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On Some Destructive Earthquakes Observed with the Tiltmeter at a Great Distance

By Eiichi NISHIMURA

Abstract

This article is intended as introductory to subsequent papers in this Bulletin. The purpose and method of observation with the tiltmeter, the extensometer, the magnetic variometer and other instruments are briefly described, along with a short account of each observation station. In addition, an unexplainable phenomenon of ground-tilt accompanying some destructive earthquakes of a great distant origin from the tiltmetric observation station will be discussed.

1. Introduction

The annual damage to human life and property caused by various natural disasters, such as earthquakes, typhoons, floods, coastal storms, volcanic eruptions, land-slides, land-subsidence and other is enormously large in our country. Among them the damage caused by destructive earthquakes is the most horrible and fatal becauses of its great violence and unforeseen occurrence. There are two ways to reduce earthquake-damage: the one is the research for and construction of low cost earthquake-proof buildings; the other is seeking the phenomena by which the occurrence of earthquakes could be foretold. The former belongs to the field of seismological, architectural and civil engineering, and the latter is an important research object of modern geophysical seismology.

Among the various phenomena observed in the epicentral region after the occurrence of destructive earthquakes, the upheaval and subsidence of the ground is the most conspicuous. And it has also been

observed by repetition of precise levelling that this sort of ground movement in some cases precedes the occurrence of earthquakes. In these cases the continuous observation of the ground movement with suitable instruments may certainly serve the purpose of foretelling earthquake-occurrence.

The first chapter of the research history of observation with the tiltmeter in the Geophysical Institute of Kyoto University dates from 1910. The observation of earth tides and crustal deformation with the tiltmeter of v. Rebeur-type was made by the late Prof. T. Shida at the underground room of the Kamigamo Geophysical observatory during the epoch of 1910 to 1911. [1912] The same instrument was used at the underground room of the Aso Volcanological Laboratory by K. Sassa [1936] to observe the tilting motion of the ground in connection with the eruption of Volcano Aso during the period of 1932 to 1934. Since 1937 various observations at several places have been made with many sets of tiltmeters with horizontal pendulums of the Zöllner suspension type, these being twenty sets of instruments at the beginning and forty at present. Most of the papers concerning these tiltmetric observations during the long period between 1937 and 1953 were published in Japanese, the few English papers being as follows; E. Nishimura [1950], K. Sassa and E. Nishimura [1951], K. Hosoyama [1952], E. Nishimura and K. Hosoyama [1953].

The observation of extension and contraction of the ground was begun in 1942 with the extensometer of Sassa type, and since then extensometric observation have been made at several places. [K. Sassa, I. Ozawa and S. Yoshikawa, 1952] and [I. Ozawa, 1952]. Observation with the tiltmeter of mercury type was begun in 1949 and twenty sets of mercury tiltmeter are now in operation at several places. [K. Hosoyama, 1953] Ten sets of the variometers of geomagnetic declination have also been installed at several places since 1946, and the concurrent observation with the tiltmeter, the extensometer and the declinometer have been made at several places to detect the deformation and state change of the earth's crust related to the occurrence of earthquake. [J. Miyakoshi, 1953] Recently five sets of highly sensitive gravitymeter of the Ichinohe type were set up at five stations and used concurrently with the other instruments [T. Ichinohe, 1951]. These research observations were made under the auspices~~es~~ of the Geophysical Institute of Kyoto University, and have recently been carried out jointly with the Disaster Prevention Research Institute of Kyoto University.

With regard to the detailed description of the construction and function of each instrument, and its method of operation, the respective original papers may be referred to. And a short review of some significant results obtained from these research observations may be mentioned here. Research of this kind is generally divided into two branches, the

one being on the earth tides and its allied phenomena, and the other on crustal deformation and changes in geophysical element relating to the occurrence of destructive earthquakes. On earth-tides Shida [1912] fully discussed for the first time the secondary effect of ocean tides and obtained a reasonable value for the elasticity of the earth's upper mantle. From tiltmetric observations in Manchuria, an accurate value for the diminishing factor of primary effects uninfluenced by ocean tides was estimated by Nishimura [1950], and, on the other hand, a time variation for the elasticity of the earth's crust was suggested from the change of observed amplitude of deformation of the ground by the tidal load of the neighbouring ocean. Sassa, Ozawa and Yoshikawa [1952] measured directly, for the first time, the value of l (Shida-number) and discussed the tidal strain of the earth. A highly sensitive gravitymeter of nearly 10^{-10} g/mm/4m was devised by Ichinohe [1951] and the detailed investigation of the tidal variation of gravity and the value of h and k (Love-number) will soon be published.

