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TOPOGRAPHICAL CHANGES ACCOMPANYING EARTHQUAKES OR VOLCANIC ERUPTIONS.

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CONTENTS.

TOPOGRAPHICAL CHANGES ACCOMPANYING EARTHQUAKES OR VOLCANIC ERUPTIONS.

By

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Introduction.

Tiltings of the earth, which may be regarded as precursors of earthquakes, seem to take place in stages or steps; a very recent example being the great Kwanto earthquake of 1923. This earthquake was preceded by tilting in its earliest stage as attested at Misaki by the slow coastal subsidence which had been going on for a few decades until the year 1920, when the movement entered the intermediate stage, and which, after continuing for two more years, was found to have resulted in an uplift of as much as 6 cm. The remarkable upheaval that preceded the Sekihara earthquake of Oct. 27, 1927, was caused by tilting of either the earliest, or the intermediate stage; in all probability the latter. On the other hand, the conspicuous upheavals that preceded the great Adigasawa earthquake of Feb. 28, 1793, and of Tango of Mar. 7, 1927, were undoubtedly owing to tiltings in their last stages.

Recent experiments by Prof. Ishimoto with his new clinograph have thrown considerable light on the foregoing phenomena. The results of his investigations seem to agree in indicating that the pre-seismic earth-tiltings in their last stages occur with every moderate shock, though he has not yet experimented with the severe or very violent ones. It is worth noting at the same time that the Sekihara earthquake of Oct. 27, 1927, revealed the existence of a close connexion between such pre-seismic tiltings and the acute tiltings that accompany actual earthquakes. Such a connexion was observed also in the case of the great Kwanto earthquake of 1923, although in a vague and ill-defined way.

From these evidences it may be regarded as established that the character of the acute earth-tiltings which accompany an earthquake is inferable from the chronic tiltings that precede the earthquake, and vice versa.

It will thus be seen that the study of pre-seismic earth-tiltings, together with that of the acute earth-tiltings, besides being of great interest scientifically, are essential to the investigation of earthquake prediction.

While the chronic earth-tiltings going on in some regions are closely related to earthquakes, it is not always possible to establish a similar relationship for those going on in other regions. All those in Japan, as far as we know, come under the first category, but cases can be cited from other regions which do not appear to be connected in any way with earthquakes. Thus in certain parts of the Baltic coast of Scandinavia the land has been rising uniformly at a yearly rate of about one cm. at the maximum.

Another phenomenon experienced in this country is that changes of land-level take place antecedent to, simultaneously with, or after, volcanic eruptions. The eruptions of Sakurazima and Ususan are good recent examples. Since it has been satisfactorily proved that topographical changes which take place prior to volcanic eruptions have characteristics in common with those that take place prior to earthquakes, the study of the former has assumed an importance in no way inferior to that of the latter.

In consideration of the foregoing it may truly be claimed that the investigation of topographical changes accompanying earthquakes or volcanic eruptions, whether they take place before, simultaneously with, or after them, takes rank as one of the most important problems of practical seismology. This was fully recognised by the Imperial Earthquake Investigation Committee who spared no pains to avail of every possible opportunity for the collection of data concerning these phenomena. The data covers a dozen earthquakes and two volcanic eruptions, some of which have already been made public by the late Prof. Omori together with a few by the present writer. There are a few earthquakes, however, the data for which have not yet received the full attention of investigators, and the present paper contains, amongst others, the results of studies of such new data, together with brief reviews of what have already been published. It is also hoped that the paper will afford access to the literature of the subject for those desirous of making extended studies of the phenomena. The contents of the paper are

Chapter I. General view of a cycle of earth-tiltings.

Chapter II. Topographical changes in the past that were accompanied by earthquakes.

No. 1. The Tosa earthquake of 684.
No. 2. The Senrigahama earthquake of 1331.
No. 3. The Bungo earthquake of 1596.
No. 4. The Kwanto earthquake of 1703.
No. 5. The Nankaido earthquake of 1707.
No. 6.* The Adigasawa earthquake of 1793.
No. 7.* The Sado earthquake of 1802.
No. 8. The Kisakata earthquake of 1804.
No. 9. The Zenkôzi earthquake of 1847.
No. 10. The Iga-Ise earthquake of 1854.

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,

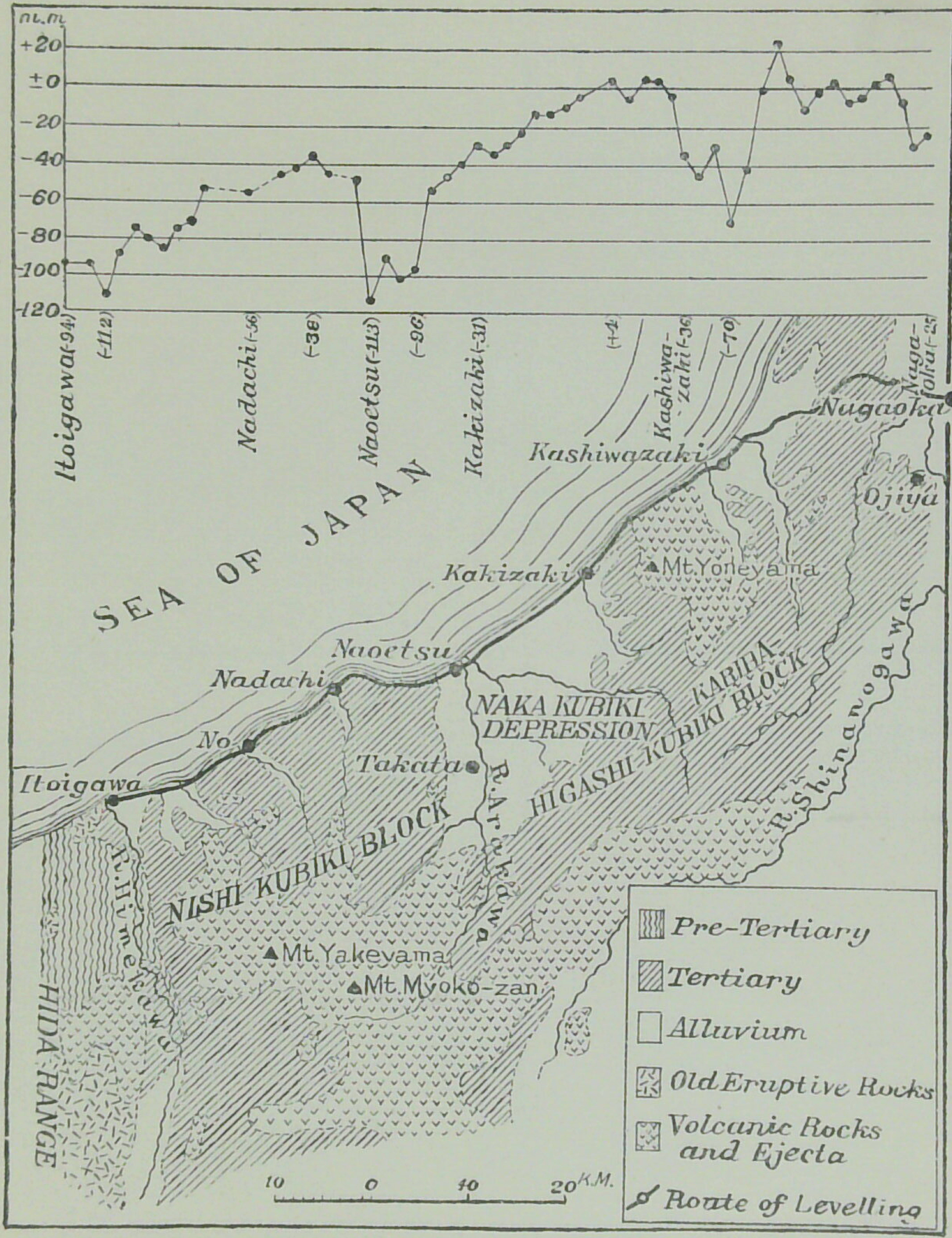

Fig. 1. The Geology of West Echigo and the Results of Levelling along the Coast in 1927. (after Yamasaki)

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.

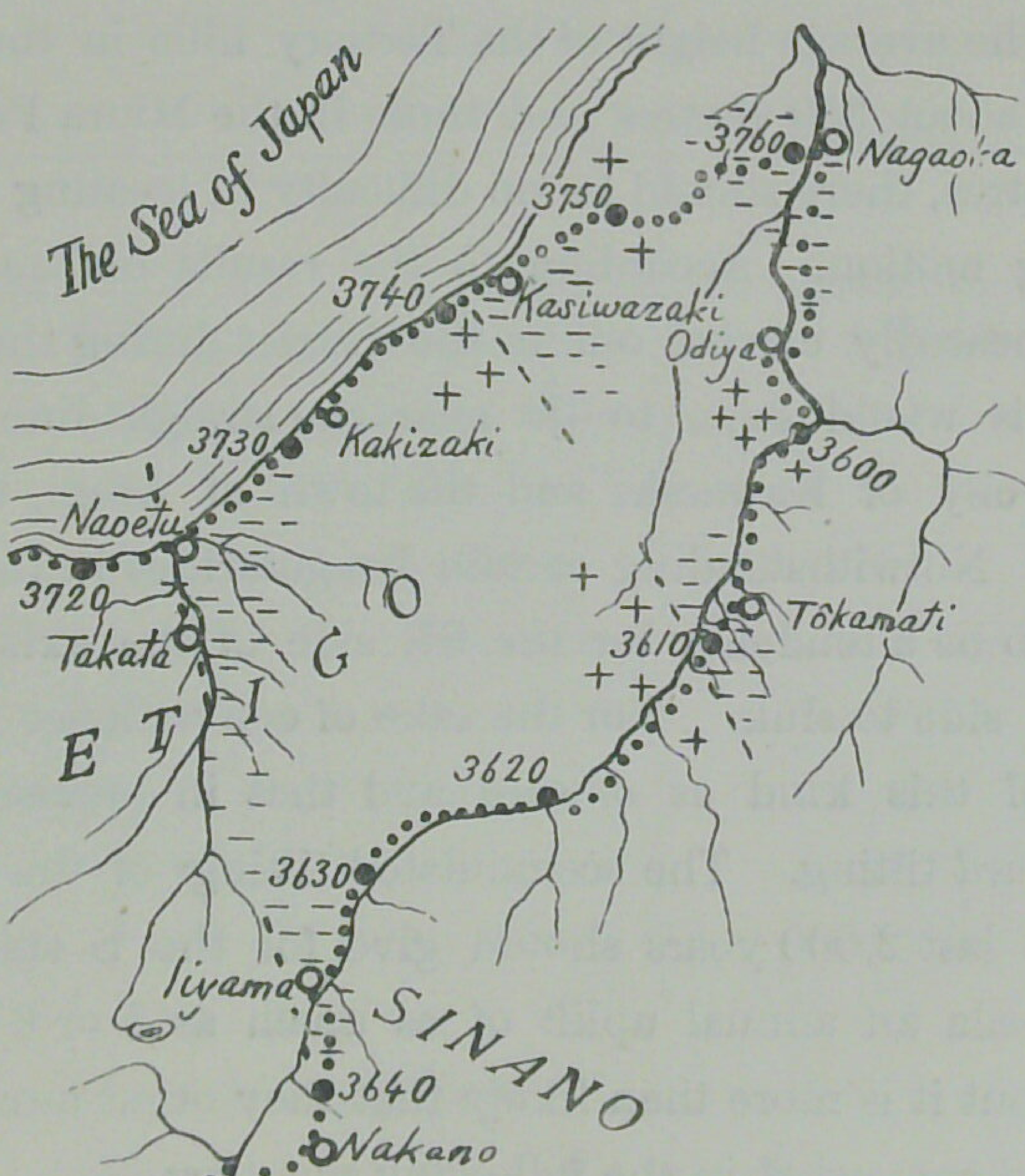

Fig. 2. Map showing the block boundaries as revealed by means of precise levellings.

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 preseismic 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.

