Chapter 1. General View of a Cycle of Earth-Tiltings.

Undoubtedly in remote geological times upheavals and subsidences of land, or more generally speaking, earth-tiltings, took place on a much grander scale than in recent times. The exact

* Earthquake accompanied by pre-seismic topographical change.

relation between these changes and those that are going on at the present time is obscure. However, changes which took place in recent geological epochs are sometimes found to be closely related to those which have taken place during historical times. For instance, the Tertiary formation, which may be regarded as having commenced its upheaving movement since the Pleistocene, is for the the most part still continuing its movement in the same sense, so that severe shocks take birth there more frequently than in the older formations.

The writer now proposes to give a typical example of the phenomenon of earth-tiltings. Thanks to the generous grant accorded by the Imperial Academy, the writer in collaboration with Prof. N. Yamasaki, found it possible to spend some years in the study of this subject. In 1927, at our request, the Land Survey Department kindly took in hand the work of precise levelling along a route which had been laid some 33 years ago over an extent of 274 km. in the littoral of Etigo and the northern part of the province of Sinano.[1)]

On working out the results of the survey, Prof. Yamasaki noticed a very striking feature in connexion with the chronic or active tiltings of the crustal blocks that he has named the Nisikubiki block and the Kariha-Higasikubiki block. His communication reads as follows:

"Any tilted block bordered by active faults may naturally be called an active, tilted block. In most cases the faults are formed instantaneously with the tilting of land blocks, as has been so well observed in the recent great earthquakes of Kwanto, Oku-Tango, etc.

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1) See Fig. 2 and Table XII.

"On the other hand we may conceive of another form of tilting, which, instead of occurring suddenly, requires a long period of time. The writer therefore distinguishes two kinds of tiltings in accordance with the length of time occupied in the movement, namely, the acute and the chronic. The former is frequently found to be associated with earth disturbances, such as we have already mentioned, but the latter kind of movement can be determined only by accurate levellings over a long period of years.

"In such a young and vigorous structure, geologically speaking, as the Japanese Islands, one naturally expects to find examples of chronic tiltings, but no such examples were forthcoming until quite recently when the writer came across a typical example by means of precise levellings that were taken along the coast of the Sea of Japan.

"Before taking up the results of the levelling we shall do well to take a momentary glance at the topography and geology of the district concerned. As the accompanying map shows, to the west of this district is the lofty Hida range, which, with its many peaks reaching 3,000 meters in altitude, is the highest mountain range in the main island of Japan. The formation is mostly pre-Tertiary with old eruptive rocks, and studded here and there with young volcanoes. It is remarkable that this range forms a gigantic scarp to the east, at the foot of which lies the tectonic valley of the Himegawa River and the depressed trench of Matsumoto-daira. The northern end of the range terminates abruptly in the precipitous cliff of Oyashirazu on the Sea of Japan.

"Sharply marked off by these tectonic lines, the district to the east of that which has just been described offers quite a different aspect, both geologically as well as in its land forms,

