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71. On the Relation between the Activity of Earthquakes and the Crustal Deformation in the Yoshino District

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1. Introduction

Some examples on the anomalous tilt of the ground were already reported by E. Nishimura in the case of the earthquakes of Tottori, Daishōji-oki, Hyūganada, Kitamino, and so on. In the case of these earthquakes, it was also observed that the anomalous ground tilt has proceeded generally through several stages. But it remained uncertain when the anomalous tilt had commenced and when it had ceased, presenting an important problem, that is to say, what is "anomalous" tilt.

In the case of the Yoshino earthquake on July, 1952, it is considered that an unusual ground tilt commenced a week before the earthquake occurrence, and changed its mode immediately after the earthquake, holding its mode until September of the next year when another prominent earthquake occurred at the same depth in the same region. This fact obliges us to suppose that the anomalous ground tilt in this case does not correspond to an earthquake, but to a series of earthquakes from that of July, 1952, to that of September, 1953. In the following, the relation between this series of earthquakes and the anomalous ground tilt will be reported in detail.

2. General description on the ground tilt connected with a series of sub-crustal earthquakes in the Yoshino District

In western Japan, sub-crustal earthquakes full into two regions, one being the region from Iyonada to Amami-ōshima through the eastern part of Kyūshū and the other being the central part of the Kii Peninsula. In this paper, the relation between the anomalous ground tilt and eleven sub-crustal earthquakes which occurred in the Yoshino District in the Kii Peninsula is discussed.

In this district there was no earthquake for twenty-six years from 1926 to 1952. After this rest period, there occurred a large earthquake of magnitude 7.0 at the depth of 70 km, the so-called Yoshino earthquake, on July 18th, 1952. Four years after that, there occurred seven earthquakes at a depth of from 60 km to 70 km in this district, and after a short rest period, the so-called Ōdaigahara earthquake occurred. Considering the conditions of occurrence of these earthquakes and the mode of the ground tilt, it is

* The contents of this paper were already reported by Prof. E. Nishimura in the annual meeting of the Geodetic Society of Japan on October, 1963, at Mizusawa. This paper was compiled by Y. Tanaka and T. Ichinohe on the basis of Prof. Nishimura's draft for the lecture after his death (on March 19th, 1964).

TABLE
Specification of sub-crustal earthquakes which occurred in the Kinki District (1952-1963)

No.	Date	Epicenter		Depth km	Magnitude
		N	E		
1*	July 18, 1952	34°.5	135°.8	70	7.0
2	Aug. 9	34 .5	135 .8	65	5.5
3	Sept. 1, 1953	34 .0	135 .7	70	6.3
4	Apr. 21, 1954	34 .3	135 .9	60	5.2
5	May 10	34 .0	135 .5	65	5.0
6	May 22, 1955	34 .2	135 .5	75	5.6
7	Oct. 31	34 .3	135 .7	60	5.0
8	Nov. 4	34 .7	136 .1	60	5.2
9	Nov. 19, 1956	34 .3	135 .8	75	5.5
10	Nov. 27, 1957	34 .7	136 .2	70	6.0
11**	Dec. 26, 1960	34 .2	135 .2	60	6.2