On the geophysical phenomena connected with the occurrence of earthquakes, the minute but characteristic tilting motion of the ground which preceded by several hours the occurrence of three destructive earthquakes was observed and reported by Sassa and Nishimura [1951]. Nishimura discussed the correlation between the time variation of the crustal elasticity and the seismic activity of the neighbouring area. [1950] The secular tilting motion of the ground as observed at the station in the epicentral region of the destructive earthquake was investigated in some detail by Hosoyama [1952], and briefly reported by Nishimura and Hosoyama [1953]. In these papers it was reported that the large ground-tilt which appeared several months before the occurrence of an earthquake and continued its tilting motion downwards towards the epicenter, and then turned its direction after the occurrence, were observed in some cases of destructive earthquakes.

This sort of research necessitates a long series of continuous observation and a ceaseless effort, and in the case of earthquake prediction especially, these conditions become more severe. It was by experience found that any phenomena, when exists, foretelling the occurrence of a destructive earthquake should be observed at the observation station within about fifty kilometers distance from the epicenter. Under these circumstances it is very difficult to obtain in every case the minute foretelling phenomena of a destructive earthquake about to occur somewhere. Success depends on the denseness of the net of the observation station, duration of observation, diligence of the observer, and on chance. For this reason the past twenty years of research observation in this field is considered to be only a small portion of a very long and persistent process of research. In the following will be given a short account of some papers contained in this Bulletin, (No. 6), which all

concern the above described research project.

The second article entitled ~~entitled~~ "On a Mercury Tiltmeter and its Application" by K. Hosoyama describes a mercury tiltmeter newly designed by him and gives a comparison of the functions of two tiltmeters of the horizontal pendulum type and the mercury type. In the cases of two destructive earthquakes the characteristic tilting motions of ground observed several months before earthquake occurrence are in some detail reported. The third article entitled "On the Local and Anomalous Change of Geomagnetic Declination" by J. Miyakoshi is a paper which reports the present state of observation with the variometer of geomagnetic declination. In it a local and anomalous change of declination observed at the station in the epicentral area is in some detail reported. The fourth article entitled "Investigation of the Structure of the Earth's Crust in Relation to Local Earthquakes (Preliminary)" by A. Kamitsuki and T. Mikumo, is a preliminary report of the series of observations of local earthquakes and after shocks of the great earthquakes with short period seismographs of high magnification. This series of research is intented to get a clear picture of the fine structure of the earth's crust from the analysis of seismometric observation of a host of local earthquakes of frequent occurrence or of the aftershocks of a great earthquake. From this it is expected that reliable knowledge of the structure and condition near the hypocenter of destructive earthquake which is generally situated at the bottom of the earth's crust, would give us a key unveiling the secret of the energy and mechanism of occurrence of destructive earthquakes.

The last article entitled "The Measurement of Radioactivity At and Below the Ground Surface" by Y. Itō describes a series of measurements of radioactivity taken at the ground surface and in a deeply seated underground room. The measurements were made as a trial observation of research for detecting any anomalous distribution of radioactivity of ground at the place geologically disturbed, or any time change, if existing, at the place near the epicenter of a destructive earthquake or near a volcanic crater in violent eruption. It is considered that each article is a relatively small brick, however fragmental, serving in the construction of a huge pyramid,– the solution of the essential problem of earthquake.

2. Observation Stations

Since 1937 many points were selected as observation stations for the tiltmetric, extensometric and geomagnetometric investigation. Under various circumstances some of them were abandoned after a short period of observation, some have been kept to the present time and a few abandoned have been re-opened as active stations after several years'