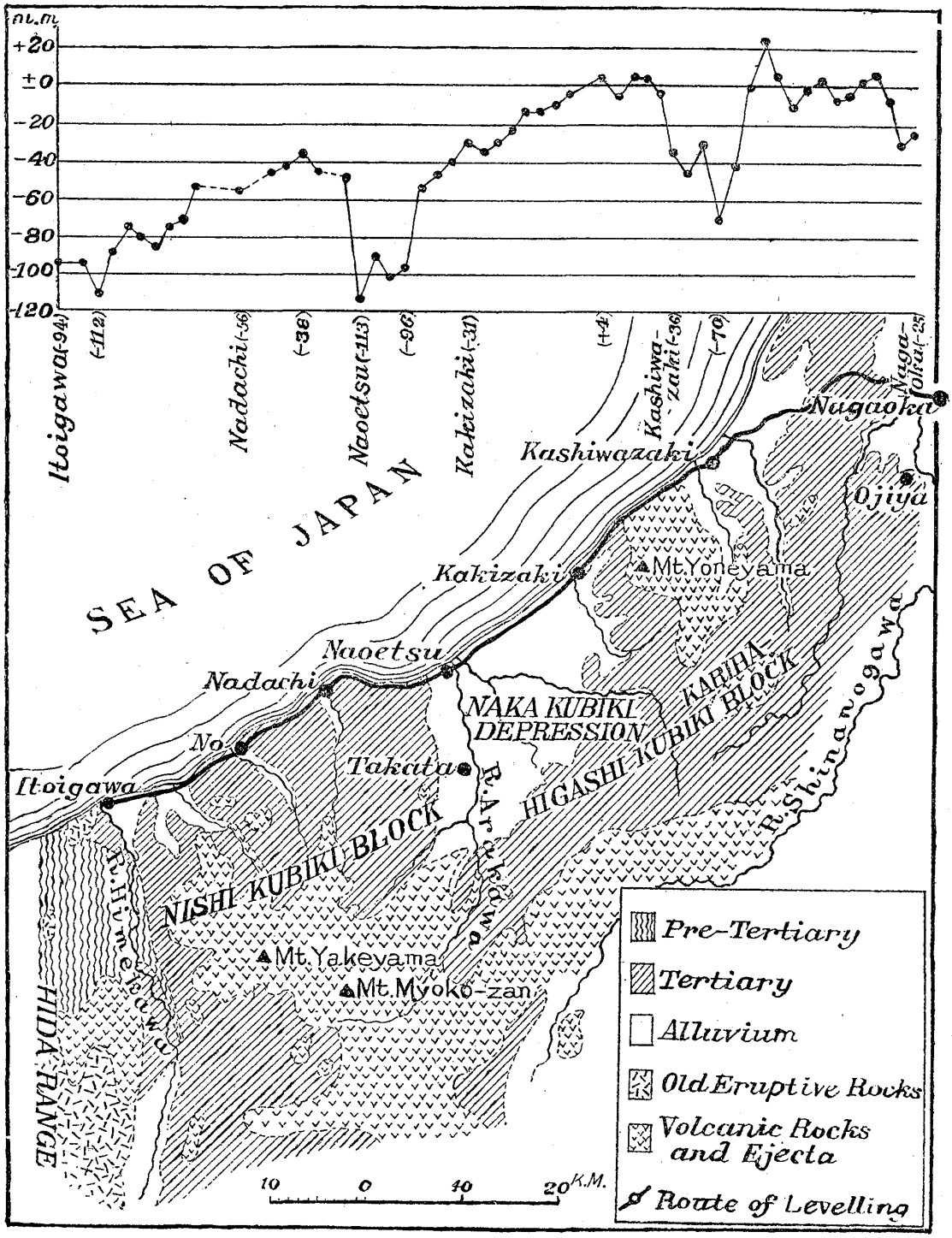

Fig. 1. The Geology of West Echigo and the Results of Levelling along the Coast in 1927. (after Yamasaki)

Here we find mostly oil-bearing marine formations of the Tertiary period through which the younger volcanic rocks were erupted, forming the gigantic cones of Myoko-zan, Yakeyama, etc. The general trend of the strike of this Tertiary strata is SW-NE.

"The Tertiary terrains in the coastal region are separated into two parts, the Nishikubiki block and the Kariha-Higashikubiki block, by a deep sunken embayment of lowland called the Nakakubiki depression. The Nishikubiki block is sharply truncated on its eastern side by a fault scarp in a N-S direction, in much the same way that we have described for its western side. The topography of the Tertiary hills of this block does not show any peculiarities, especially in their southern part, where they are mostly covered by young lavas and other ejectamenta. On the other hand the Kariha-Higashikubiki block to the east consists of parallel ranges of Tertiary hills of altitudes varying between 200–600 metres on the average. The trend of the ranges coincides with that of the strike of the strata. The western ends of these hills sink into the lowland of the Nakakubiki depression, while their eastern sides are cut off by the longitudinal valley of the River Shinano-gawa. Yoneyama, a young volcano prominent in this region, rises sheer from the coast and does duty as an ideal landmark for mariners.