* Yoshino earthquake
** Ōdaigahara earthquake

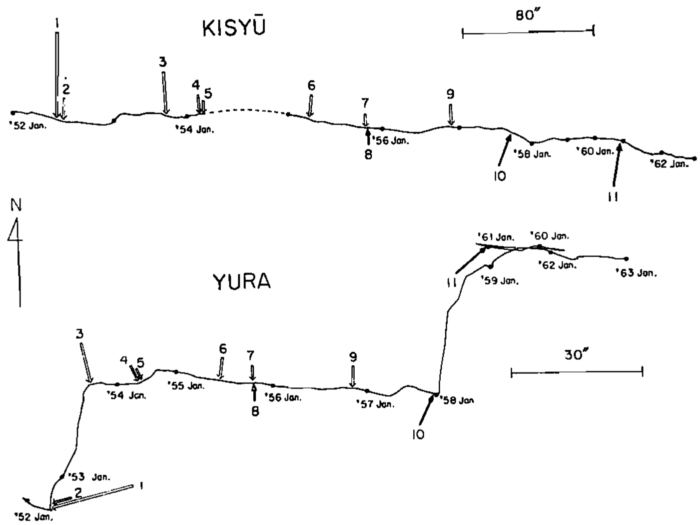

Fig. 1. Vector diagram of the secular change of ground tilt observed at Yura and Kishū.

supposed that these earthquakes were generated by the same cause.

Fig. 1 shows the vector diagram of the secular ground tilt from 1952 to 1963, observed with the tiltmeters of horizontal pendulum type at the Yura and Kishū observatories in Wakayama and Mie Prefectures. In Fig. 2, the ground tilt in the period of several months before and after the individual earthquake is shown by two components of the radial (R) and transversal (T) directions to the epicenter. As seen in Fig. 2, the mode of the ground tilt before and after the earthquake was common to all earthquakes, es-

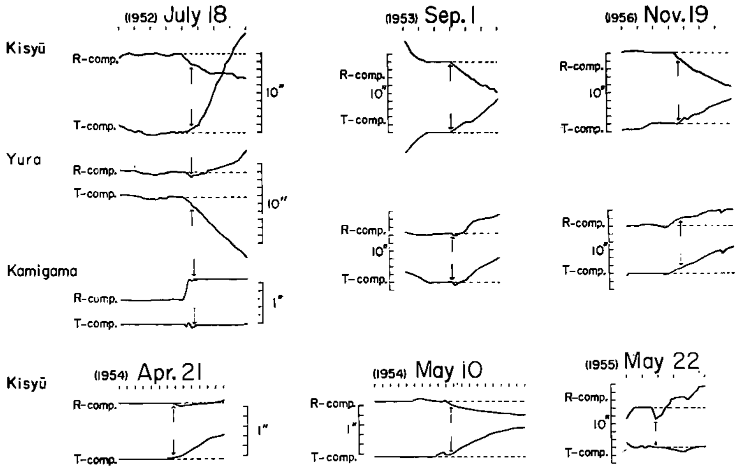

Fig. 2. Ground tilt in the radial (R) and transveral (T) directions to the epicentral region of the earthquakes of Yoshino series.

pecially the tilting speed suddenly changed after the earthquake to continue till the next earthquake.

This is different from the usual type of the ground tilt that an anomalous ground tilt commenced sometime before the earthquake and gradually decreased its speed to recover the initial state. Another noticeable characteristic in these earthquakes is that the anomalous ground tilt was found rather in a specific direction than the radial or transversal direction to the epicenter.

As mentioned above, it is the characteristic of a series of sub-crustal earthquakes in the Yoshino District to change the tilting speed suddenly after the earthquake, to hold its speed till the next earthquake, and to change its speed again. This characteristic was not found in case of the Ōdaigahara earthquake.

3. Occurrence mechanism of the earthquakes of the Yoshino series

Next, let us examine the occurrence mechanism of these earthquakes. Fig. 3 shows the distribution of "push" and "pull" in the ground motion in the time of these earthquakes. As seen in Fig. 3 the Yoshino earthquake (No. 1 in the table) belongs to a cone-type rather than a quadrant-type in view of the occurrence mechanism. The earthquake of No. 3 surely belongs to a cone-type. It is very interesting that the cone axes (XX′ in Fig. 3) of these two earthquakes perfectly coincide with each other in its azimuth. The cone axes of the other six earthquakes also substantially coincide with those of the two earthquakes as seen in Fig. 4.

