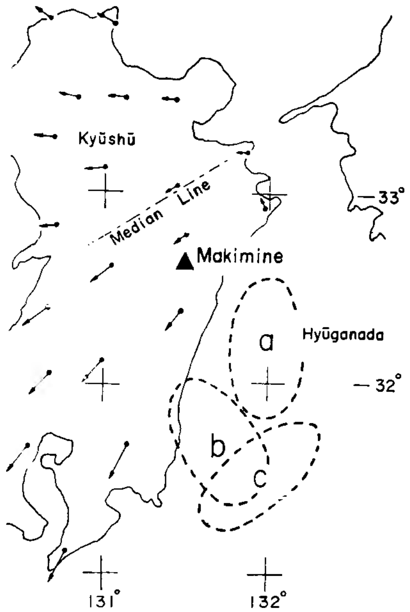

Fig. 6. Distribution of the epicentres of shallow earthquakes occurred in Hyuganada region.

the peaks or troughs of the curve of ground tilt, and in the 2nd period they occurred at the peaks or immediately later. In the 3rd period it is complicated, and it seems the combined case of the 1st and 2nd periods. The deep earthquakes ② and ③ occurred correctly at the epochs that the mean tilting velocity changed. The uppermost curve in Fig. 5 shows the summation of the square root of energy emitted by seismic waves.

As mentioned hitherto, so far as our Makimine station is concerned, the ground tilt characteristically appears at first in the direction of horizontal displacement of the ground, in other words in the direction of operation of geotectonic force. But it is an unsolved problem what relation exists between the geotectonic force and earthquake-generating force. Such a characteristic relation of the ground tilt and seismic activity we can find in other districts of Japan.

3. Characteristic ground tilt at Ogoya station

Left side of the upper figures in Fig. 7 shows the distribution of the epicentres of earthquakes occurred in the central district of Japan (Mino-echizen district) during eight and a half years from January 1951 to August 1959, and the right side shows that of four years from September 1959 to August 1963. Our observing stations Kamioka and Ogoya are represented by K and O respectively.

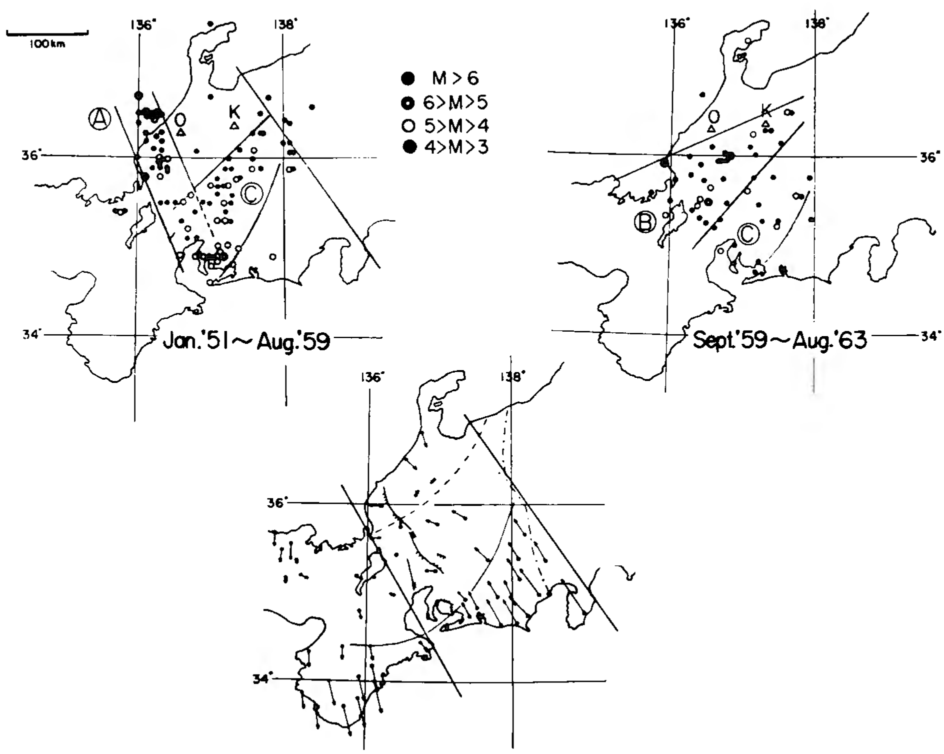

Fig. 7. Distribution of the epicentres of earthquakes occurred in the central district of Japan and the horizontal displacement of the triangulation points in that district.