"Local earthquakes have often troubled these regions. History records 1614, 1666 and 1751 as the years when the coastal districts received these unwelcome visitations—and they were very severe. The regions bordering the river Shinano-gawa had the unenviable distinction of being the epicentres of several severe earthquakes in the years 841, 1714, 1718 and 1828; while that of 1847 is well-known as the great Zenkozi Earthquake.

The disturbances have continued to recent times and some strong shocks were felt in 1888, 1889, 1890, 1897, and 1918.

"The precise levelling of these regions was carried out for the first time in 1894. In comparing the results of that survey with those of the new levelling which were repeated some 33 years later, it is interesting to note the change of level and the mode of disturbance in both the Nishikubiki and Kariha-Higashikubiki blocks. With the exception of a few bench-marks near Kujiranami in the latter block which have arisen a mere 3–4 mm, both blocks have subsided since the previous levelling, the differences varying between 2 mm and 113 mm. A remarkable fact is that in each block the amount of subsidence diminishes as we go from west to east, reaching its minimum near the eastern end of the block, where it suddenly attains its maximum, making a steep gap in the line as shown at the top of the figure. In the Nishikubiki block it is −94 mm at the western end, gradually decreasing to −38 mm in the eastern end, but in Naoetsu along the old fault line it increases abruptly to −113 mm. In the Kariha-Higashikubiki block it begins with −96 mm in the west and becomes 4 mm in the east, and then increases suddenly to −70 mm. Obviously the movement of both of these blocks is a subsidence, and while the rate was not uniform for each bench-mark, it amounted to a tilting with its scarp side in the east coinciding with preexisting fault lines and with the back slopes in the west. The tilting was therefore in the same sense in both blocks; the subsidence in the west having been greater than in the east. These tilting movements have been going on during these 33 years unaccompanied by any sudden disturbances of land features such as the formation of new clefts or fault lines, but continued slowly for a prolonged period, the tilting being active and chronic."

Prof. Yamasaki, it will be noticed, has not commented in his paper on the tilted feature of both blocks on their southern sides, although these have been well brought out by the results of the same survey over the route along the river Sinano-gawa. Thus in the Kariha-Higasikubiki block, corresponding to B. M. No. 3723 which is situated on the coast route at the western end of the block the change is as much as -113 mm., while there is B. M. No. 3638 on the river-side route which has changed its height as much as -97 mm.; and corresponding to B. M. 3747 which is situated on the coast route at the eastern end of the same block and has changed its height as much as -66 mm., we have B. M.