From the fact that these eight earthquakes have the same push-pull distribution as seen in Figs. 3 and 4, and are accompanied with the same ground tilt as shown in Fig. 2, it is concluded that these eight earthquakes were caused by the same earthquake-generating force, and it is supposed

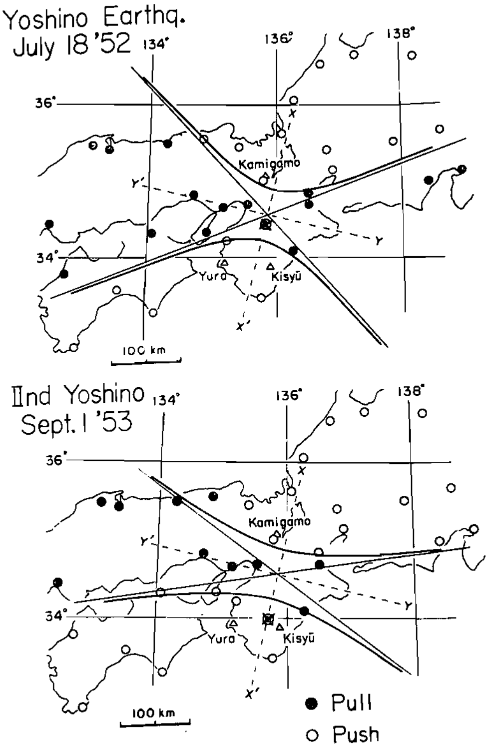

Fig. 3. "Push"-"pull" distribution of the initial ground motion in the Yoshino and the second Yoshino earthquakes.

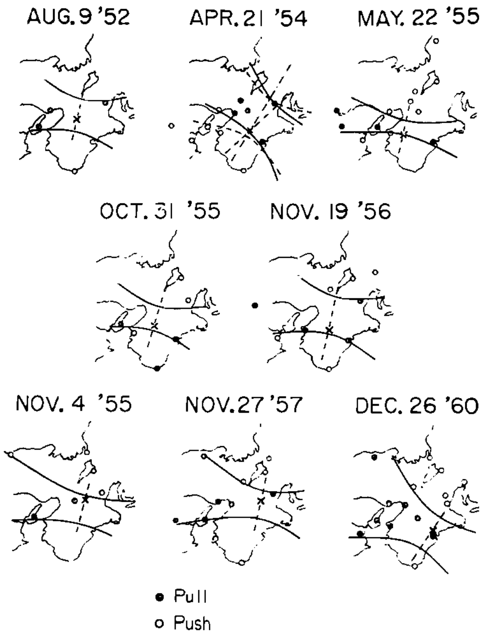

Fig. 4. "Push"-"pull" distribution of the initial ground motion in the sub-crustal earthquakes which occurred in the Kinki District.

that the same stress was operating on the central region of the Kii Peninsula during this period.

4. Specific tilting movement of the ground at Yura and Kishū

If these eight earthquakes were caused by the same earthquake-generating force, it will be naturally supposed that there should be some specific direction in the anomalous ground tilt connected with the direction of the above-mentioned force. Fig. 5 shows the mode of the ground tilt at the Yura and Kishū observatory, dividing it into the two directions of XX′ in Fig. 3 and YY′ perpendicular to XX′. In Fig. 5, two large ground tilts will be found in the times of the earthquakes No. 10 and No. 11. These two ground tilt were connected with the activity of the other series of earthquake, and had no relation with the earthquakes of the Yoshino series under consideration. The ground tilt from which the tilt connected with the other series of earthquakes was eliminated is shown with chain-lines in Fig. 5. The tendencies of the ground tilts expressed with chain-lines at the two observatories resemble each other as far as the X-component is concerned. Turning our attentions to the Y-component, the grounds of the Kishū and