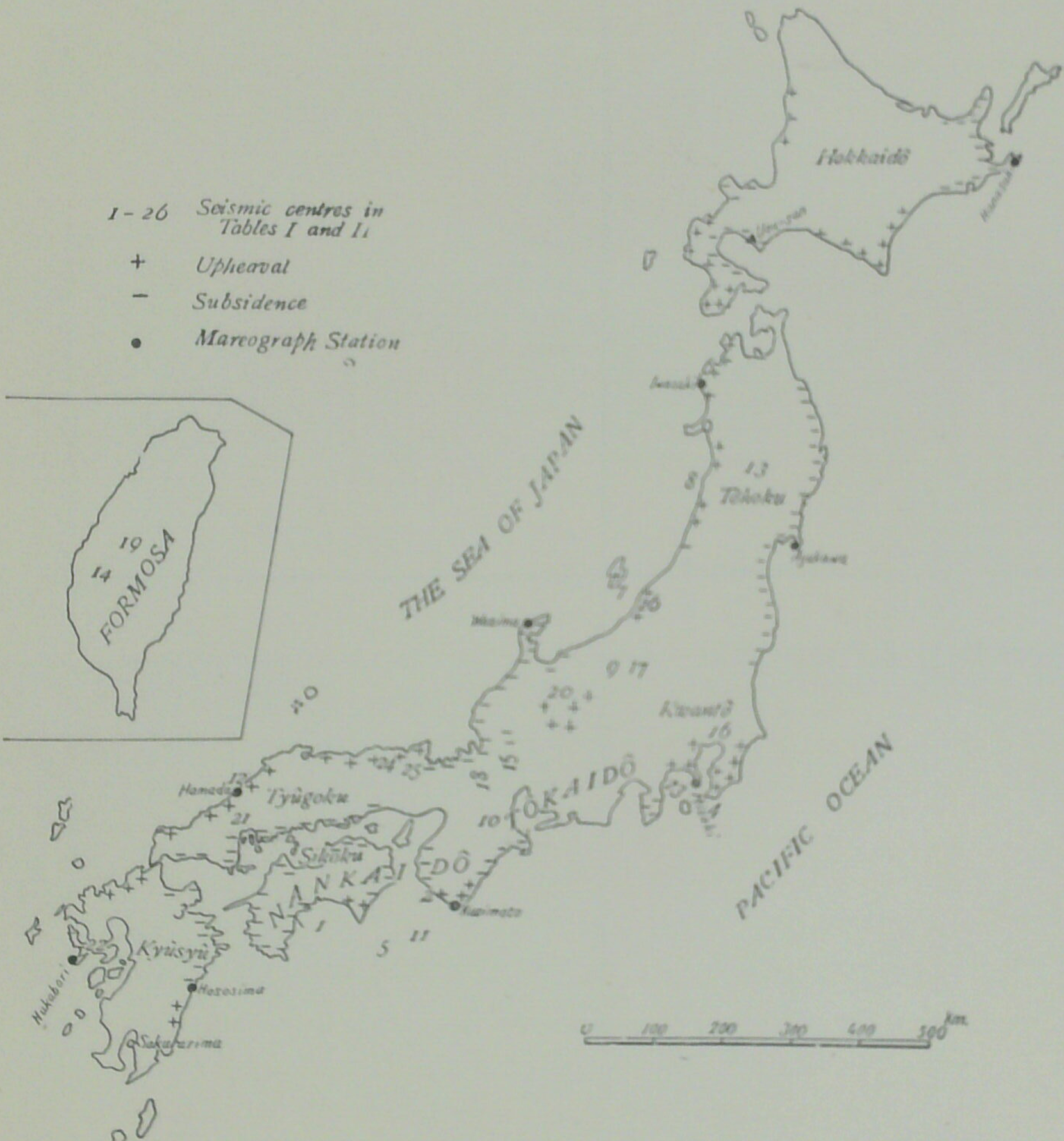

Fig. 3. Map showing the distribution of seismic centres No. 1–26, with that of upheavals and subsidences.

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

Table I.

No.	Date	Locality[1]	Upheaval		Subsidence		Remarks
			Extent	Max. height	Extent	Max. height	
1	684 XI 29	Tosa			9 km²	?	Sank under the sea
2	1331 VIII 15	Senrigahama, Kii Prov.	3 km	2 or 3 m			
3	1596 IX 4	Ooita, Bungo			10 km²	10 m	Uriu Is. sank under the sea.
4	1703 XII 31	Kwanto	1500 km²	6 m			
5	1707 X 28	Nankaido	SE coast of Tosa	3 m	NW coast of Tosa	3 m	
6	1793 II 8	Adigasawa, Mutu Prov.	12 km	3 m			Preceded by slow upheaval
7	1802 XII 9	S part of Sado	25 km	2 m			Do.
8	1804 VII 10	Kisakata, Ugo Prov.	10 km	2 m			
9	1847 V 8	Nagano	8 km	1.2 m	8 km	1.2 m	
10	1854 VII 9	Iga & Ise			1 × 0.2 km	1.5 m	
11	1854 XII 24	Nankaido	500 km²	1.3 m	1500 km²	1 m	
12	1872 III 14	Hamada, Iwami Prov.	20 km	2 m	20 km	3 m	Preceded by slow upheaval
13	1896 VIII 31	Rikutyu & Ugo.	60 km	1 m	60 km	1 m	
14	1906 III 17	Kagi, Formosa	25.5 km	1 m	25.5 km	1 m	

1) See Fig. 3.

than 500,000 siro (8.25 sq. km.) which sank under the sea. Judging from local traditions, this submergence would seem to have taken place, either on the coast in Takaoka county situated southwest of the city of Kôti or in the vicinity of the city itself. It is said that on this occasion two villages called Oora and Oda, each with its thousand habitations, were swallowed up by the sea. The region is Cretaceous with a shore line of the *rias* type—a formation it would seem eminently suited for such happenings. It may be remarked here that a similar state of things happened also in the case of the Nankaido earthquake of 1707.

No. 2. The Senrigahama earthquake of 1331.

Senrigahama is the name given to a strip of coast on the western

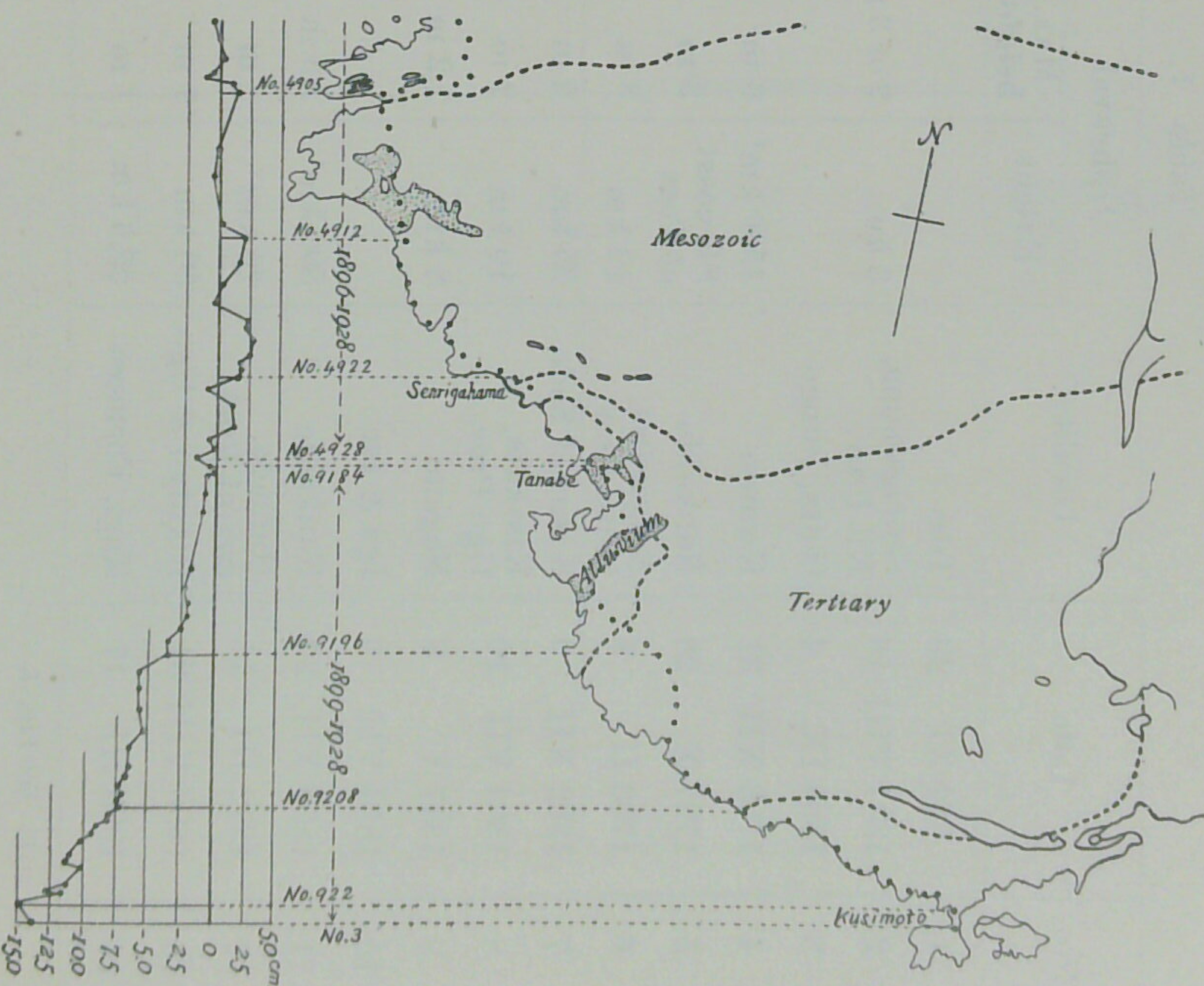

Fig. 4.

side of the Kii Peninsula. Bench-marks Nos. 1920–1923 of the Military Land Survey lie quite close to the shore here, so that the precise levellings of 1896 and 1928 should be helpful in the study of this earthquake.[1]

The earthquake took place on Aug. 15th. In consequence, the shore of Senrigahama was suddenly elevated, and it was found that for a distance of nearly three km. it had widened considerably when compared with what it was before the earthquake. Since this seashore today has nothing like the imputed width, we think we may safely put the change down to one of the minor phases of that change on a much larger scale which has been and is still going on in this peninsula. The earthquake although destructive was quite local in character, and might well have been the precursor of the non-local destructive earthquake of 1361, which caused such awful havoc in the southern part of Central Japan, especially in the Kii Peninsula, besides bringing in its train *tunamis* on the shores of Kii Channel and Osaka Bay. Furthermore, since the recent chronic tilting of the locality, as revealed by the levellings already referred to, was a sharp backward tilt, and quite independent of the contiguous rock mass, it may be legitimate to assume that the topographical change that came with the earthquake of 1331 consisted of a sharp, independent tilting of the mosaic block which is the northernmost segment of the Tertiary block forming the end of the peninsula.

No. 3. The Bungo earthquake of 1596.

This earthquake was felt on the fourth of September after a month of more or less continued seismic activity. It came about 7 hours before the celebrated Husimi earthquake which became

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

famous in connexion with an incident in the life of the great historical personage Taiko-Hideyosi. In former times there was an island called Uriu-zima situated a short distance off the site of the present city of Ooita, and which had an area of 2.3 km. N-S by 4 km. E-W with a population of as much as 5,000. This island is

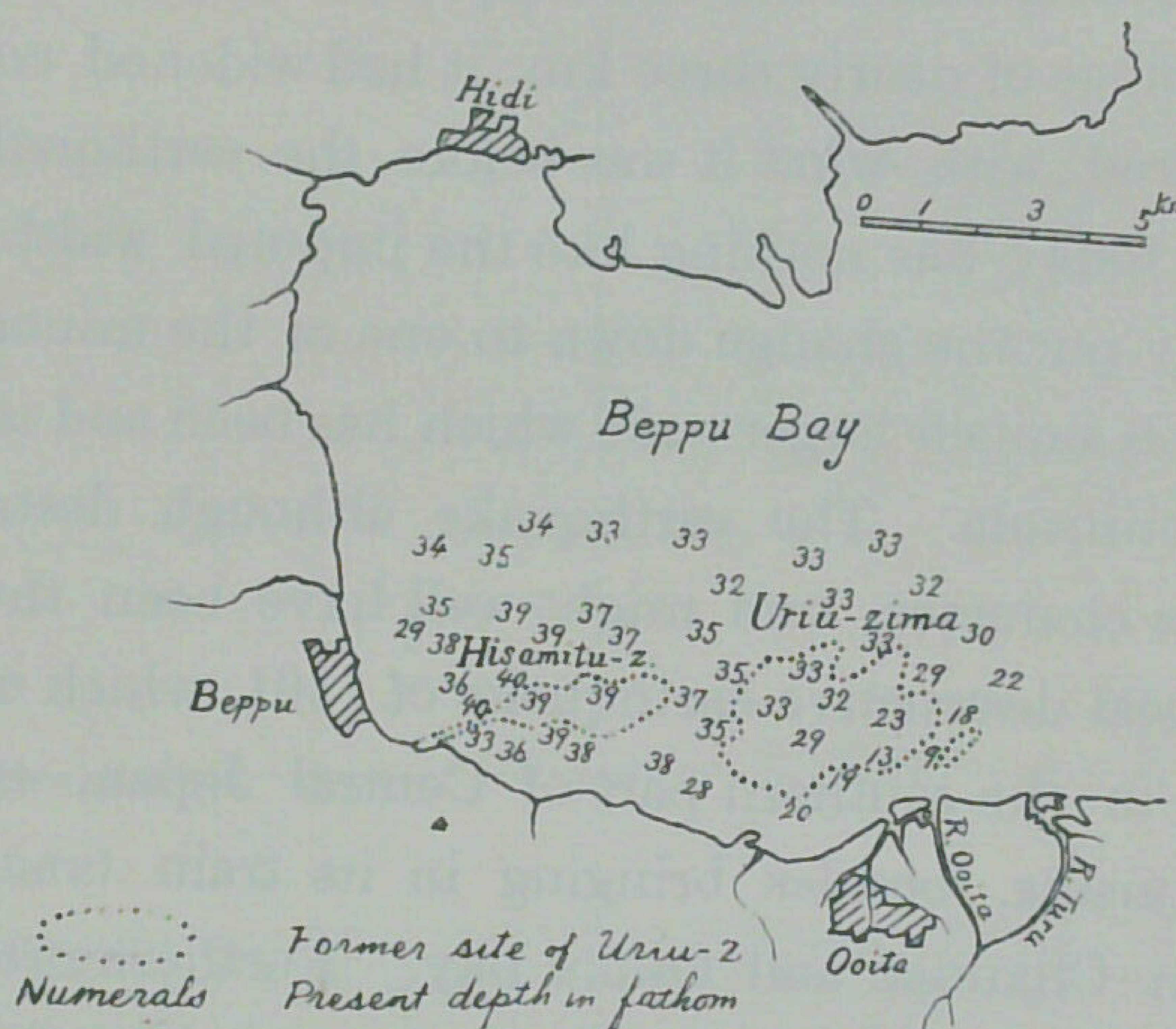

Fig. 5.

now no more above water, lying as it does some 30-40 fathoms below the surface of the sea. Contrary to what is the experience with most big earthquakes, the destruction was not instantaneous; that is to say, it did not come as a single blow so to speak. In the afternoon of the eventful day a shock was felt that was severe enough to open fissures in the ground and cause damage to buildings. Then quiet reigned for a while, but at 5 p.m. was distinctly heard that ominous, dull roar so characteristic of approaching *tunami*. Panic-stricken, the people fled for safety; some to high ground and others to the shore opposite, but 708 persons were unfortunately caught in the on-rushing flood. On the following morning to everyone's amazement, Uriu-zima (island) was found to have subsided to a considerable extent and that three-quarters of its area had been drowned. Needless to say, later subsidences must have added their quota to the reduction of the island to its present plight of submergence under 30 odd fathoms of water, but the denuding action of sea waves and other agencies must also have had their share in the work.