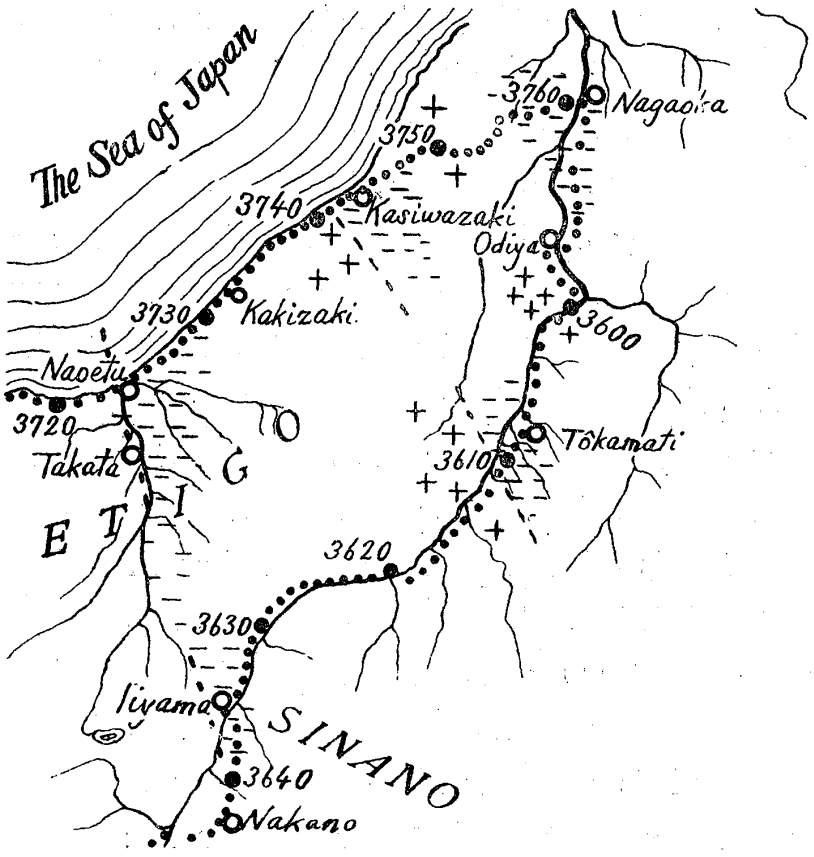

Fig. 2. Map showing the block boundaries as revealed by means of precise levellings.

3610 on the southern branch of the route showing a conspicuous depression when compared with neighbouring marks although the actual change in height here has been nil. In the same way, by the results of surveys of the southern branch, we gain a better insight into the way in which the other blocks have tilted.

We shall now consider the earth-tiltings that have been going on in the Kwanto district. The south-eastern part of this district which is mostly Tertiary in formation and may be regarded as having commenced its upheaving movement since the Pleistocene, is still keeping up the same movement, whereas in its north-western part which is mostly pre-Tertiary in formation, the movement is opposite in sense. The change therefore is a tilting motion, and the fact that the average height of the Tertiary hills in the Bo-So Peninsula is about 350 metres and those in the Miura Peninsula about 220 metres, there should be no difficulty in locating the axis of the tilting motion. According to the results of the precise levellings repeatedly carried out in the district during the last 43 years the axis would seem to lie near the straight line passing through the city of Kawasaki and the town of Atugi, trending ENE-WSW. Notwithstanding certain irregularities in the tilting there seems to be a tendency for the SE side of the axis to rise and the NW side to sink. For the sake of convenience we shall call tilting of this kind as *onward* and that in opposite sense to it as *backward* tilting. The accumulated tiltings of the Kwanto block for the last 2,000 years should give for the S end of the Bo-So Peninsula an annual uplift of as much as 5 or 6 mm. on the average, but it is more than likely that they occur more or less irregularly and somewhat in the following manner:—

(i) Practically no tilting for a century or so—seismically dormant.

(ii) Slight backward chronic tilting for a few decades—pre-seismic tilting of the earliest stage accompanying a number of large local earthquakes.

(iii) Slight onward chronic tilting for a few months or a few years—pre-seismic tilting of the intermediate stage accompanying large local earthquakes with greater frequency, and possibly with gravity disturbances.[1)]

(iv) Large acute tilting with pre-seismic tilting of the last stage and accompanying a non-local destructive earthquake.

(v) Repetition of the slight backward or onward tiltings for a few years, which however gradually diminishes in magnitude until it eventually ceases.

Later movements consist of a repetition of these five processes, and which may well be called the cycle of tilting motion of the Kwanto block. The problem was discussed by the writer elsewhere[2)] so that there will be given here only a brief sketch of it together with some amendments.

It is very probable that during the past 2,000 years the Kwanto district was visited by four non-local destructive earthquakes of the kind that cause widespread destruction throughout the Kwanto area, and accompanies conspicuous earth-tilting such as that experienced in the great earthquake of 1923. They are distinguished from local destructive earthquakes in which the destruction wrought is limited to a small area of, say, a circle of 10 km. radius, and accompanies an earth-tilting discernible only by instrumental aid. Of the four non-local destructive earthquakes just mentioned, the earliest has been given the hypothetical date of year 33, whereas the remaining three occurred in 818, 1703 and 1923. The

1) M. Ishimoto et K. Tuzi: Proc. Imp. Acad., Vol. V, No. 1.
2) A. Imamura: Jap. Jour. Astr. & Geop., Vol. V, No. 3.