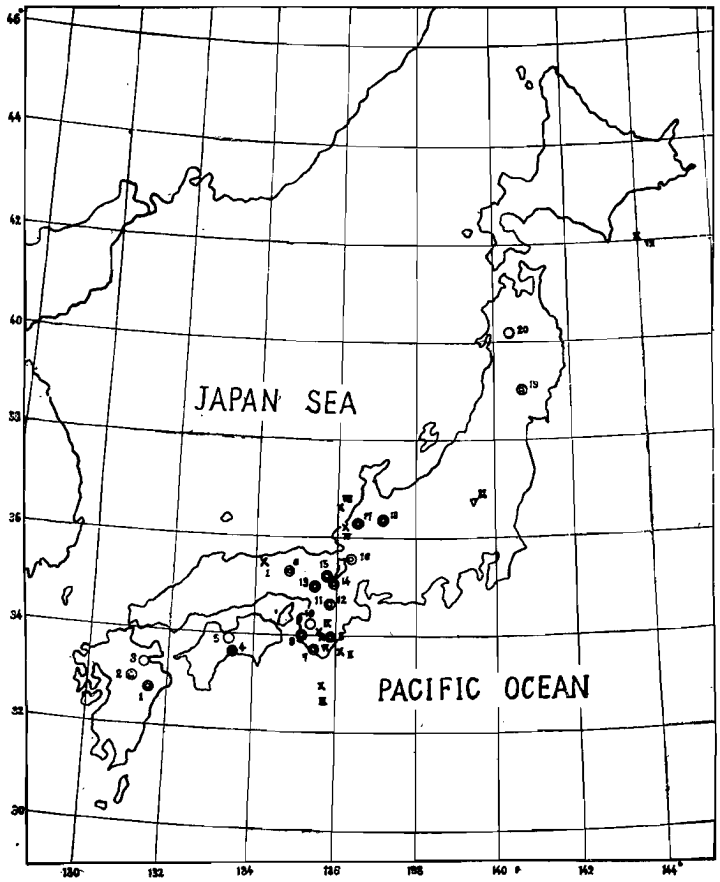

Fig. 1 Observation Stations.

A double circle denotes an active station, a single circle a station in suspension, and a cross the epicenter of destructive earthquake in the recent ten years.

1-Makimine, 2-Aso, 3-Beppu, 4-Kôchi, 5-Bessi, 6-Ikuno, 7-Susami, 8-Kishyu, 9-Yura, 10-Iimori, 11-Ide, 12-Tamamizu, 13-Abuyama, 14-Osakayama, 15-Kamigamo, 16-Tsuchikura, 17-Ogoya, 18-Kamioka, 19-Hosokura, 20-Osarizawa; I-Tottori Earthq. (Sept. 10, 1943), II-Tônankai; Earthq. (Dec. 7, 1944), III-Nankaido Earthq. (Dec. 21, 1946), IV-Fukui Earthq. (June 28, 1948), V-Imaichi Earthq. (Dec. 26, 1949), VI-Nanki Earthq. (Apr. 26, 1950), VII-Tokachi-Oki Earthq. (Mar. 4, 1952), VIII-Daishoji-Oki Earthq. (Mar. 7, 1952), IX-Yoshino Earthq. (July 18, 1952).

interruption. In Figure 1 the observation stations are shown, in which the stations active at present are denoted by a double circle, and the stations in suspension of observation are denoted by a single circle. As the amount of change to be observed is very minute and the disturbing

effect caused by meteorological change is very large in case of the observation at a shallow seated room, nearly all observation rooms are deeply seated below the ground surface and some of them are actually in the adits of metal mines. In the following each station is in some detail described and in it the following abbreviations may be used; T. H. (Tiltmeter with horizontal pendulum of Zöllner suspension), T. M. (Tiltmeter of mercury), T. W. (Tiltmeter of water tube), E. S. (Extensometer of Sassa's type), M. D. (Variometer of geomagnetic declination), M. Z. (Variometer of geomagnetic vertical intensity), G. I. (Gravitymeter of Ichinohe's type).

1. *Makimine*

(place) In the adit of the Makimine Copper Mine; (position) 131° 27′E, 32°37′N; (height from sea level) 130m high; (depth below the ground surface) 165m deep; (geological formation of the ground rock) clay slate of the Chichibu Palaeozoic system; (epoch of observation) 1942–the present time; (names and numbers of set of the instruments for observation) T. H. (4), E. S. (1), M. D. (2).

2. *Aso*

(a) *Kenkyusho*

In the adit of the small hill of the Aso Volcanological Laboratory and distant 7km W from the volcanic crater; 131°00′E, 32°53′N; 540m high; 22m deep; Aso volcanic rock; 1937–1940 (scheduled to re-open in 1953); T. H. (2)*.

(b) *Senrigahama*

In the pit of the mountain ridge and distant 3km W from the volcanic crater; 131°03′E, 32°53′N; 1130m high; 10m deep; Aso volcanic rock; 1937–1940; T. H. (2).

(c) *Miyazi*

In the pit of the plain and distant 8km N from the volcanic crater: 131° 07′E, 32°57′N; 520m high; 3m deep; Aso volcanic ash; 1937–1940; T. H. (2).

(d) *Hondo*

In the underground room and distant 800m SW from the volcanic crater; 131°05′E, 32°53′F; 1150m high; 1m deep; 1937–1943 and on May, 1953, re-opened; T. H. (2), M. D. (1), M. Z. (1), G. I. (1).

3. *Beppu*

Six points in the City of Beppu were selected to observe the anomalous difference of the tilting motion of the ground deformed by the tidal load of water of the Beppu-Bay; nearly 131°30′E, 33°16′N; 4m~110m high; 2m~6m deep; alluvial sand or volcanic lava mud; 1937~1939; T. H. (8).

4. *Kōchi*

In the adit of the hill; 133°32′E, 33°34′N; 10m high; 40m deep; Paleozoic system; 1949–the present time; T. H. (2), M. D. (1), E. S. (1).