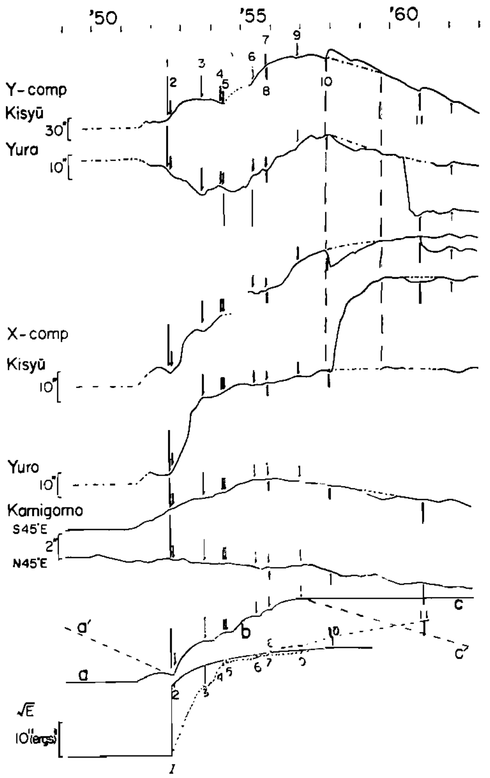

Fig. 5. Secular ground tilt in the X- and Y-directions at Yura, Kishū and Kamigamo, and the earthquake energy emitted as seismic waves.

Yura observatories tilted in the opposite directions during the period from earthquakes No. 1 to No. 5, having a good resemblance. After earthquake No. 5, the ground tilt at Yura turned its sense. Concerning this turing in the direction of the ground tilt at Yura, some discussions will be made later. Kishū reaches about three times that of Yura in the amount of the ground tilt. This will be understood well by taking into consideration the difference between the distance from the epicenter of these earthquakes to the observatories.

5. Formula of the earthquake energy emitted as seismic waves

In the lowest part in Fig. 5, the energy of the individual earthquake emitted as seismic waves is shown in the amount of its square root. The curve showing the summation of the energy can fully be expressed by the formula of $a+b \log t$. This formula also expresses the deformation of rocks in some compressional experiments. These observational and experimental facts offer us important information concerning the occurrence mechanism of this series of earthquakes.

6. Synthetical examination on the occurrence mechanism of the earthquakes

Let us synthetically examine the relation between the activity of the earthquakes of the Yoshino series and the crustal deformation in this district. The left side figure in Fig. 6 shows the surface distribution of the epicenters, and the lower figures show its projection on the section of the XX′- and YY′-directions. The XX′-direction in this figure differs from the XX′-direction defined in Fig. 3. That is defined by the line connecting the epicenter of earthquake No. 1 with that of earthquake No. 3, the YY′-direction being perpendicular to the XX′-direction. It is noteworthy that these two kinds of the XX′-directions show a good coincidence, and further, the epicenters of the earthquakes are distributed along the XX′-line. The right side figure in Fig. 6 shows the direction of an anticline axis in the neotectonic movement in the Kii Peninsula. It is also noteworthy that the direction of this anticline axis coincides with the XX′-direction. It is also noteworthy that the more southwards the hypocenter of the earthquake exists, the more steep the incline of the cone axis is.

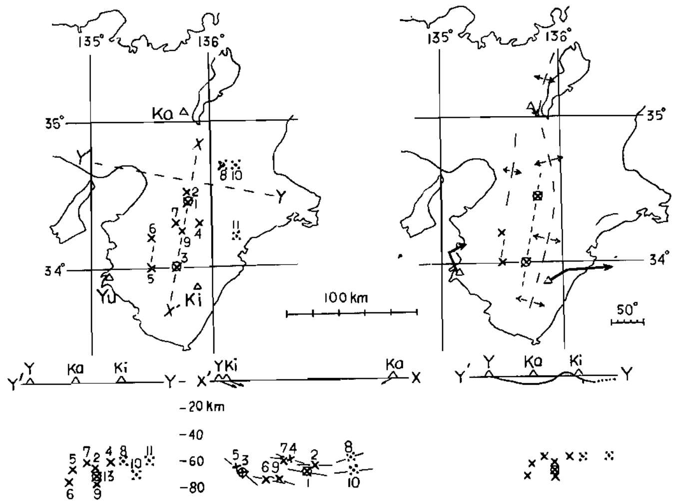

Fig. 6. Left: Distribution of the epicenters of the sub-crustal earthquakes which occurred in the Yoshino District.