We might add that about a year later, on Sept. 10, 1597, the region was visited by another severe shock when the small promontory of Hisamitu-zima, situated between the above mentioned island and the city of Beppu, vanished under the sea.

No. 4. The Kwanto earthquake of 1703.

This non-local, destructive earthquake, having characteristics much in common with its 1923 namesake, took place about two in the morning of Dec. 31st. In the severity with which it shook the Kwanto region as well as in the extent of area shaken, it nearly equalled that of the 1923 earthquake; but in the topographical changes on land which the earthquake accompanied and in the magnitude of the tidal waves, those of the 1703 earthquake were much greater. In Yedo (now Tokyo) and in Odawara fires started from a number of centres and added to the horrors. The total killed was 5,233 while the houses thrown down numbered 20,062.

That the *tunami* was bigger in the case of the present earthquake will be apparent from the following records. In Kamakura and neighbourhood the wave came as far as the second gate of the Hatiman Shrine, that is into the grounds of the Kômyôzi Temple, and swept away most of the houses in the villages of Kotubo and Katase, while in Itô 163 persons were drowned. On the Pacific side of the Bo-So Peninsula the wave was so high that on the coast of Kuzyûkurihama it rushed as far inland as 2.4 km. from the beach. The shores of Tokyo Bay were also flooded, and in the

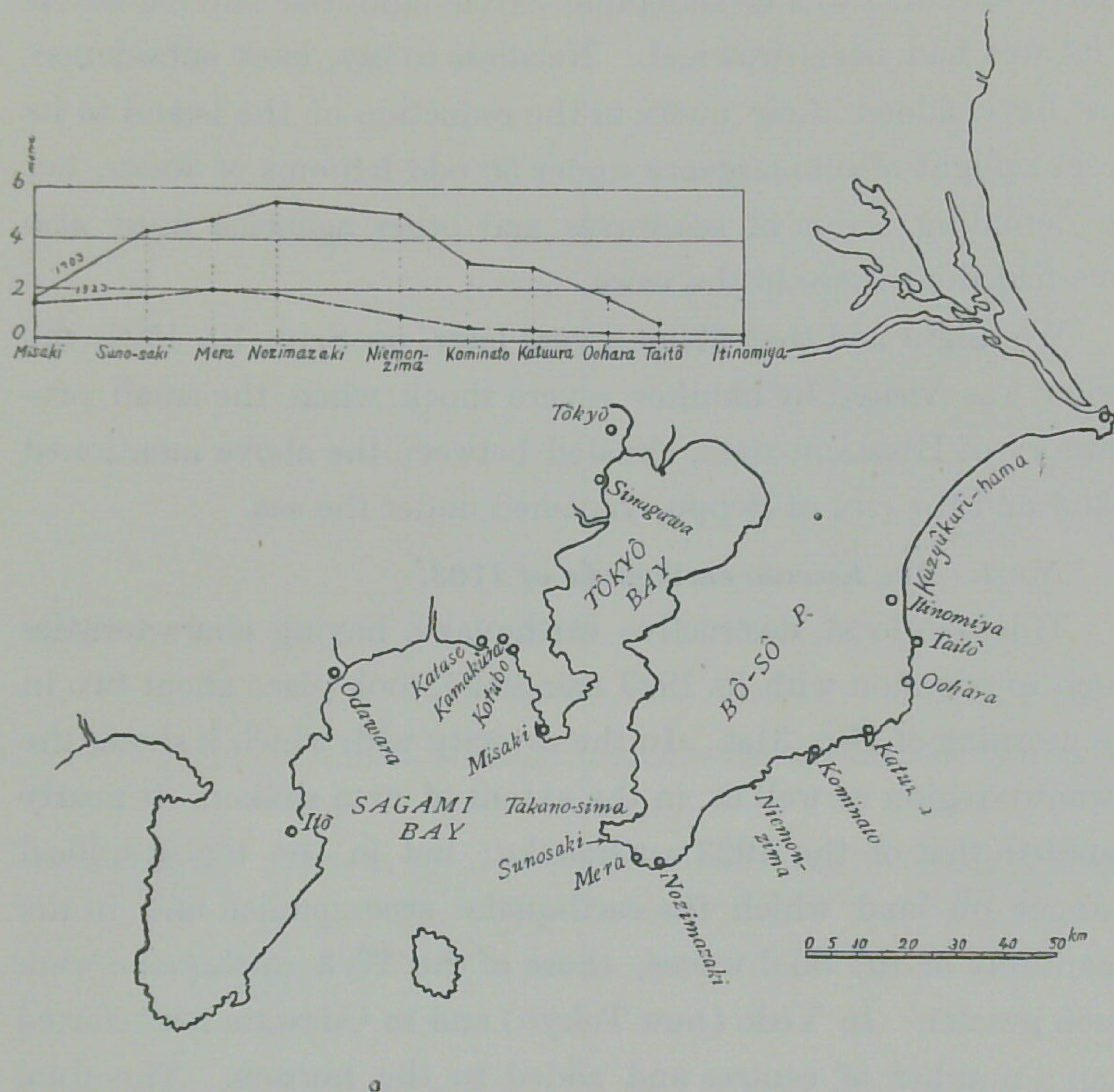

Fig. 6. Map showing the topographical change accompanied by the Kwanto earthquake of 1703.

city itself the wave came as far as the south of Sinagawa. These facts would seem to suggest that the changes wrought in the sea-floor were on a larger scale than was the case with the 1923 earthquake.

The changes that took place on land were no less remarkable. We give below a comparative table of the upheavals associated with each of these two earthquakes for various points on the southern coasts of the Miura and the Bo-So Peninsulas.

Table II.

	Misa-ki	Taka-sima	Suno-saki	Mera	Nozi-ma-z.	Nie-mon-zima.	Komi-nato	Katu-ura	Ooha-ra	Taito	Itino-miya
1703	1.6 m	2.5	4.2	4.7	5.5	5.0	3.0	2.9	1.7	0.7	?
1923	1.4	1.6	1.6	2.0	1.8	0.9	0.5	0.4	0.3	0.3	0.2

Of these data, those for the 1923 earthquake were deduced from precise levellings and geodetic triangulations, while those for the 1703 earthquake were estimated by the writer after careful consideration of the pre-seismic mean sea-level as indicated on the faces of Tertiary cliffs by perforations of the boring shells, *Lithophaga nasuta.*[1] It might be added in passing that an ancient map of Mera and environs dating back to 1653 and records of the upheaval of Nozima, formerly an islet but now a peninsula, have shown themselves to be in fairly good agreement with our data for these two places as given in the above table.

It will thus be seen that the topographical changes, both terrestrial and submarine, connected with the earthquake of 1703, occurred on a larger scale than those connected with the earthquake of 1923. We shall also find that the upheavals undergone by the various points on the Bo-So Peninsula, from the westernmost one up to that on the extreme south of the peninsula, namely, Misaki, Sunosaki, Nozima-zaki and Niemon-zima, indicate that the direction of the tilt was in the main NW-SE. This coupled with the fact that the uplift at Mera, Nozima-zaki and Niemon-zima, all of which lie on a line trending SW-NE, i.e. perpendicular to the direction mentioned in the preceding lines, are almost equal in amount, lead us to the conclusion that the tilting of the

1) A. Imamura: Jap. Jour. Astr. & Geop., Vol. V, No. 3.

Kwanto block associated with the 1703 earthquake was *onward* hence similar to that which occurred in 1923, although the neutral axis seems to have been shifted slightly towards the southeast.

No. 5. The Nankaido earthquake of 1707.

This earthquake, which occurred on the 28th of October at about one in the afternoon, was of the non-local, destructive type. It originated off the coast of Nankaido and was the most violent ever recorded in this country. Houses were shaken down in 26 provinces; the distant outlying ones being Suruga, Kai, Sinano, Mino and Oomi in the east and north; Harima in the north-west; and the eastern provinces of Kyûsyû in the west. The disasterous effects of the terrible *tunami* were felt as far as Idu in the east to Kyûsyû in the west. The wave reached its maximum at Tanesaki near Kôti where it attained the enormous height of 70 feet. After passing through the Bungo Channel it washed the coasts of Suo and Nagato in the Inland Sea, while another wave sweeping through the Kii Channel entered Osaka Bay and charged into the city of Osaka. Here the piled up waters tore thousands of boats from their moorings in the harbour; some being wrecked while others were carried further up the river, destroying every bridge that stood in the way. The dead numbered 4,900 and the number of houses either destroyed or washed away totalled 29,000.

As regards topographical changes, we have a few records covering Kii and Tosa. Judging from the subsidences that occurred at Tanabe and Singu, both in Kii Province, it would appear that an acute, onward tilting took place in the southernmost Tertiary block of the peninsula in much the same way that we have seen in connexion with the earthquake of 1854.

The changes in Tosa consisted of an upheaval on the eastern, and a subsidence on the western, side of the river Monobe, which in all probability, occurred in two different ways, namely, (i) block-tilting on the eastern side with its strike trending NE-SW lifting the SE side of the block, and (ii) block-tilting on the western side with its strike trending W-E and dipping northwards. (See Fig. 8.)

The evidences of the tiltings of the different blocks are as follows:—

For block A—Muroto and Turo were elevated as much as 7–8 feet. The eastern coast from Muroto as far as None, which are Tertiary in formation, escaped the effects of the *tunami*, whereas the section of the coast lying to the north of None suffered much damage.

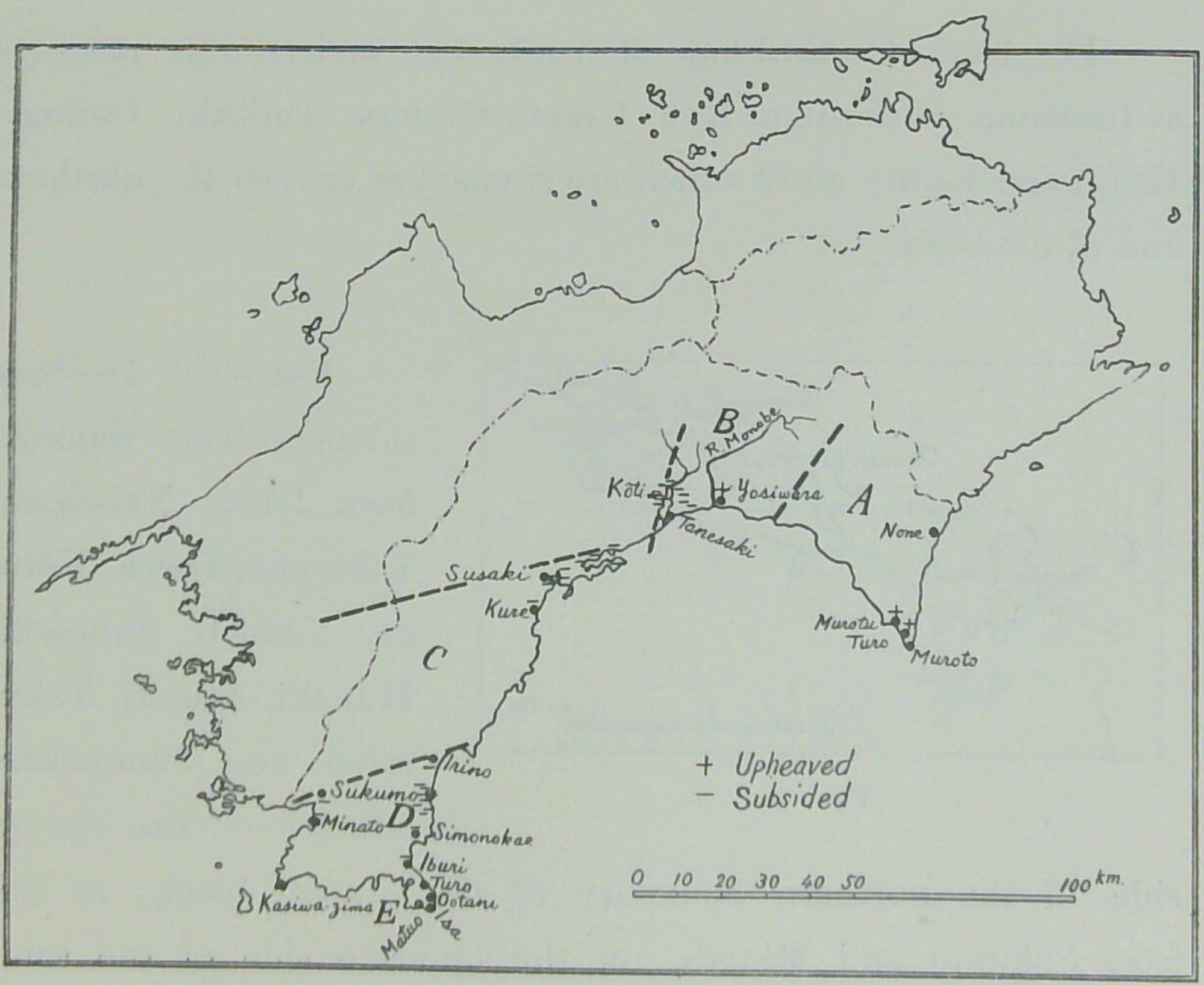

Fig. 7.