5. *Bessi*

In the adit of the Bessi Copper Mine; 133°19′E, 33°52′N; 660m high; 750m deep; Chlorite-schist; 1949–1951; T. H. (2), E. S. (1), M. D. (1).

6. *Ikuno*

In the adit of the Ikuno Copper Mine; 134°50′E, 35°10′N; 440m high; 719m, 326m, and 237m deep; Liparite; 1943–the present time; T. H. (6), E.S. (1), M. D. (2), G. I. (1).

7. *Susami*

In the cave of the slope of the rock hill; 135°30′E, 33°32′N; 5m high; 10m deep; Paleogene, 1943–the present time; H. M. (2).

8. *Kishyu*

In the adit of the Kishyu Copper Mine; 135°53′E, 33°52′N; 90m high; 60m deep; Tertiary sandstone and shale; 1947–the present time; T. H. (2).

9. *Yura*

In the U-shaped adit of the rock mountain; 135°07′E, 33°57′N; 10m high; 30m deep; Mesozoic sandstone and shale; 1951–the present time; T. H. (2), T. M. (2), M. D. (1), G. I. (1)*, a gravitational torsion balance and a magnetic torsion balance.

10. *Iimori*

In the adit of the Iimori Copper Mine; 135°26′E, 34°15′N; 220m high; 40m deep; Chlorite-schist; 1943–1945; T. H. (2).

11. *Ide*

In the adit of the old copper mine; 135°49′E, 34°48′N; 150m high; 15m deep; Paleozoic system; 1951–the present time; T. H. (2), E. S. (6).

12. *Tamamizu*

In the adit of the Taga Manganese Mine; 135°49′E, 34°48′N; 250m high; 30m deep; Paleozoic system; 1948–1951; T. H. (2).

13. *Abuyama*

In the adit of the rock mountain of Abuyama Seismological Observatory; 135°34′E, 34°52′N; 200m high; 20m deep; Paleozoic system; 1938–the present time; T. H. (2), T. M. (2), E. S. (3), M. D. (1), G. I. (1), a gφemagnetic variometer of induction type.

14. *Ōsakayama*

In the old tunnel of the railways; 135°51′E, 34°59′N; 130m hight; 150m deep; Paleozoic system; 1947–the present time; T. H. (2), T. W. (4), E. S. (6), G. I. (1), a gravitational and a magnetic torsion balance.

15. *Kamigamo*

One in the adit of the rock mountain and another at the underground of Kamigamo Geophysical Observatory; 135°46′E, 35°04′N; 190m high; 10m and 9m deep; Paleozoic system; 1937–the present time; T. H. (2), T. M. (2), M. D. (1), G. I. (1)*.

16. *Tsuchikura*

In the adit of the Tsuchikura Copper Mine; 136°18′E, 35°36′N; 400m high; 170m deep; Paleozoic system; Apr., 1953–the present time; T. H. (2)*, M. D. (1), a magnetic torsion balance and a gravitational torsion balance,* G. I. (1)*.

17. *Ogoya*

In the adit of the Ogoya Copper Mine; 136°33′E, 36°17′N; 210m high; 300m deep; Tertiary Tuff; 1948–the present time; T. H. (2), T. H. (6)*, T. M. (8), E. S. (1), M. D. (1).

18. *Kamioka*

In the adit of the Kamioka Zinc-Lead Mine; 137°19′E, 36°21′N; 920m high; 800m deep; Gneiss; 1952–the present time; T. H. (2), G. I. (1)*, M. D. (1)*, M. Z. (1)*.

19. *Hosokura*

In the adit of the Hosokura Zinc-Lead Mine; 140°54′E, 38°48′N; 130m high; 160m deep; Tertiary system; 1944–the present time; T. H. (2), M. D. (1).

20. *Osarizawa*

In the adit of the Osarizawa Copper Mine; 140°45′E, 40°11′N; 320m high; 300m deep; Tertiary tuff and shale; 1944–1946; T. H. (2), E. S. (1), M. D. (1).

Remarks: a star (*) suffixed to the name of instrument shows the instrument scheduled to be set up in 1953.

3. Far distant earthquakes observed with the tiltmeter

In the above described observation with the tiltmeter of the horizontal pendulum of Zöllner suspension, many far distant earthquakes of large magnitude have been recorded in the tiltgrams. They are very distinctly recorded as the both periods of the horizontal pendulum and the seismic wave are nearly equal, and moreover the pendulum has no damper. All earthquakes of sufficiently large magnitude which occurred anywhere on the earth, even at the antipodal country will be caught by the tiltmeter as the longly continued oscillatory motion of the pendulum. Relative to such oscillatory motion of the pendulum caused by far distant earthquakes, some interesting phenomena observed in the tiltgrams may be reported.