hypothetical date was inferred by a method derived from a careful study of old strand-lines visible on Tertiary cliffs washed by the waters of the Pacific Ocean. We are on surer ground as regards the second earthquake, which according to the Ruisyu-kokusi, an authentic record, took place in the seventh month of the ninth year of Konin, which, is the year 818, and laid waste the provinces of Sagami, Musasi, Simôsa, Hitati, Kôduke, Simoduke, etc. Valleys for miles were buried by landslides and mud-avalanches; a countless number of people having perished under fallen houses. So great was the disaster that the Emperor sent special messengers to the stricken people distributing alms and remitting taxes. This earthquake evidently satisfied the first condition attached to non-local destructive earthquakes as outlined in one of the preceding paragraphs. Now for the second condition. Tradition has it that the lagoon in Takane-Hongo, near Itinomiya, Tiba Prefecture, which was formerly connected with the mouth of the River Itinomiya, in the same way that the lagoon Itinomiya is connected at the present time, suddenly upheaved as much as 3 metres some thousand years ago—very possibly on the occasion of that earthquake.[1] Then again a study of the borings of the marine shells, *Lithophaga nasuta*, on the Tertiary cliffs mentioned above, has brought out evidence of the occurrence on the south-eastern coast of the Kwanto district of a conspicuous uplift, comparable in magnitude with that associated with the 1703 earthquake. Putting all these together we arrive at the conclusion that the earthquake of 818 was connected with an earth-tilting of greater magnitude than that which we know to have occurred with the earthquake of 1923.

Regarding the earthquake of 1703, although details will be given later, in magnitude as well as in other respects it resembled

1) Imamura: Rep. Imp. Earth. Inv. Comm., No. 100 B, pp. 91–93.

the earthquake of 1923. For two or three centuries the district was seismically quiescent, after which followed a period of local destructive shocks which kept up for 80 years, and then came the final big shock of catastrophic violence. The southern parts of the Miura and Bo-So Peninsulas received the brunt of the shock; the coastal districts facing Sagami Bay and the Pacific being devastated by *tunami*. The coastal regions in both peninsulas underwent an uplift on a greater scale than in 1923. As to the pre-seismic tiltings, we are without any knowledge, although if there were any, it could only have been slight, judging by the perforations of boring shells. The post-seismic changes on the other hand were so apparent, on the coast of Awa at any rate, that they did not escape the attention of the villagers.

With regard to the 1923 earthquake a full account will be found in another chapter. We might state here however that the last great earthquake suffered by this region came in 1703, so that it was enjoying comparative seismic immunity for 150 years, followed by a shorter period of 70 years, during which short interval local destructive shocks were frequent, as witness the great Odawara earthquake of 1853 and the Yedo earthquake of 1855, etc. It must be remarked though that even in the so-called period of seismic quiescence, fairly strong shocks were sometimes felt, such as the Yedo earthquake of 1706 (one of the aftershocks of the 1703 earthquake), the W. Sagami earthquake of 1782 and the Kanagawa earthquake of 1812; but they were all harmless, the damage being confined to cracking of plaster walls and overturning of crockery. There was no comparison with the activities that were displayed during the 70 years period. Not only did there occur in the Kwanto district a dozen or more earthquakes belonging to the category of the Odawara earthquake, but evidences have accumulated indicating that the

remarkable pre-seismic tilting associated with the 1923 earthquake began its career in the early part of this 70 years period. Fishermen in the southern part of the Bo-So Peninsula were aware that the coast had subsided as much as 80 cm. during the 60–70 years preceding the 1923 earthquake. During the same interval the southern part of the Miura Peninsula had subsided fully 50 cm. Accurate measurements of the tilting however were not begun until 1895 when mareographic observations were initiated at Aburatubo, Misaki, in the Miura Peninsula, while routes for precise levellings were laid out along the highways of Tôkaidô, Nakasendô and in and around the city of Tokyo. Constant observation of the sea level at Misaki, together with precise levellings carried out over the different routes, have enabled Messrs. Atumi and Muto of the Military Land Survey to prove that during the 70 year period preceding the year 1920, the Kwanto region underwent a slight, steady, backward tilting.[1] That this changed later into an onward tilting is too well known to need emphasis here.