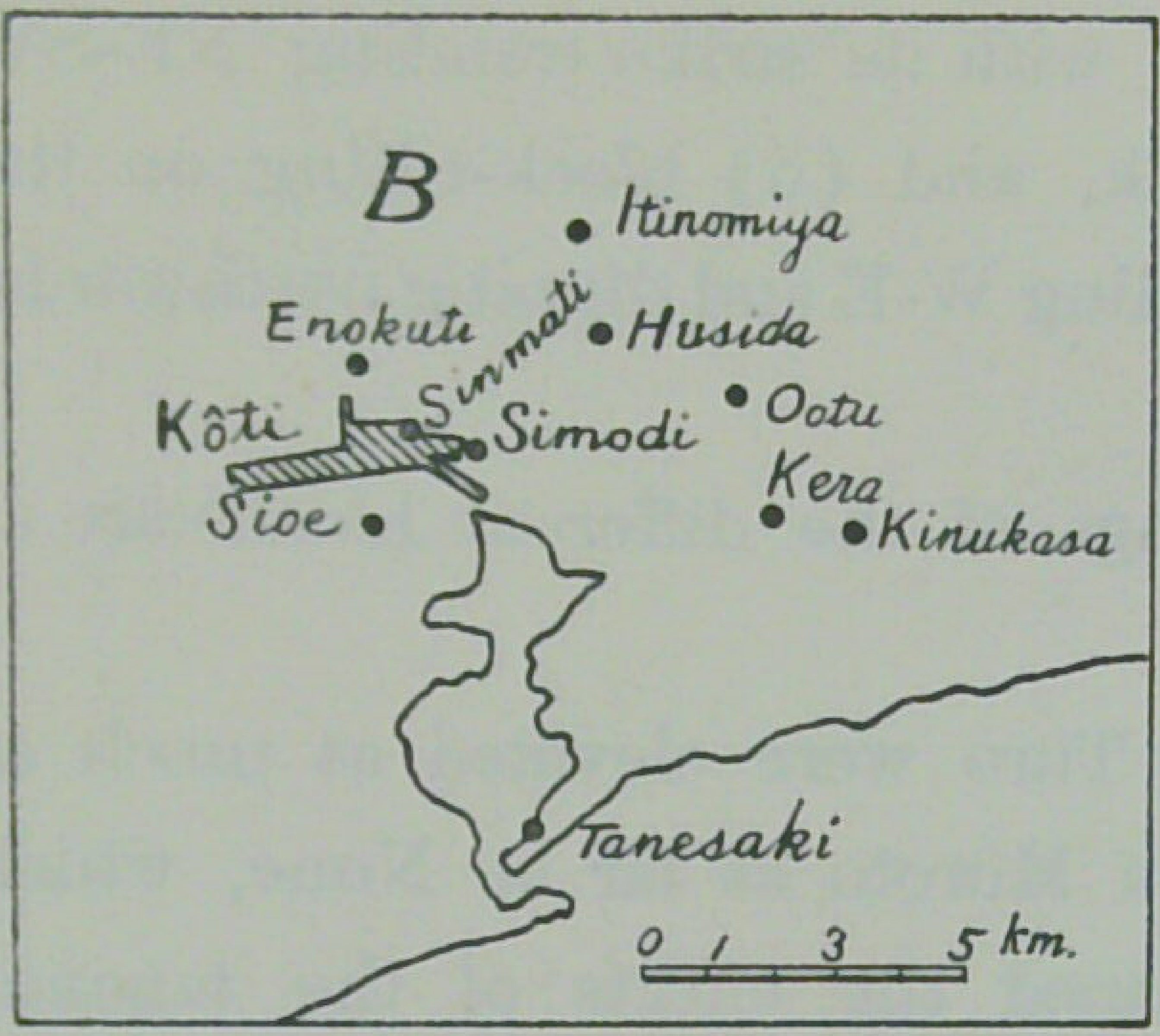

Fig. 8.

For block B—The towns and villages in and around the city of Kôti, such as Sinmati, Simodi, Sioe, Enokuti, Itinomiya, Husida, Ootu, Kera and Kinugasa, subsided sufficiently to be under more or less sea-water since the day of the catastrophe, whereas Yosiwara was uplifted nearly 7 feet.

For block C—Sinkings of nearly two metres were recorded at Inohama, Hukusima, Ryû, Urauti, Okuura, Tutizaki, Oonogô, Ikeuti and Kure; all of which are situated at or near the northern end of the block.

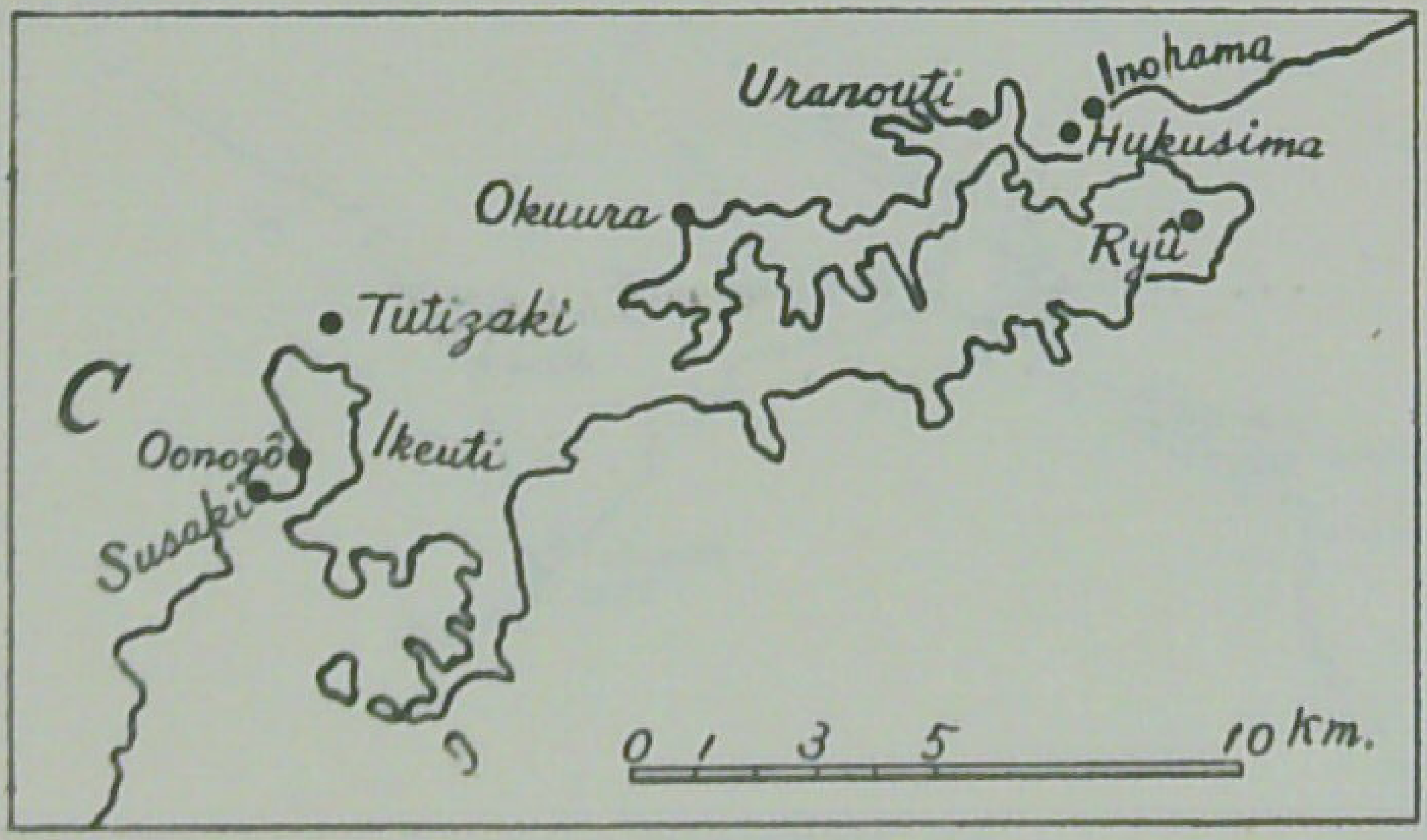

Fig. 9.

For block D—Subsidences were reported from Irino, Nabesima, Takesima, Isawa, Kotuga, Yamadi, Sanesaki, Hukaki, Masaki, Tukurabuti and Simonokae, situated on the eastern side of the northern boundary of the present block; as also from Sukumo and Minato, on the opposite side of the same boundary.

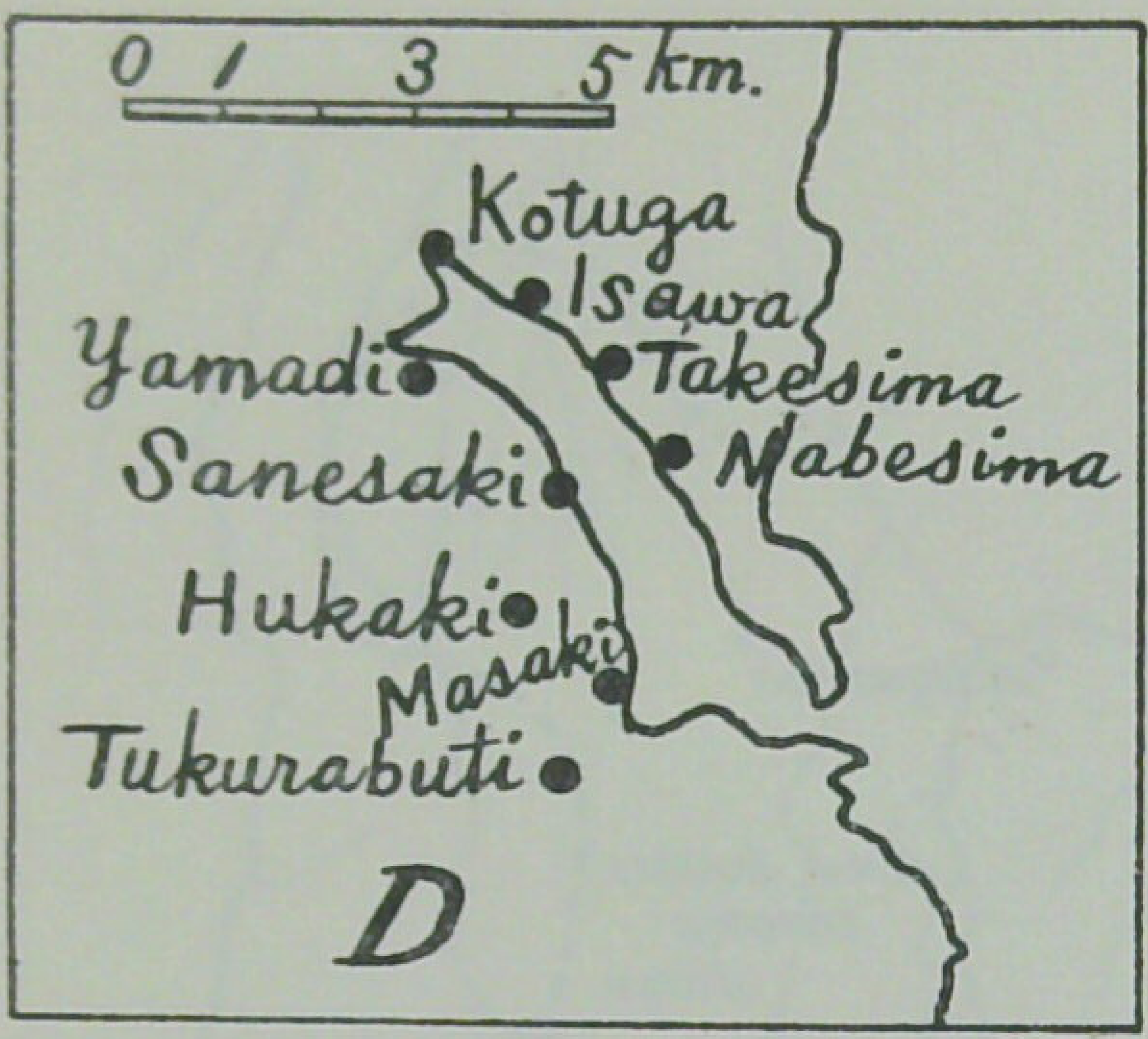

Fig. 10.