Right: Anticline axis and vector diagrams of the secular ground tilt during the active period of the earthquakes.

Lower: Profile of the tilted ground surface and the vertical distribution of the hypocenters.

In Fig. 5, there is shown the secular ground tilt at the Kamigamo observatory situated in the northern part of Kyoto City. In this diagram, the anomalous ground tilt connected with the individual earthquake is not clear because the Kamigamo observatory is too far from the epicentral region. But, turning our attention to the secular change, it will be found that although it is monotonous till the middle of 1951, the ground tilt appears about one and a half years before the Yoshino earthquake, and further, its tendency resembles to the Y-component in the ground tilt at the Kishū observatory. This fact obliges us to suppose that the ground tilt as mentioned above covered the whole Kii Peninsula during five years from 1951 to 1956. The vector diagram of the ground tilt at the three observatories is shown in the right side figure in Fig. 6. The turning points of the vector diagrams in the figure correspond to the time of earthquakes No. 5 and No. 6, and these two earthquakes define another XX′-axis parallel to the main XX′-axis. From the existence of these two XX′-axes along which the earthquake epicenters distribute, and the mode of the crustal deformation observed at the three observatories, the following conclusions may be drawn: in the period from earthquake No. 1 to No. 4, the region of the anticline axis was being upheaved and both sides of the regions were subsiding; and after the time when earthquakes No. 5 and No. 6, which define another XX′-axis, occurred, the ground tilt at the Yura observatory turned its direction to coincide with that of Kishū. The profile of the maximum surface deformation in the YY′-direction, the situation relation between the Yura, Kamigamo, and Kishū observatories, and the position of hypocenters of the earthquakes are shown in the lower part of the right side figure in Fig. 6.

As mentioned formerly, if the formula of $a+b\ \log t$ actually expresses an experimental result in the compressive strain of rocks, it may naturally be concluded that the earthquakes of the Yoshino series would have some relation with the release of compressive strain energy. Taking into consideration the distribution of the hypocenters, the mode of deformation of the ground surface, the fact that the occurrence mechanism of all these earthquakes belongs to so-called cone-type, and some geological evidences, it is further concluded that the earthquakes of the Yoshino series might be caused by some intrusive force such as magmatic intrusion.

7. Summary

From the fact that the ground tilt connected with the sub-crustal earthquakes which occurred in the Yoshino District showed a similar mode in each case of the earthquakes, it is supposed that all these earthquakes were caused by the same earthquake-generating force, being considered to be a representation of the neo-orogenic force in the Kii Peninsula. Advancing our supposition farther, this force might be caused by some intrusive force such as magmatic intrusion. In this paper, the relation between the Ōdaigahara earthquake and the deformation of the crust has remained untouched. Some discussion will be made in due time on this problem.

Short History of Professor Eiichi NISHIMURA

The late Professor Eiichi Nishimura.

The late Professor Eiichi Nishimura was born on February 4, 1907, in Kyoto. He entered Kyoto University in 1928, after graduating from Third High School in the same year. In 1931, he graduated from Kyoto University, getting a degree of Bachelor of Science in the special study of geodesy and seismology. Throughout a long period of over thirty years from that time, Professor Nishimura exerted himself in Kyoto University both for the development of research work and of teaching.

The research fields of Professor Nishimura were extremely wide, covering geodesy, seismology, volcanology and geomagnetism. We can say, therefore, that his interests and research works extended over almost all problems related to the solid earth. It seems convenient to divide Professor Nishimura's research activity into four periods. For about five years after his graduation in 1931, he studied and mastered the fundamental thought and method concerning how to attack the geophysical problems in various fields above-mentioned, under the guidance of the late Honorary Professor T. Shida, the Honorary Professor M. Hasegawa and Honorary Professor K. Sassa. This experience, the cooperative work with these excellent scholars in their respective fields, is believed to have made a great contribution to Professor Nishimura's own research activity in later years. Also in this period he studied the activity of the Volcano Aso in relation to the Volcanic tremors.