Generally the tiltgram does not show any special change before and after the oscillatory motion of the pendulum caused by the arrival of

the distant earthquake, as shown in the upper two tiltgrams of Figure 2. But on some occasions the minute but peculiar tilting motions of the ground are observed shortly before (as shown in the lower tiltgram of Figure 2) or after oscillation by the distant earthquakes. On the other hand, the rapid or somewhat slow changes of the zero-point of the tiltmeter in the middle of the oscillation by the distant earthquake, are also recorded. These facts had been noticed early, but explanation had been postponed until such a time when sufficient data would have accumulated, especially the data of such tilting motions as concurrently observed at several observation stations. In recent years a number of observation stations has obtained a fair increase in data, and some examples of this peculiar tilting motion, though still insufficient in number, were obtained concurrently at several observation stations. Hence, in the following, a short account of the phenomena will be given as a plain report on the observed fact. But in this article the problem of the

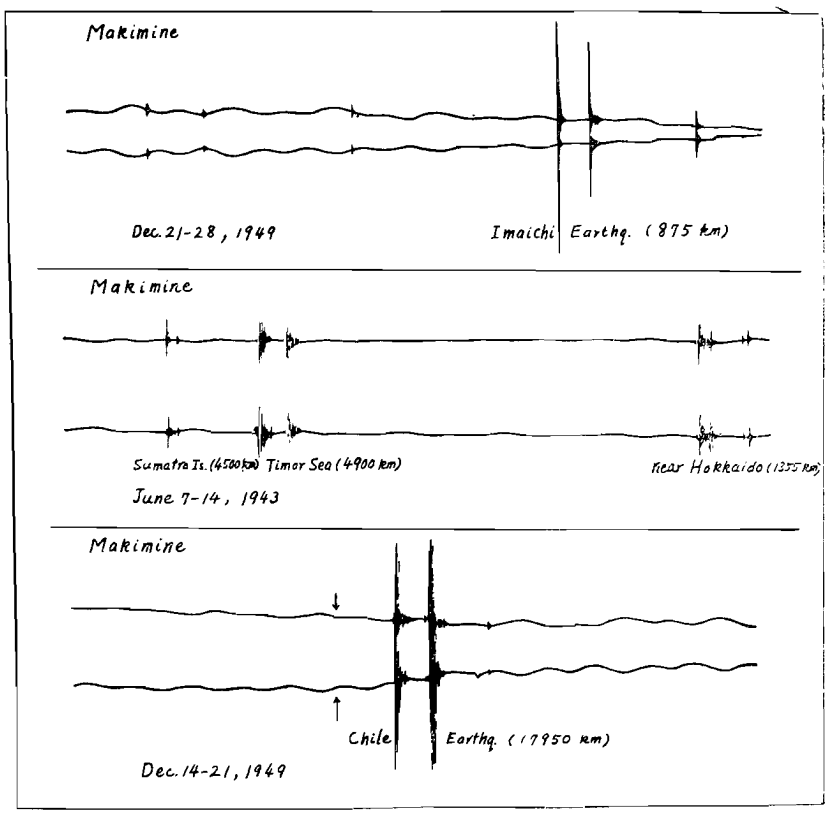

Fig. 2 Examples of tiltgrams disturbed by the far distant earthquakes at Makimine Station.

rapid or slow change of zero-point of the tiltmeter in the middle of the oscillation is not treated, as there are various cases in which the zero-displacement is caused by any seismically mechanical shock of the tiltmetric instrument and in other case it is more reasonable to consider the zero-displacement as caused by a real tilting motion of ground. As the problem is very interesting and important, a conclusive report will be published at an another opportunity after the sufficient accumulation of observed data.

(a) The Case of an Earthquake in Tibet, August 18, 1952.

The destructive earthquake occurred in Tibet (91°.5E, 30°.5N) on August 18, 1952 with the seismic magnitude of 7½, in Pasadena Scale. The seismic oscillations were recorded by the tiltmeters at the observation stations in Japan, the tiltgrams thus obtained being shown in Figure 3. In it three tiltgrams at Ikuno, Kamigamo (distant 4130km from the epicenter) and Ogoya are inserted to show a minute ground-tilt of about 0.1″ which preceded the arrival of seismic wave by about 10 hours. Their directions and amounts of downward tilting motion are indicated as the arrows on the map of the right side of Figure 3. The numerals annexed to the stations mean the numerical values of hours in which the appearance of the ground-tilt concerned preceded the arrival of seismic wave.