For block E—The only subsidence recorded was at Iburi. The fact that the *tunami* was quite harmless at Turo, Isa, Ootani and Matuo, all of them on the opposite side of the block, strongly suggests that the latter side underwent no subsidence.

No. 6. The Adigasawa earthquake of 1793.[1]

At about 1 p. m. on Feb. 8, this earthquake having its epicentre at Ootose, violently shook the western half of the province of Mutu, causing a loss of 12 lives and the collapse of 164 houses. The rather light casualty despite the severity of the shock was owing to no other cause than that the region was sparsely populated. There was a *tunami* but the damage was trifling.

The topographical changes on the other hand were most remarkable. A strip of the coast extending for some 12 km. with Ootose as its approximate centre, was lifted as much as 3 metres at the highest point. But what is still more remarkable was the pre-seismic change of the last stage that was experienced at Adigasawa, a town lying some 12 km. to the east of Ootose. It is said that on the morning of that fateful day some people standing

1) For details see A. Imamura: Rep. (in Japanese) Imp. Earthq. Inv. Comm. No. 95.

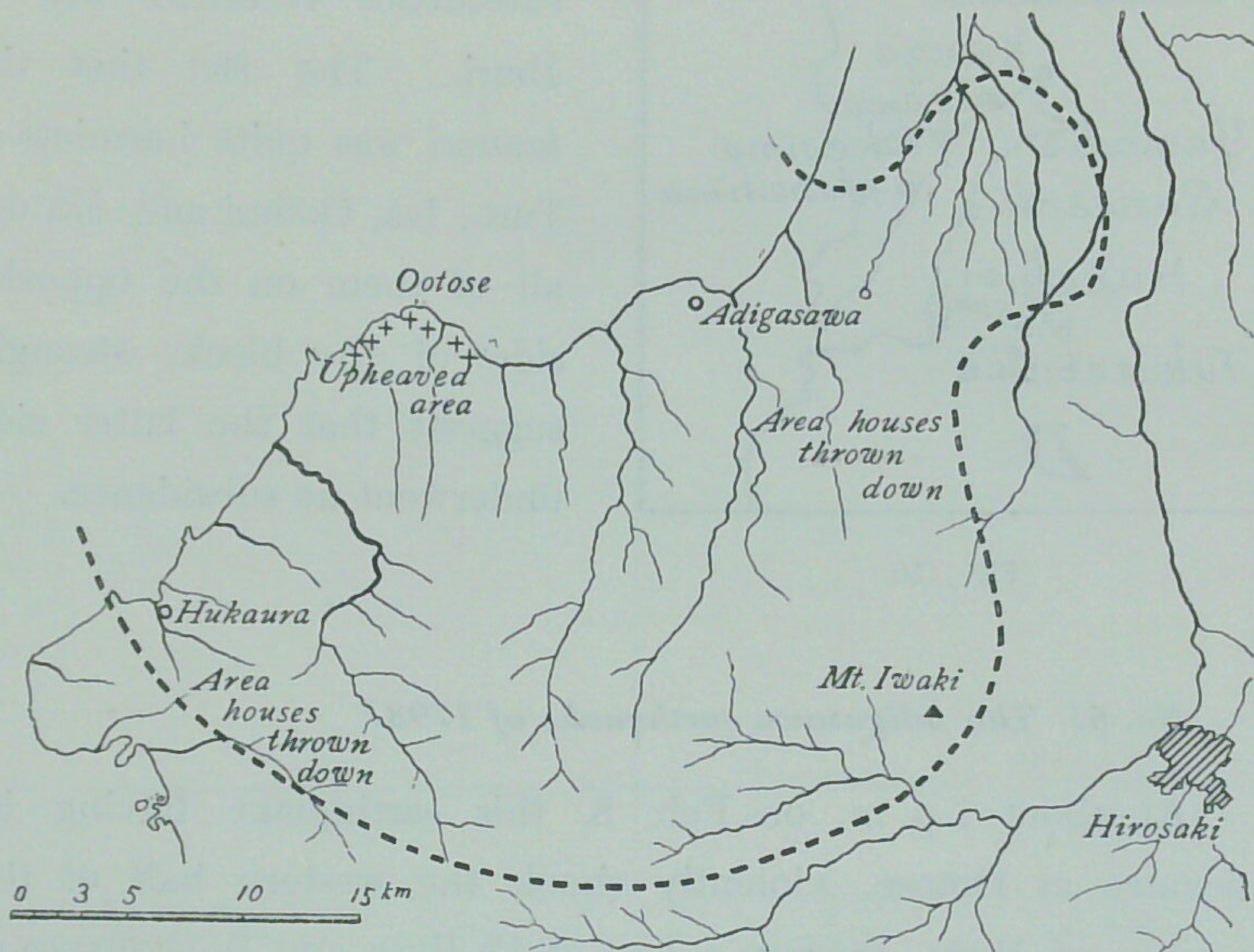

Fig. 11. Map showing the disturbed area in the Adigasawa earthquake of 1793.

on the seashore noticed an extraordinary ebbing of the tide which was mistaken for the warning of an approaching tunami, whereas it was nothing more than an upheaving process actually going on before their eyes. Horror stricken they fled into the hills and for some hours anxiously awaited there the dreaded tunami. To their consternation, however, what eventually did come was not the much dreaded wave but a tremendous earthquake. Owing to landslides and to falling boulders and other rock debris, they promptly forsook their place of refuge and made for the beach again, whereupon they were at last overtaken by the object of their first apprehension—the tunami.

It might be added that the district is Tertiary in formation, overlain here and there with new eruptives.

No. 7. The Sado earthquake of 1802.

This earthquake which took place on the 9th of Dec. at two in the afternoon, shook with great violence the southern part of Sado Island and caused the destruction of 1,150 houses through collapse or fire and a loss of 19 lives. The little seaport town of Ogi received the brunt of the shock, and here most of the buildings were shaken down, when eventually 328, out of the total number 453, caught fire.

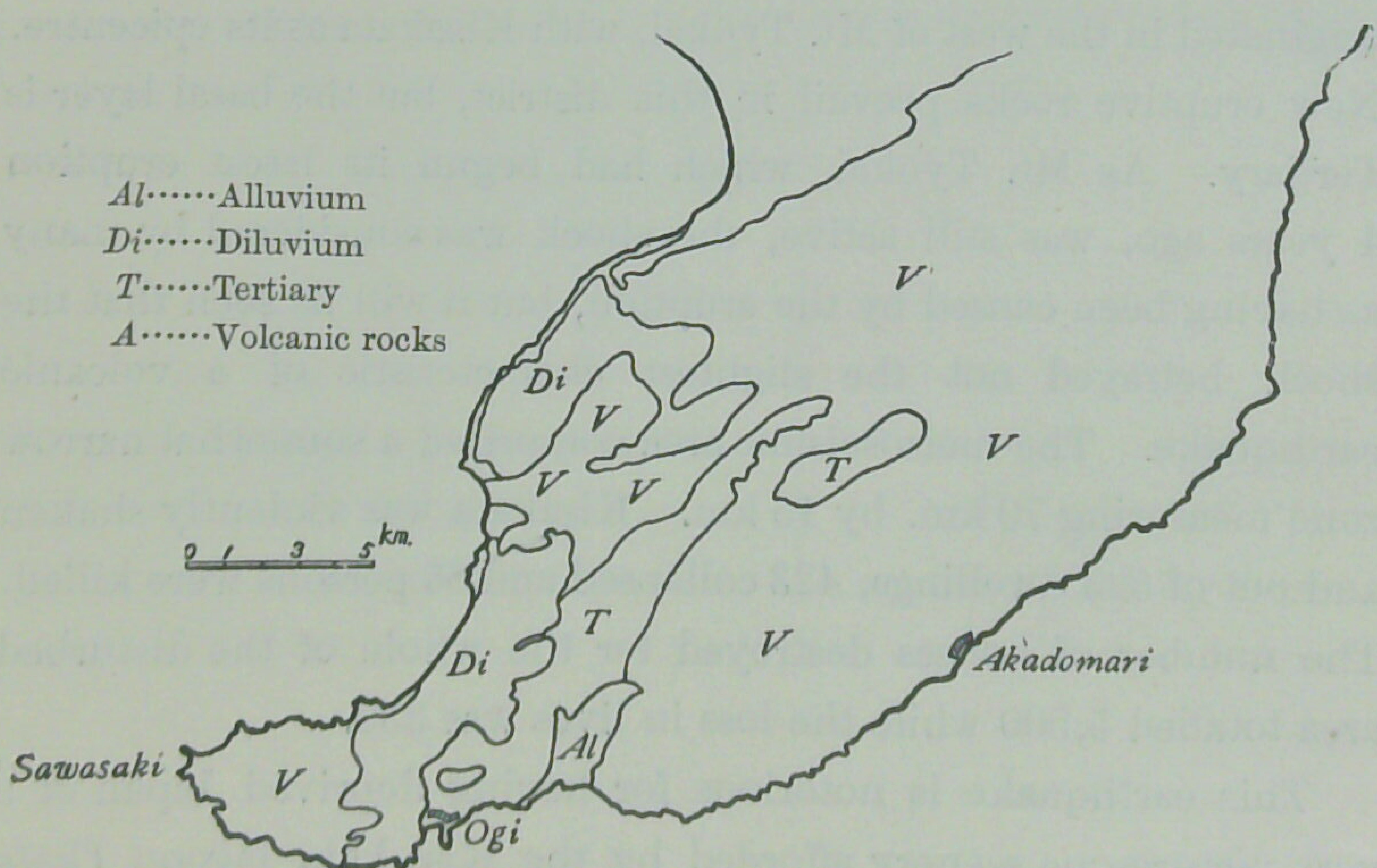

Fig. 12. Map showing the seismic area of the Sado earthquake.

At about 10 in the morning of the same day the place was visited by a somewhat milder shock. By this time an extraordinary ebbing of the tide was taking place until some parts of the harbour had become actually dry. The inhabitants however misinterpreted the phenomenon for the harbinger of a tidal wave, just as they did at the time of the Adigasawa earthquake as described in the preceding paragraphs. An accurate measurement of this upheaval is wanting, but we shall not be far wrong in assuming it to have been about a metre. The permanent uplift at Ogi however was as much as 2 metres. The coast was raised from Sawasaki in the east to as far as Akadomari in the east—a distance of nearly 25 km. The character of the formation here is also Tertiary, pierced at places by new eruptive rocks.

No. 8. The Kisakata earthquake of 1804.[1]

This earthquake which took place at midnight on July 10 originated in the west of Mt. Tyôkai, with Kisakata as its epicentre. New eruptive rocks prevail in this district, but the basal layer is Tertiary. As Mt. Tyôkai, which had begun its latest eruption 4 years ago, was still active, the shock was considered by many as having been caused by the eruption, but it will be seen that the shock betrayed not the slightest characteristic of a volcanic earthquake. The meizoseismic area comprised a somewhat narrow zone measuring 70 km. by 15 km. Kisakata was violently shaken and out of 523 dwellings, 423 collapsed and 65 persons were killed. The number of houses destroyed for the whole of the disturbed area totalled 5,500 while the loss in lives was 330.

This earthquake is notorious for having deprived Japan of a very picturesque scenery afforded by the Kisa-kata lagoon (kata

1) Loc. cit.

means lagoon). The lagoon had a circular area of about 2 km. radius and was filled to an average depth of 2 metres with clear sea water. The charm of the lagoon was greatly enhanced by 99 pine-clad islets that were dotted all over the placid waters. But the topography was changed overnight as the result of an upheaval of which the earthquake was an accompaniment, and with the sudden disappearance of the pretty lake there arose an aggregation of unsightly lands and muddy pools. Kisakata had arisen at least two metres, while at Konoura, some 6 km. away, the amount arisen was about 1.3 metres. It must be remarked that not all the changes were elevations: at localities not far removed there were subsidences as well. Thus at Kotaki about 4 km. to the southeast of Kisakata, an area of a few sq. km. was depressed about a metre in consequence of which the course of a stream was completely altered.

No. 9. The Zenkôzi (now Nagano) earthquake of 1847.