Whether or not the pre-seismic tilting went through its last stage is a point that could not be decided by the mareograph observations at Misaki. An Omori clinograph installed at our institute, however, registered conspicuous tiliting which strongly resembled what Prof. Ishimoto had observed in some Kwanto earthquakes.[2] The latter was a very conspicuous and abnormal tilting downward in a W-by-N direction, and which, beginning on July 31 lasted until Aug. 17 with accumulated tiltings of as much as 1″.7. During the subsequent fortnight there occurred slight tiltings downward, at first in a NE direction but later SW, showing

1) Read before the meeting of the Earthq. Res. Inst. on April 24, 1928, but not yet published.

2) A. Imamura: Proc. Imp. Acad., Vol. IV, No. 4.

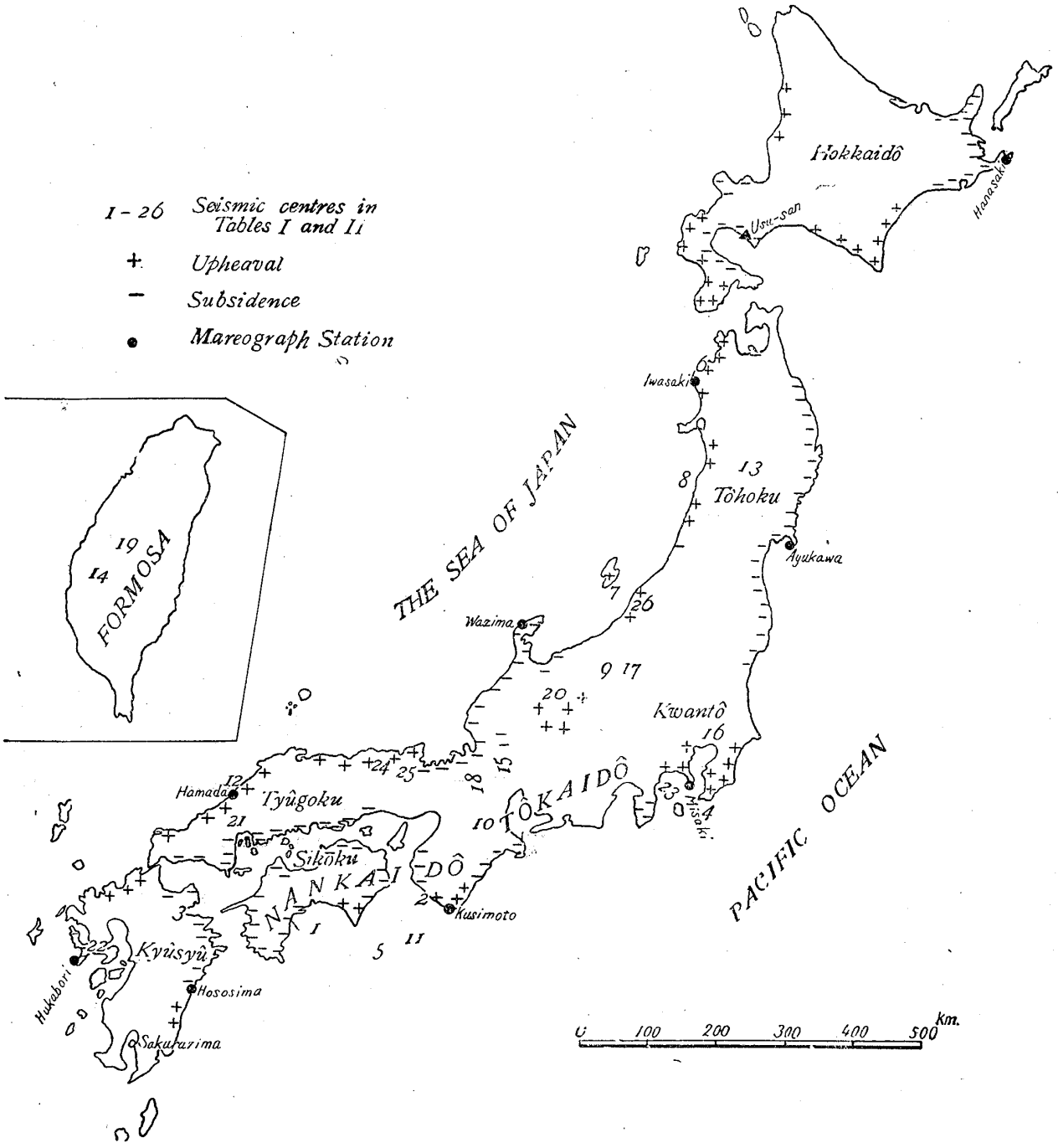

Fig. 3. Map showing the distribution of seismic centres No. 1–26, with that of upheavals and subsidences.

in both cases quite normal characteristics with respect to temperature variations. Lastly on the morning of the fateful Sept. 1, there was a sharp tilt westward of as much as 0″.3 and this continued for 8 hours when it was cut short by that tremendous shock. Needless to say, it was in conjunction with this great shock that the conspicuous acute tilting, to which allusions have so frequently been made in this paper, took place.

The earth-tiltings which have been going on in the southern part of Central Japan, or in the Kii Peninsula at least, resemble on so many points those just described in connexion with the district. In the first place the peninsula, which is, broadly speaking, in its southern part composed of Tertiary blocks and in its northern part of pre-Tertiary blocks, made at the time of the great earthquake of 1854 a conspicuous acute tilt in the onward sense which uplifted the southern part and depressed the northern. Secondly, it is well to note that the chronic tilting which has been going on during the last 30 years is in the backward sense, so that by assuming it to correspond to the first stage of pre-seismic tilting in connexion with some impending catastrophe, the relation between this and the acute tilting will be found to be identical with what has been observed in the case of the Kwanto earthquake.[1)]