In 1936, Professor Nishimura was appointed an assistant at the Geophysical Institute. The nine years therefrom, up to 1945 when he was promoted to an assistant professor, should be called the second period, in which Professor Nishimura devoted himself to the problem of the earth tides. The articles successively worked out in this period, "On Earth Tides", No. 1 to No. 7, are certainly imperishable contributions, and in fact a value of "Diminishing Factor", obtained from his superior observations in former Manchuria in 1940 and 1941, has been cited as "Nishimura's value" by many investigators in the world. By virtue of this work, he was early recognized all over the world as one of the authorities in this field. The degree of Doctor of Science was conferred on him in 1942.

He was appointed assistant professor in the Geophysical Institute in 1945, and professor of geodesy and seismology in 1951. We may call the 16 years from 1945 to 1961 the third period of Professor Nishimura's career. He was extremely busy and active in this period, both in research work and in education. On the one hand, he was an excellent teacher, more than twenty young research scholars having been brought up under his guidance and direction in various fields of geodesy, seismology and geomagnetism. This fact may suggest Professor Nishimura's broad outlook and superior ability over wide areas of geophysics. On the other hand, Professor Nishimura energetically guided the research works in his own laboratory in cooperation with his colleagues and staff members. These works are ultimately related to a final problem, namely, the forecasting of earthquake-occurrence. Professors Sassa and Nishimura certainly were two pioneers in the study of this problem, which is particularly serious for Japan. They have bravely pushed forward this difficult and troublesome work. The first station to observe the crustal deformation was founded early in 1937, for the purpose of detecting any relation between the crustal deformation and earthquake-occurrence. Their efforts were steadily continued, bringing about many fruitful results. Now, stations of this kind amount to more than twenty and many interesting phenomena have been found out concerning the above relation. The so-called "Research Group for Earthquake-Forecasting Project" established in 1961 by the seismologists and geodetists in Japan was greatly indebted to these two professors for its realization.

The last three years, from 1961 to 1964, were a period in which Professor Nishimura's efforts were directed toward the application of fundamental works so far carried out on the earthquake-occurrence to a realization movement. First, Professor Nishimura made every effort for the establishment of the above Research Group as one of the most powerful promoters. On the other hand, he asserted the necessity for international collaboration to develop the study of earthquake-occurrence. His attempts were set in the right direction, when in 1962 he visited Central and South America and promised to cooperate in the observation of earthquake and crustal deformation with the researchers in three countries, Chile, Peru, and Mexico. Unfortunately Professor Nishimura did not live to see the commencement of this plan, but we believe this project will be continued and successfully carried out by his successors.

During the same years, a tendency of collaboration between Japan and the United States on various problems in seismology and geodesy had become stronger and stronger. The first conference by the top-class researchers in both countries regarding the foretelling of earthquake-occurrence was planned to be held at Kyoto University on March 19, 1964. It is to be greatly regretted that, just on the same day, Professor Nishimura passed away without seeing the meeting which had been one of his greatest hope.

Professor Nishimura held many official posts and has a member of many committees. In Kyoto University, he was a member of the Council of Kyoto University, Director of Disaster Prevention Research Institute, Director of Abuyama Seismological Observatory, Director of Aso Volcanological Laboratory and Director of Kamigamo Geophysical Observatory, he was a member of the Geodetic Commission, and the Committee of Geophysical Research Connection in Science Council of Japan. Thus, Professor Nishimura was one of the leaders in Japan not only in seismology but also generally in geophysics, and moreover, his great activity had been strongly counted upon for the development of international interchange and collaboration.