This earthquake, at about 9.30 on the evening of May 8, originated near Zenkôzi and laid waste the northern part of Sinano and the western part of Etigo; throwing down as many as 30,000 houses besides an additional 13,000 which were partially levelled. It came in the midst of a religious service at the Zenkôzi Temple so that thousands of devout worshippers were among the victims, besides some 8,500 others that met the same fate.

Fires promptly broke out in the towns of Zenkôzi, Iiyama, Inariyama, Sinmati, etc., and practically completed the destruction. In Zenkôzi out of a total of 2,236 dwellings only 142 were left unscathed by fire or earthquake.

The most characteristic phenomenon in connexion with this earthquake, however, was the extraordinary large number of landslides that took place and the consequences which they brought about. It is said that the number altogether did not fall short of 43,000, hence small wonder that many villages were buried under falling debris. The largest of these occurred between Komatubara and Sinmati (see Fig. 13) and completely blocked the course of the River Saikawa, with the result that in the course of a week or two there came into existence a temporary lake measuring 28 km. by 4 km. at its widest part. This new lake however was not destined to remain for long, for at the end of 19 days the blocking dam gave way and let loose the enormous quantity of water, giving rise to a terrible inundation which carried destruction before it, sweeping everything off both banks of the lower river course. Some 4,800 houses and 28 persons were thus swept away.

The topographical changes, with which we are most concerned in connexion with our studies, duly appeared in the form of a conspicuous fault line. It was in the meizoseismal area with a trend SW-NE and extended for about 8 km. At a point near Nagano the NW side of the fault had arisen as much as 2.4 metres relatively to the opposite side.

No. 10. The Iga-Ise Earthquake of 1854.[1]

This disasterous earthquake, which took place on July 9 at about two in the morning, laid waste not only a great part of the northern section of the province of Iga where it originated, but also the NE part of Ise and the N corner of Yamato as well; the casualties being some 5,000 houses destroyed and 1,352 persons killed.

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1) For details see A. Imamura: Rep. (in Japanese) Imp. Earthq. Inv. Comm. No. 77

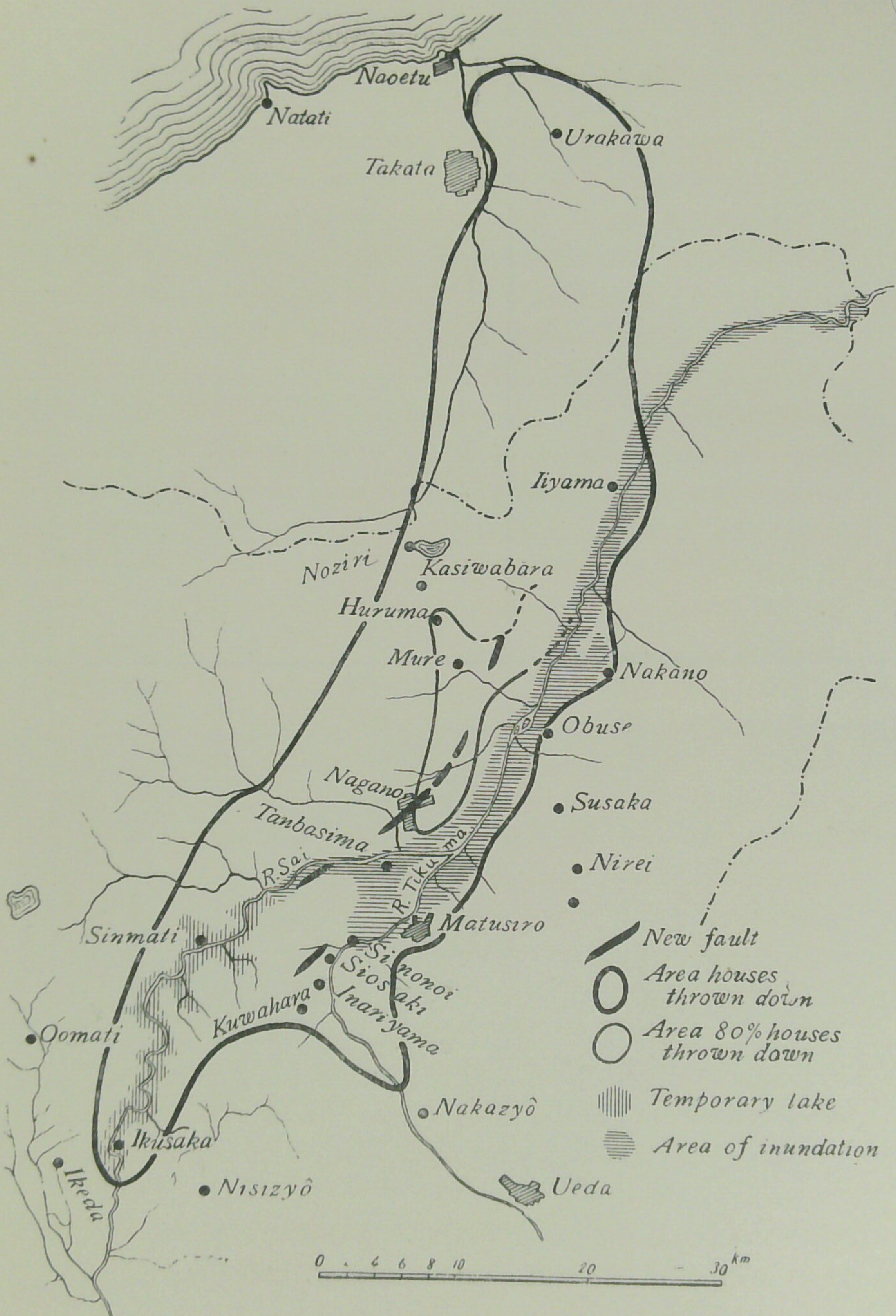

Fig. 13. Map showing the disturbed area in the Zenkôzi earthquake of 1847.

The coming of this earthquake was heralded by many fore-shocks, the earliest of which was felt 3 days before in the town of Ueno as scarcely more than subterranean rumblings. At noon of the 7th a strong shock was felt, followed by one still stronger two hours later. After that a succession of slight shocks followed, although most of them were mere rumblings. Twenty-seven of them were counted before evening. On the 8th things seemed to have quieted down somewhat, although in addition to a number of slight shocks, a moderate one was felt near two in the afternoon, succeeded by two or three more slight shocks until at 2 a.m. of the following morning came the final destructive shock.

The topographical change consisted of a relative subsidence in the epicentral area on the right bank of the river Tuge lying due north of the town of Ueno. For about 1 km. along the river course a strip some 200 m. wide had sunk down, and at the northern boundary of this sunken area was a dislocation with a trend WSW-ENE, while on its southern side there was a relative sinking of about 1.5 m. maximum. The result of this was that the water of river Tuge began to accumulate in the newly formed depression so that in the course of a few weeks a lake had been formed, and it was only after the river bed at a point lower down in its course had been cut down that the river assumed its normal flowage.

No. 11. The Nankaido earthquake of 1854.

This earthquake, which occurred on Dec. 24 at about 5 in the evening, that is 33 hours after a similar earthquake had originated off the coast of Tokaido, belonged to the non-local, destructive class and resembled in many ways the great earthquake of 1707 although its destructivity was not so great. The most violently shaken regions were the two provinces of Tosa and Awa and the southwestern part of Kii, the air-line distance from west to east of this area being 300 km. It also shook the northern part of Idumo levelling some 150 houses, but we have reasons for believing that this was owing to another large independent earthquake which was set in motion there by the earthquake under discussion.

As usual fires broke out in the towns of Kôti, Tokusima and Tanabe where 2,491, 1,000 and 383 houses were burnt down respectively. In addition to these, fires occurred also in Nakamura, Sukumo, Teiura, Yasuura, Hatanaka, Simoda, Simonokae and Urato.

The *tunami* travelled as far as the Bo-So Peninsula in the east and the eastern coast of Kyûsyû in the west. Its effects were most disasterous on the western coast of Kii and the western portion of the Tosa coast; the wave having swept away as many as 9,000 houses in the former and 3,200 in the latter. The scourging received by Osaka from the earthquake wave of 1707 was almost duplicated, the loss to small craft and bridges being considerable, while as many as 392 persons were drowned in the rivers. Waves also swept through the Bungo Channel and washed the shores of Mitugahama in Iyo Province.

The full casualty list reads:—10,000 houses levelled, 6,000 reduced to ashes, 15,000 washed away and 3,000 people killed.

As to the topographical alterations, there is abundant reason for assuming that those which took place in Tosa more or less resembled those associated with the earthquake of 1707, especially was this the case with the subsidences that took place in Kôti and environs, although they were on a somewhat smaller scale. In Kasiwazima, situated on the northern boundary of block E (see Fig. 7), there was a depression of at least one foot.

As regards changes in the Kii Peninsula, they have been fully discussed by the writer elsewhere.[1] Briefly, it consisted of an acute, onward tilting in a meridional direction, raising the southern end of the southernmost Tertiary block as much as 1.3 metres and causing the so-called *median line* in the north to dip as much as 1 metre.

No. 12. The Hamada earthquake of 1782.[2]

This earthquake, which took place at about 5.20 p.m. on March 14, originated in the central coast of Iwami with Hamada in its epicentral area. The area of maximum disturbance, however, embraced in addition the north-eastern part of Iwami and the north-western part of Idumo, all of which would suggest that the earthquake had its origin in a comparatively narrow zone running near the coast and parallel to it. Some 5,000 houses were shaken down with a loss of 552 lives.

The topographical changes which the earthquake accompanied were indeed remarkable. Briefly stated, the upheaval was on the south-eastern side of a line drawn through Hamada in a north-westerly direction, while the subsidence was on the opposite side of this imaginary line. Taken southwards in order from the north-east corner, the records of upheaval are:—Kawanami an appreciable amount; U-sima more than 2 feet; Kusiro 2–6 ft.; from Matusima as far as Kanasubu 4–5 ft.; Tatamiura 3–4 ft.; a hill in the south of Hamada 1–2 ft.; and the coast SW of the same town 5 ft.

The records of subsidence on the other hand give:—Gosyoyu in Kokubu village 1.5 ft.; Matubara an average of 4 ft.; a hill in the

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

2) For details see A. Imamura: Rep. (in Japanese) Imp. Earthq .Inv. Comm., No. 77.

north of Hamada 1-2 ft.; at Siroyama (hill) 12 ft.; the western coast of Hamada 1-2 ft.; Setogasima (island) 3 ft.; Nagahama (about 4 km. SW of Hamada) 3 ft.; and at Ooasa (about 5 km. SW of Nagahama) 3 ft. along the coast for a distance of 1 km.

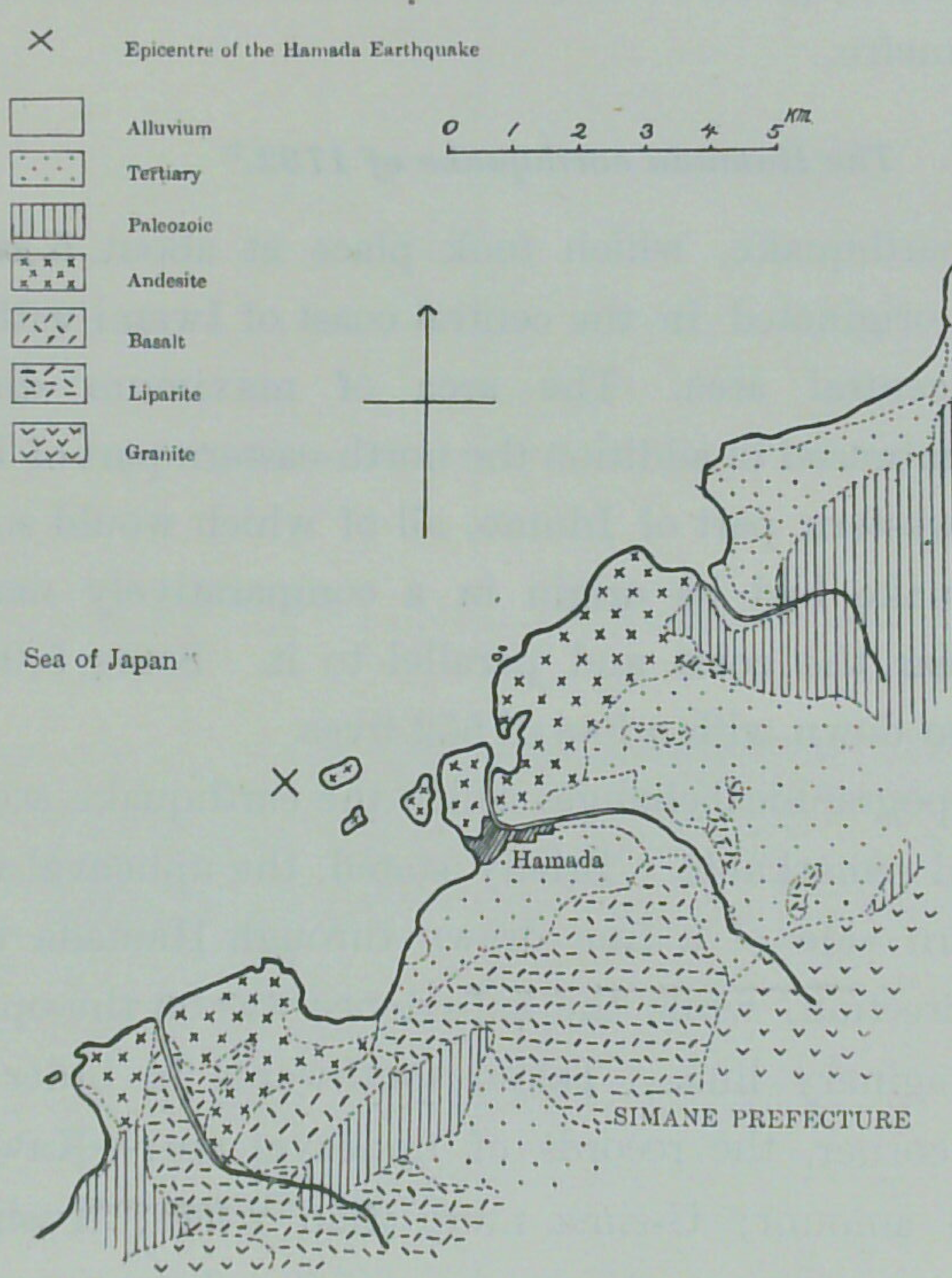

Fig. 14. Geological map of the Hamada district.