Comparing these two figures, it will be clearly found that seismically active region has removed with time, namely in the former period seismicity was active in the regions Ⓐ and Ⓒ, and in the latter period it was active in the regions Ⓑ and Ⓒ. The lower figure in Fig. 7 shows the horizontal displacements of the triangulation points during recent several decades. Two solid lines in this figure show the discontinuous boundaries of horizontal displacements. From this figure, we can easily suppose that in the region Ⓐ some shearing force was operating, and in the region Ⓑ some compressional force. This supposition is proved to be correct by the existence of the famous Neodani fault which appeared at the time of the great Nobi earthquake in 1891. We can also suppose that the shearing force might have operated thereafter and have ntimate relation with the occurrence of earthquakes in the region Ⓐ.

Contrary to this, earthquakes in the region Ⓑ are supposed to be related with compressional force. This supposition is also proved to be correct by seismometric observations. From the point of view on "push" and "pull" distribution of the initial ground motion, almost all the earthquakes in the region Ⓐ belong to the so-called quadrant type, and almost all the earthquakes in the

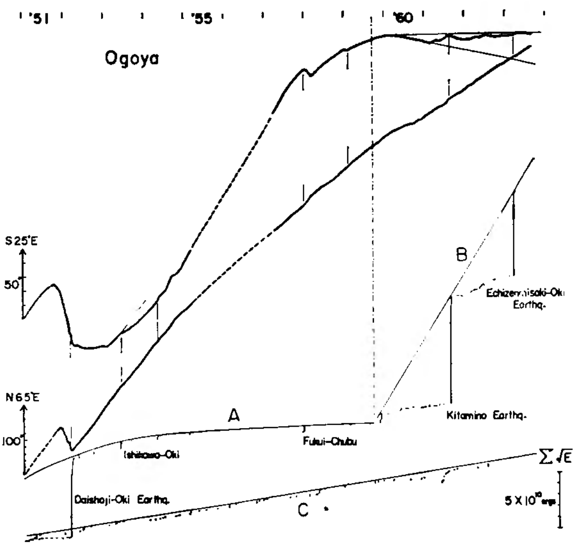

Fig. 8. Ground tilt at Ogoya station.

region Ⓑ belong to the cone type. This difference can be found on the results of our tiltmetric observations.

Fig. 8 shows the ground tilt at Ogoya station. The uppermost curve shows the ground tilt in the direction of horizontal displacement of the ground at Ogoya, and the lower curve shows that in the direction normal to it. In this figure, we can see that the velocity of the ground tilt changed in 1959 which was a boundary epoch of seismic activities in the regions Ⓐ and Ⓑ. Curve A in Fig. 8 shows the summation of the square root of energy emitted by seismic waves from the region Ⓐ, and the curve B shows that from the region Ⓑ. The curve A appears to be exponential, and B to be linear, notwithstanding there occurred two large earthquakes. From the region Ⓒ seismic energy has been emitted constantly through all the period.

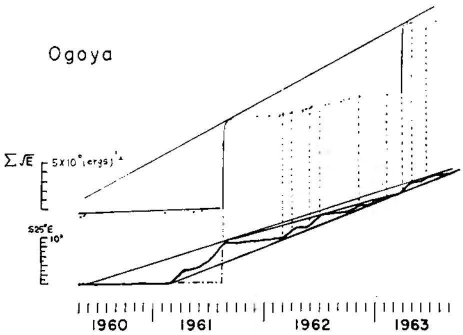

Fig. 9. Details of the ground tilt at Ogoya relating to the activity of earthquakes.

The lower curve of Fig. 9 shows the details of the relation between the above-mentioned two large earthquakes and the ground tilt at Ogoya. Comparing this with that of Makimine, we can find a fine similarity in the mode of ground tilt, relating to seismic activities.

Our observational results on the ground tilt in the direction of horizontal displacement are as mentioned above. But the ground tilt relating with earthquake appears not only in that direction but in other direction. Just before the occurrence of earthquakes it seems more prominent in the direction towards the epicentre.