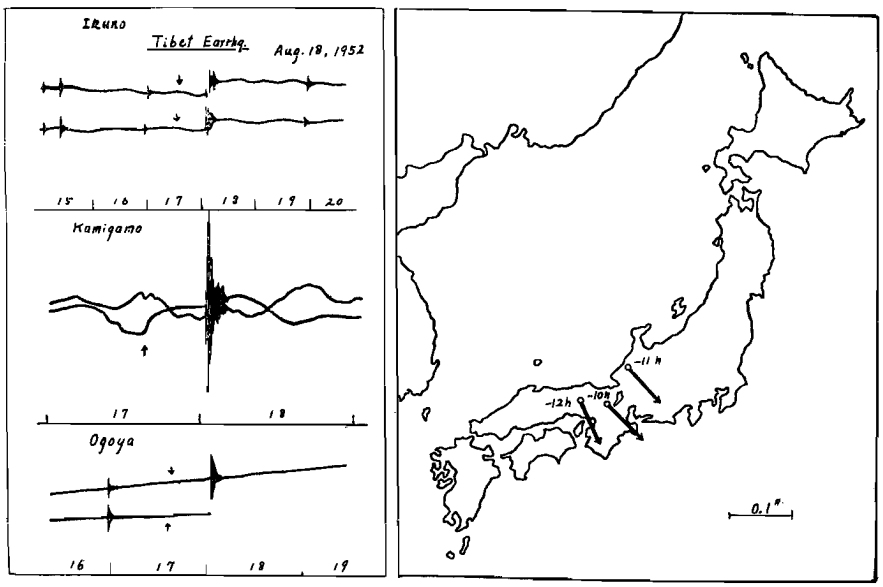

Fig. 3 Tiltgrams disturbed by Tibet Earthquake on August 18, 1952.

(b) The Case of an Earthquake in The East Indies, February 14, 1952.

The destructive earthquake occurred in The East Indies, (126°.5E, 7°.5S) on February 14, 1952 with the seismic magnitude of 7¼. In Figure 4, two tiltgrams observed at Makimine and Kamigamo (distant 4600km from the epicenter) are inserted to show the minute but sharp ground-tilt amounting to about 0.1″ in the downward direction of SE. They preceded the arrival of seismic waves by about 3 hours and their change are vectorially indicated on the right side of Figure 4.

(c) The Case of an Earthquake in Formosa, October 22, 1951.

The destructive earthquake occurred in Formosa (122°E, 24°N) on October 22, 1951 with the seismic magnitude of 7. Four tiltgrams obtained at Ikuno, Makimine, Ogoya and Kamigamo (distant 1800km from the epicenter) respectively are shown in Figure 5. In this case the ground-tilt of about 0.1″ preceded in a somewhat longer time of more than 20 hours the arrival of seismic waves.

(d) The Case of an Earthquake near The Kurile Islands, June 23, 1952.

The large earthquakes occurred near The Kurile Islands (153°.5E, 46°N) on June 23, 1952 with the seismic magnitude of 7. In this case the minute ground-tilts of about 0.05″ were clearly observed soon after the tail of the tiltmetric oscillation at four stations of Ikuno (distant 2000km from the epicenter), Makimine, Kishyu and Ogoya. The tiltgrams

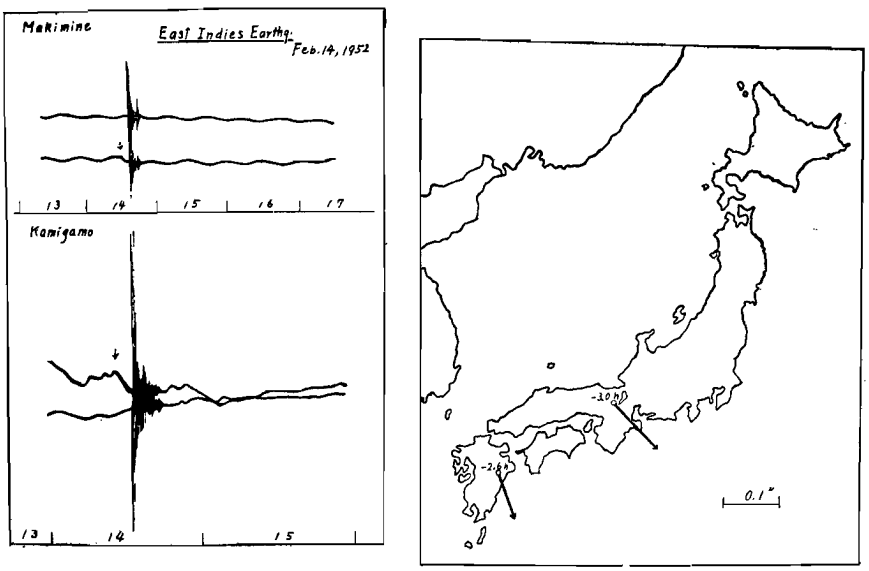

Fig. 4 Tiltgrams disturbed by East Indies Earthquake on February 14, 1952.