The coast line along which these changes occurred is about 20 km. long. We would add that the raised places were generally of Tertiary formation while those that had sunk down were mostly of pre-Tertiary age. The dominant feature of these topographical changes was that the greater the distance of a locality from the line separating the uplifts from the depressions, the more pronounced was the elevation or depression as the case might be. Thus the change of level at a place in a line drawn at right angles

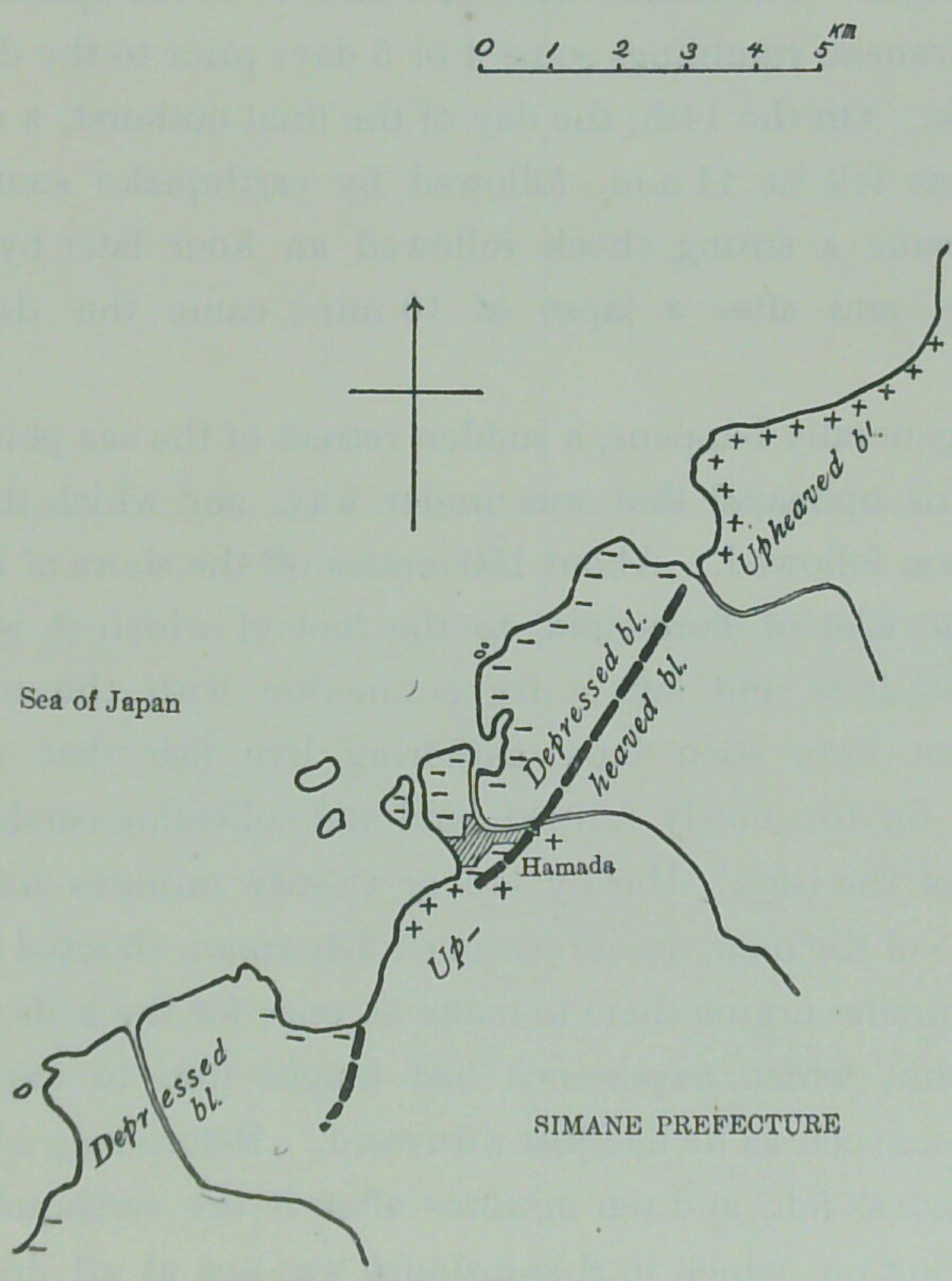

Fig. 15 Map showing the topographical changes accompanied by the Hamada earthquake.

to the boundary line just mentioned would appear as diagrammatically shown in the accompanying figure, a character so often exhibited in connexion with the appearance of a fault line.

Two more interesting phenomena were observed in connexion with this earthquake, namely, fore-shocks and pre-seismic topographic changes. The former were first noticed at the epicentral area as subterranean rumblings some 4 or 5 days prior to the day of the big shock. On the 14th, the day of the final outburst, a moderate shock was felt at 11 a.m. followed by earthquake sounds. At 4 p.m. came a strong shock followed an hour later by one less energetic, and after a lapse of 10 min. came the destructive shock.

As generally happens, a sudden retreat of the sea pointed to a pre-seismic upheaval that was under way, and which this earthquake soon followed. About 150 metres off the shore of Hamada-ura is the islet of Turu-sima, to the foot of which it is said the water withdrew and left a dry connexion with the mainland. Fishermen were soon busy gathering live fish that were left stranded on the newly formed land and collecting earshells from the foot of the islet. Hardly ten or twenty minutes had passed when one of the men, an old seasoned fisherman, shouted excitedly to his comrades urging them to make at once for the hills to escape the tunami, which experience had taught him to expect from phenomena such as he had just witnessed. Before long a tremendous shock was felt, and ten minutes after it the earthquake wave came rolling on, which in this instance was not at all destructive. We are told that similar phenomena repeated themselves also at Nagahama and Kokubo, situated about 10 km. from Hamada, as well as at Isotake and Yusato some 40 km. distant from the same town.

No. 13. The Riku-U earthquake of 1896.[1]

This earthquake occurred on Aug. 31 at 5.06 p.m. in that district whose central axis forms a part of the boundary of the provinces of Rikutyû and Ugo. The earthquake was unique in more respects than one. It took place in a strong gale, when the anemometer of the Akita Meteorological Station was recording a velocity as high as 20 m/s, thus furnishing an exception to the statement made by the late Prof. Omori that destructive earthquakes take place in fair weather. Another remarkable thing was that in spite of the high wind there was no outbreak of fire, with the result that the ratio of deaths to the number of houses thrown down was very small; the respective figures being 206 and 6,000. This extraordinary small ratio is to be explained, however, by the occurrence of remarkable fore-shocks which served as timely warnings to the inhabitants of the approaching big shock, so that they were able to extinguish all fires and betake themselves outdoors.

The fore-shocks began on the 23rd with a slight one at 4.25 a.m. and another one at 1.33 p.m. The first strong shock, however, was felt at 3.57 p.m. of the same day in the northern part of the above-mentioned district with the village of Obonai as its centre. Altogether, the following shocks were experienced:—

On the 23rd—Five weak shocks between 4–6 p.m. and ten moderate ones between 6–11 p.m.
do. 24th—Five slight shocks between 0–5 a.m. and one at 9.16 a.m.
„ 25th—A weak shock at 5.13 a.m. and at 1.32 p.m.
„ 26th—Two or three slight shocks.
„ 27th— do.

1) See N. Yamasaki: Rep. Imp. Earthq. Inv. Comm., No. 11 and A. Imamura, do. 79.

On the 28th—A weak shock at 6.27 p.m.
do. 31st—Weak shocks at 8.33, 8.52, 9.58, and at 10.13 a.m. A slight shock at 3.07 and at 3.18 p.m. A strong shock at 4.42 p.m. followed by a weak shock at 5.50 p.m. The final destructive shock at 5.06 p.m.

The morning of the eventful day was unusually active. Then there was a short lull which was broken by a strong shock that came at 4.42 in the afternoon. Thenceforth it appeared to the

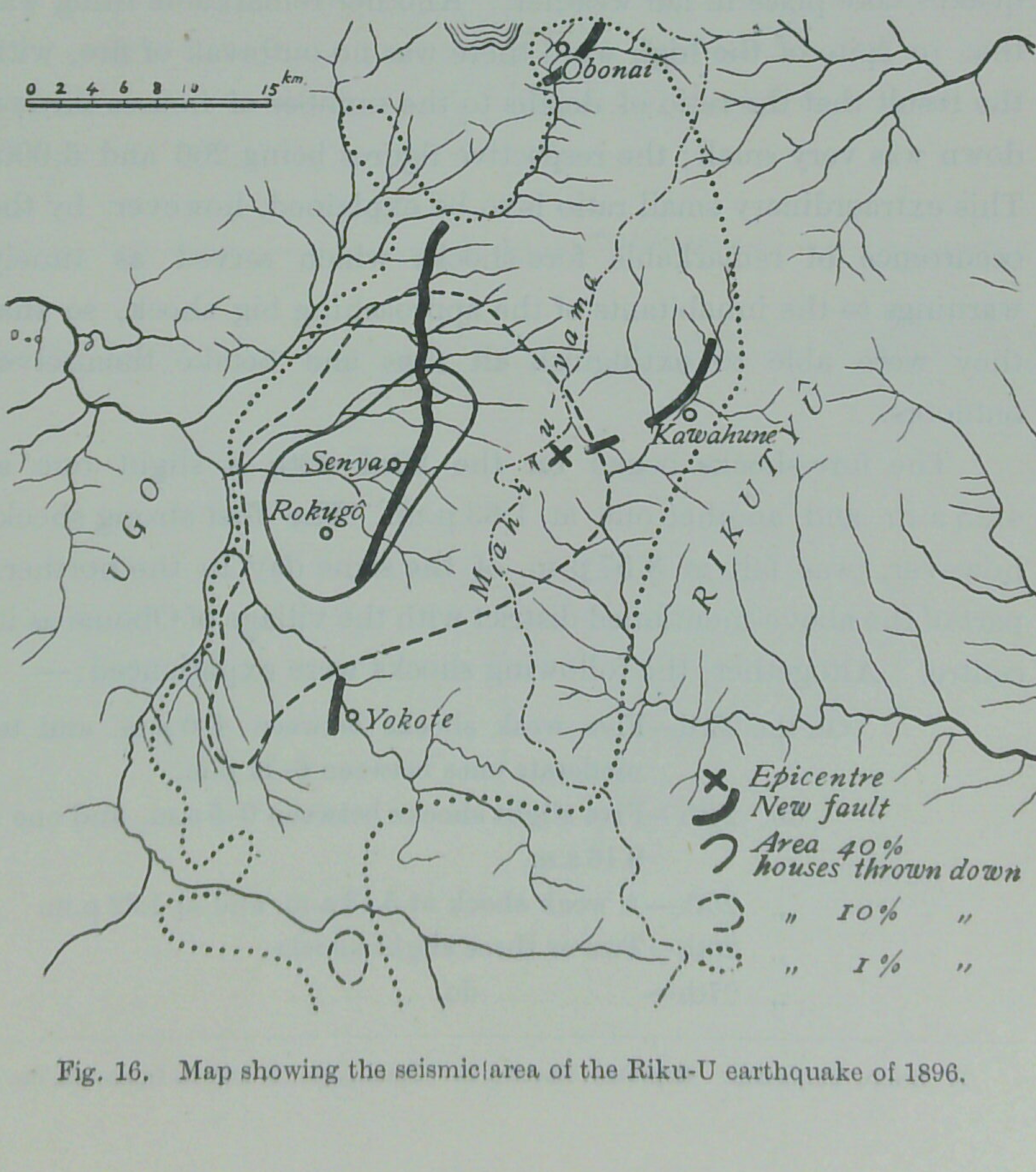

Fig. 16. Map showing the seismic area of the Riku-U earthquake of 1896.

anxious people as if the earth had been trembling incessantly for almost an hour when the climax was reached with the arrival of the tremendous shock that caused such wide-spread damage.