4. Characteristic ground tilt before and after the occurrence of earthquakes

Fig. 10 shows the vectorial diagrams of the ground tilts before and after the occurrence of some remarkable earthquakes. In this figure, the triangles indicate the location of our observing stations, the chain-lined arrows the direction of horizontal displacement of the ground at the observing stations, the crosses the epicentres, the elliptic areas closed by dotted lines the aftershock areas, the thick curves the ground tilts, and the signed numerals indicate the numbers of days before and after the occurrence of the earthquakes.

In the case of the Daishoji-oki earthquake in 1952, 90 days before the earthquake occurrence the ground at Ogoya began to tilt towards the epicentral region, 30 days before it turned back, and 10 days before it turned again towards the epicentral region. Concerning the other earthquakes it is as seen in the

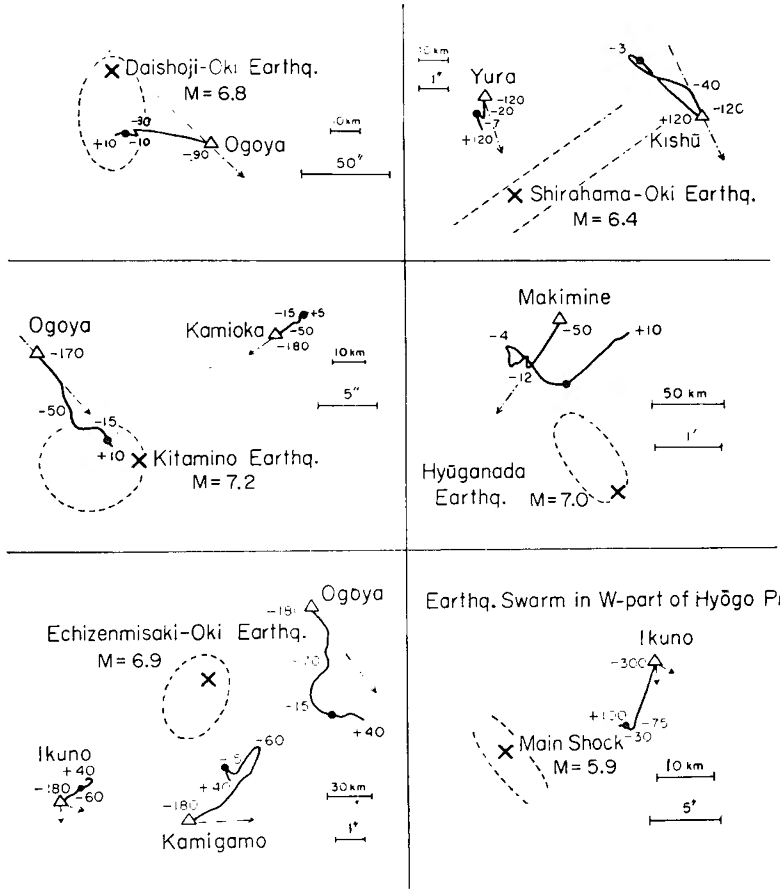

Fig. 10. Vectorial diagram of the ground tilt before and after the occurrence of some remarkable earthquakes.

figures.

5. Summary

Summarizing all the above mentioned observational results, it seems to be able to say that the ground tilt relating to the earthquake occurrence proceeded generally through three stages.

In the first stage, the ground tilt generally proceeded in the direction of operation of geotectonic force which caused the horizontal displacement of the ground at the observing station, though it is unsolved problem what relation exists between the geotectonic force and earthquake-generating force in this case.

In the second stage, the ground tilt was prominent in the direction towards the epicentral region. The ground tilt in this stage seems to be closely relating to the accumulation of strain energy in the epicentral region.

In the third stage, just before the occurrence of earthquakes, the ground tilt generally increased its speed or reversed the sense of its direction. The ground tilt in this stage is considered to be closely relating to the rapid creep or forerunning fractures of rocks in the epicentral region.

After the occurrence of earthquakes, the ground tilt used to continue until the termination of the activity of aftershocks.

We are studying now whether such a regular process of the ground tilt as mentioned above exists or not in other districts of Japan. We hope some clues for earthquake prediction would be derived from the observational results as mentioned above.