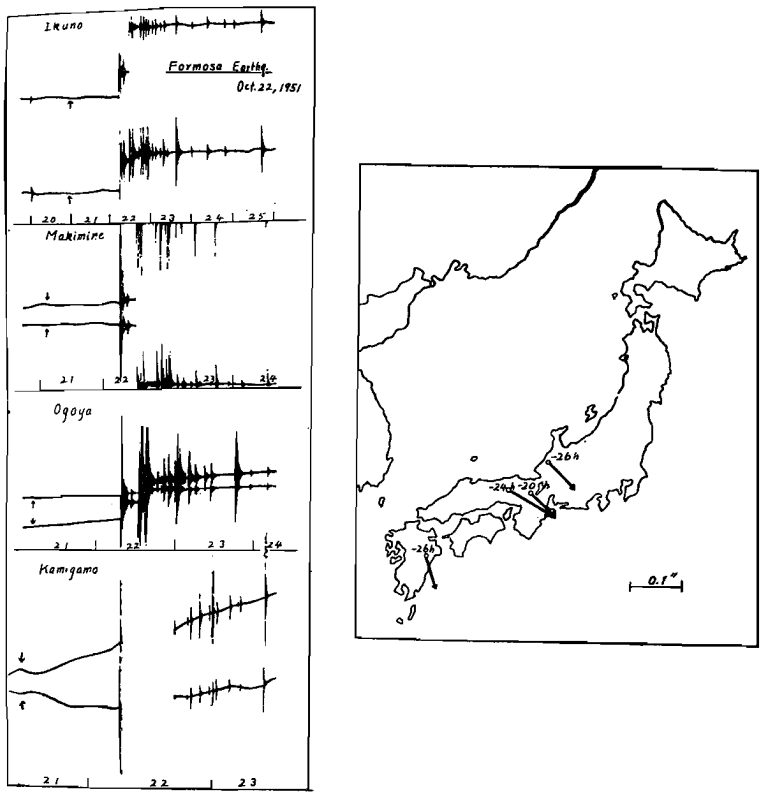

Fig. 5 Tiltgrams disturbed by Formosa Earthquake on October 22, 1951.

concerned are shown in Figure 6 with the vectorial representation of these ground-tilts. It is to be remarked that the changes of ground-tilt in question are recorded as considerably magnified by the effect of the time coincidence with the earth's tidal deformation.

(e) The Case of an Earthquake in Costa Rica, September 9, 1952.

The destructive earthquakes occurred near Coast of Costa Rica (84.°5W, 9°N) on September 9, 1952, with the seismic magnitude of 7. In this case a very slight but characteristic ground-tilt was observed at the three stations of Ikuno, Yura and Kamigamo (14500km distant from the epicenter) which preceded the arrival of seismic waves by about 5 hours. As shown in Figure 7 it is characteristic because the ground-tilt concerned showed two minor pulsatory motions of 0.″01–amplitude and 1.3^h–period, and moreover interesting because time of appearence of

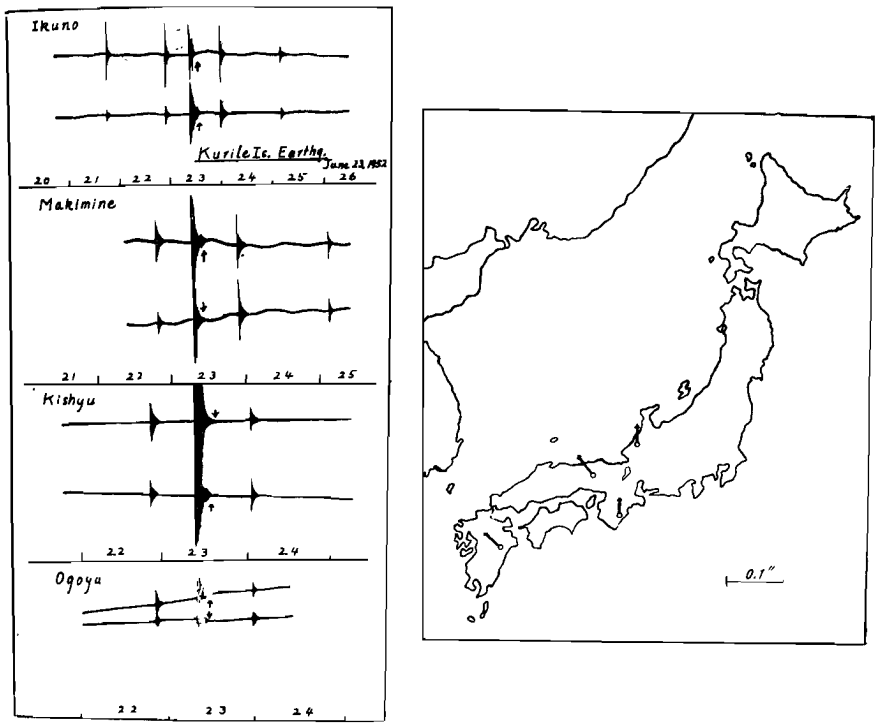

Fig. 6 Tiltgrams disturbed by Kurile Islands Earthquake on June 23, 1952.