Although little is known of the precise manner in which acute and chronic tiltings occur in other parts of our country, we are in possession of data by means of which the character of an acute tilting or a crustal movement that has taken place in recent years can be ascertained. Thus the southern coast of Sikoku seems to have been tilting in an irregular manner, the N–S component of which caused the blocks to the west of the city of Kôti to sink in the north and to upheave more or less in the south. In this respect

1) A. Imamura: Jap. Jour. Astro. & Geop., Vol. VII, No. 1.

the north-eastern coast of Kyûsyû is merely a prolongation of the western coast of Sikoku. The results thus far attained are shown in Fig 3.

Chapter II. Topographical Changes in the Past that Were Accompanied by Earthquakes.

The *Dai-Nippon Disin-siryo*, a catalogue of Japanese earthquakes compiled by Mr. M. Tayama, originally under the supervision of Prof. Sekiya but later under that of Prof. Omori, records ten cases of earthquakes which accompanied conspicuous topographical changes. Among these ten there was only one in which the changes were co-seismic as well as pre-seismic. The writer, however, has brought to light two more such cases, namely the Adigasawa earthquake of 1793 and the Hamada earthquake of 1872; the records relating to them having been unearthed in the courses of record-hunting trips to these localities. Particulars of all these changes, together with those of two recent occurrences, will be found summarised in the table on page 18.

Detailed accounts of these earthquakes with special reference to the topographical changes which they accompanied are given in the following paragraphs.

No. 1. The Tosa earthquake of 684.

This earthquake is said to have taken place shortly before midnight on Nov. 29. The *Nihon-syoki*, the oldest authentic history of Japan extant, speaks of land-slides and river-floods; of the numberless dwellings, shrines and temples destroyed in the various provinces; of the countless number of men and cattle killed and wounded, and of the thermal springs of Iyo that ceased to flow. Mention is also made of a tract of land in Tosa measuring no less