these pulsations coincides exactly with that of the geomagnetic disturbance of bay-type amounting to 8′ and lasting for about 2.2 hours. Though it is a question as to whether this concurrent appearance of geomagnetic variation and ground-tilt is by mere accident or not, its relation is an interesting subject for research and will be discussed in near future.

The above quotated earthquakes are examples of comparatively clear appearence of ground-tilt which are considered to be related to the arrival of far distant earthquakes. Besides these examples there are many cases which are less conspicuous or lacking records at more than two stations. On the reliability of connection of such ground-tilts with the arrival of far distant earthquakes of large magnitude, a brief argument should be mentioned. First, there is doubt that this connection is only apparent and the two really independent phenomena were concurrently observed by mere chance. To answer this question the observed data are far too insufficient in number, and this most essential point will be fully discussed in future after a sufficient accumulation of observed

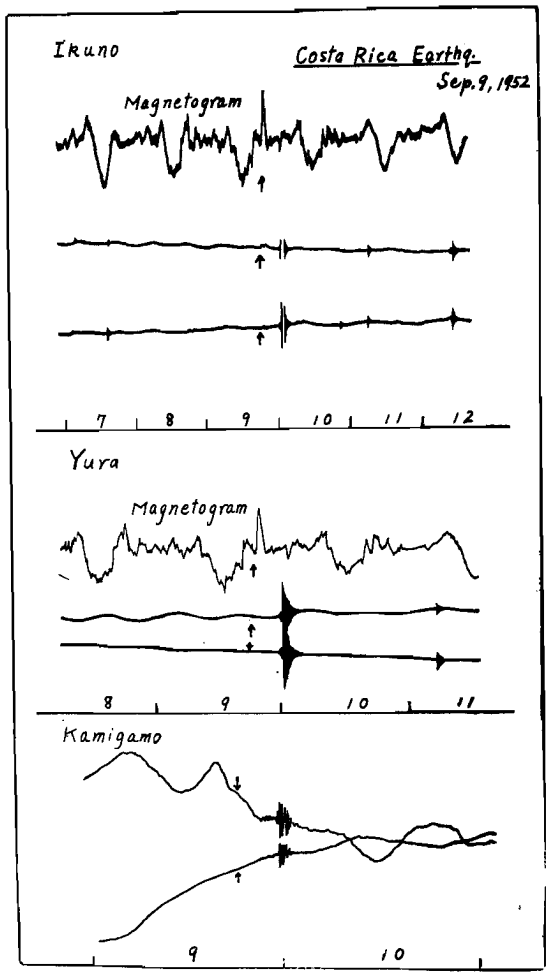

Fig. 7 Tiltgrams and magnetogram disturbed by Costa Rica Earthquake on September 9, 1952.

data of various cases. The next question is in the point that whether this minute change (until now provisionally referred to as the ground-tilt) of the tiltmeter connected with the distant earthquake lies in the tilting motion of ground or the direction change of plumb line. This point is also undeterminable at the present, because we have no tiltmeter which records separately the ground-tilt and change of plumb line. But recently it was ascertained, by the repetition of the precise determination of plumb line deviation of many stations, that change of several seconds in angle of direction of the plumb line may possibly be observed at the

stations in the epicentral region on the occurrence of great earthquakes. Considering these facts it is more reasonable to interpret this minute change of tiltmeter as direction change of plumb line rather than as the ground-tilt when we assume any connection of it with the arrival of seismic waves of destructive earthquakes which occurred far distant from the station of tiltmetric observation.

In conclusion, we have mentioned in this article some examples of peculiar phenomena observed with the tiltmeter, in which the minute change of the tiltmeter and the pendulum oscillation caused by the far distant destructive earthquake are concurrently observed as if they have a close connection. Although there remain many questions on the reliability of their connection, the phenomena contain many interesting problems which are to be urgently pursued and which will undoubtedly throw much light upon the solution as to the nature of earthquakes. And it might to be remarked here that the concerned minute changes of the tiltmeter in each example are all of the same direction, intensity and occurrence-time at all stations respectively in each case. Apart from the problem of connection with the distant earthquake, it is a very interesting that all tiltmeters show the same changes on so wide an area as several hundreds kilometers in length. Also in this point the minor fluctuation of geoid may conveniently be postulated for the explanation of the concerned minute changes of the tiltmeter.

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