A remarkable topographical change was the appearance of two faults named the Senya and Kawahune faults by Prof. N. Yamasaki, who was the first to investigate them. The former could be traced from Obonai in the north to Yokote in the south, with a track trending N-by-E to S-by-W along the boundary of a Tertiary hill called Mahiruyama and a flat Diluvium ground skirting the former. It extended for about 60 km. with a maximum vertical dislocation of nearly 2.5 m. near Senya, upheaving the Tertiary side relatively to the western side. The Kawahune fault was somewhat similarly placed along the eastern boundary of the same hill; extending for some 10 km. with a maximum vertical dislocation of nearly 2 m., and raising the western Tertiary side relatively to the opposite side. Neither of the faults showed any traces of horizontal shifting.

Prof. Yamasaki believed that the Kawahune fault ran almost parallel to the other fault, but the writer after careful examination on the spot in 1910, came to the conclusion that the southern part of the Kawahune fault had its trend nearly at right angles to the other fault.

The mechanism involved in the case of this earthquake would seem to have consisted of an uplift of the wedge-shaped Tertiary block relatively to the contiguous block—a character that was also exhibited in the case of the Mino-Owari earthquake of 1891.

No. 14. The Formosa earthquake of 1906.[1]

The earthquake of Mar. 17, 1906, was the worst that shook

1) For details see F. Omori: Bul. Imp. Earthq. Inv. Comm., Vol. I, No. 2.

Formosa in recent years, being even more destructive than the well-known shock of June 8, 1862. The casualties were

Number of dwellings totally destroyed.	7,284
" " " partially "	30,021
" " persons killed.	1,266
" " " wounded.	2,476

The heavy fatalities were due in large measure to the poor quality of the native houses. They were built of sun-dried, mud bricks measuring 22 × 33 × 9.5 cm, loosely cemented with a mortar of mud, and at best mixed with a small quantity of lime. Obviously, houses constructed of such weak material had not the slightest chance of withstanding a vigorous shock, and this coupled with the heavy roofs, made matters worse so that with the

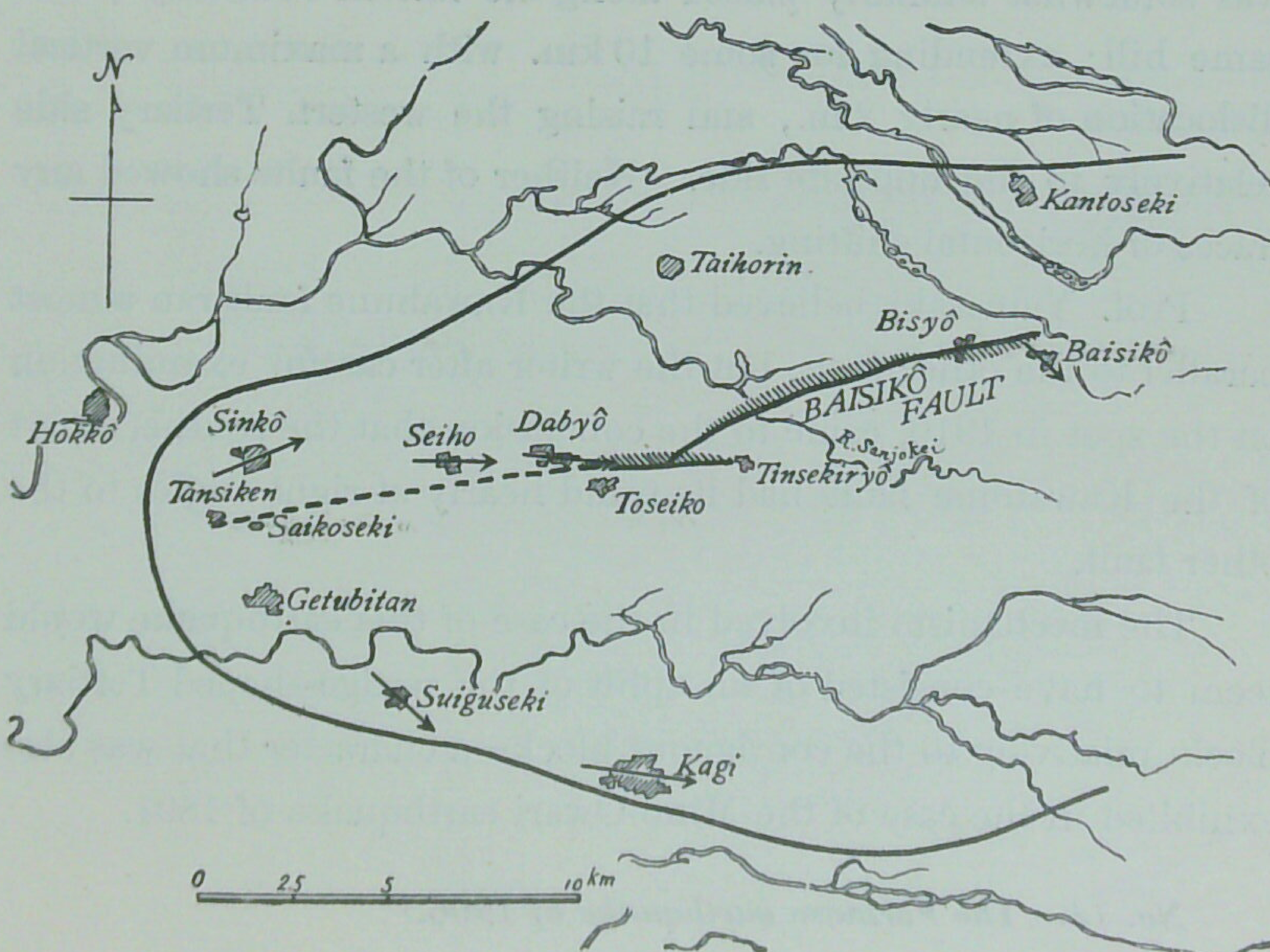

Fig. 17. Map showing the seismic area of the Formosa earthquake of 1906 (The shaded part is the depressed side, the arrow the direction of max. earth-movement.)

first violent shock they were mostly shattered to pieces, leaving little time for the inmates to escape.

The meizoseismic area, which is of Tertiary formation partly overlain by Diluvium, was about 50 km. in length, extending from the vicinity of the town of Baisikô on the east to the city of Sinkô on the west, and about 30 km. in width from the vicinity of the city of Kagi on the south to that of the village of Tarimu on the north. From the limited extent of the area of severe motion, it may be inferred at once that the earthquake centre was not situated deep below the surface, as was in fact indicated by the formation of faults.

The main fault line is most conspicuous at its eastern end, where it crosses the road leading from the town of Taihorin to Baisiko, at a distance of about one km. from the latter town. The fault here runs in a direction N75°E-S75°W, the south side being depressed 6 feet and sheared relatively 6 feet westwards. The small village of Bisyô, under which the fault passed, was completely destroyed. The western continuation of the fault crosses the spur of a Tertiary hill, appearing again to the south of the village of Kaigenkô, at about a km. from Bisyô. The fault then takes a mean direction of N75°E-S75°W and crosses the River Sanzyo-kei, eventually joining the branch fault of Tinsekiryô. This second fault starts from about half a km. to the west of Tinsekiryô, from the top of a gently sloping hill of hard clay, where it shows itself for the first time as a remarkable deep crack two feet wide and 11 feet deep. This fault is nearly in the E-W direction and its western continuation runs through paddy fields to the north of the village of Toseikô, finally reaching the city of Dabyô, beyond whence the disturbance of the ground ceases to be visible. The length of the main fault is about 11 km. while that of the branch fault is a little over 4 km., the entire length between the Dabyô and Baisikô extremities being 13.5 km.

As stated above, at the eastern extremity of the main fault the south side was depressed and sheared westwards. This condition, however, was reversed in the remainder of the fault, the depression now being invariably on the north side with the shearing eastwards. The maximum amount of the eastward shear was 8 feet and occurred at the village of Kaigenkô, while the northward depression of 4 feet occurred at the last-named place, and also at, as well as near, the place where the fault crosses the Sanzyo-kei River. Along the Tinsekiryô fault the depression was always on the north side, and the shear, the maximum amount of which was 5 feet, was eastwards. In this case, the vertical dislocation was slight and hardly amounted to a foot; too often the only indication being a gradual depression which caused the waters in the paddy fields to collect on one side of the line of disturbance, leaving the other side dry.

To the west of Dabyô there was no surface manifestation of tectonic disturbance; but it is highly probable that there exists an underground continuation of the fault for about 12 km. in the direction W-by-S, as far as the vicinity of the city of Sinkô. Along the zone about this imaginary fault, which is marked in Fig. 17 by a dotted line, large quantities of sand and mud were ejected. Especially, in the vicinity of the villages of Tansiken and Saikoseki, the ejected sand reached a thickness of more than two feet and covered wide areas sometimes half a km. or more in width. The total length of the fault between Baisikô on the east and Tansiken on the west is 25.5 km.

Chapter III. Recent Topographical Changes that Were Accompanied by Earthquakes and which Were Investigated by Means of Precise Levellings.

During the past 40 years in Japan, there have been numerous occasions in which it was possible, by means of precise levellings, to determine accurately the topographical changes that have taken place in connexion with earthquakes. Particulars of results thus attained will be found summarized in the accompanying table. From data given in this table it will be seen that topographical changes have occurred even in the case of moderate shocks, for earthquakes Nos. 17, 20, 21 and 26 can by no means be ranked as severe. It must, however, be admitted that most of the data have been derived, either in whole or in part, from observations that were carried out over lengthy periods prior to, or after, the occurrence of the particular earthquake concerned, so that the data may not altogether be free from the secular variations of land-level. Strictly speaking, the only data which are free from this objection are those due to earthquake No. 26—the Sekihara earthquake of 1927. Since in this case the levellings were carried out three times, the dates of the second and third of which were very close to that of the occurrence of the earthquake, the one being before and the other being after it, there was no difficulty in estimating the secular as well as the acute variations. It must be remarked, however, that the change of land-level which had been going on for 33 years prior to the earthquake was quite similar in character and almost equal in magnitude to the change that came with the earthquake itself. Or in other words, had the second survey never been held, the only data at our disposal would have been the algebraical sum of two unknown quantities, which in the

TABLE III.

Earthquake			Bench-mark route	Year of survey		Topographical change	
No.	Date	Locality[1]		Former	Later	Place	max. height
							cm.
15	1891 X 28	Mino & Owari.	360 km. (across)	1885	1894–99	Whole disturbed	77
						area.	−42
16	1894 VI 20	40 km. N.	100 km. in S part	1892	1895, 1898,	N part of survey-	−3.3
		of Tokyo.	of epic. area.		1902.	ed area.	
17	1897 I 17	N part of Sinano.	50 km. (across)	1894	1927	Meizoseismic area.	8
18	1909 VIII 14	Anegawa.	S part of	1896,	1899	SE protuberance of	3.4
			epic. area.	1899	1917	meizoseismic area.	−12.1
19	1917 I 5	Horisya, Formosa.	170 km. (across)	1914	1924	Epic. area.	16
20	1918 XI 11	Oomati, Sinano.	111.7 km. (across)	1891–93	1920	Epic. area.	19
						60–70km. N of epic.	−20
21	1919 XI 1	Miyosi, Bingo.	300 km. (across)	1892	1921	Near epic.	−7.8
22	1922 XII 8	Simabara, Hizen.	130 km. (around)	1894, 1897	1923	Near epic.	8
23	1923 IX 1	Kwanto.	1500 km.	1800–1920	1923–25	Near epic.	201
						NW part of Kwanto.	−162
			84 km. (across)	1923	1924	Miura Peninsula.	−5.4
			do.	1924	1925	do.	2.6
24	1925 V 23	Tazima.	SE part of epic. area.	1887–88	1927	S part of epic. area.	−35
25	1927 III 7	Tango.	100 km. (across)	1887–88	1927	Meizoseismic area.	90
							−32
			do., with additional	1927	1927	do.	1.2
			routes.				−1.4
				1927	1928	do.	
26	1927 X 27	Sekihara, Etigo.	20 km. (across)	1894	1927		2.7
				1927	1927		2.1

1) See Fig. 3.

present case happen to be almost equal to each other, so that we may regard one-half the sum as an approximate indication of the chronic or the acute variation, whichever we may choose to take. More examples might be offered of cases in which the dates of the pre-seismic and post-seismic surveys were near the dates of the earthquake concerned; namely, earthquakes Nos. 15, 16, 18, and 23.

In all these cases, the topographical changes deduced in the manner just stated may be regarded as being very nearly the same as those changes wrought by the earthquake itself. This is especially the case with No. 18, the Anegawa earthquake of 1909, the district of which was surveyed four times—the first three before, and the last one 8 years after the occurrence of the earthquake. Granted that secular variation took place in a fairly uniform manner during the pre-seismic period, it may then be said that we have here sufficient data for evaluating both changes of land-level, secular and acute.

As regards the Anegawa and the Sekihara earthquakes, it will be noticed that besides other topographical changes, pre-seismic changes had duly taken place. As the change occurred in the same sense as that of the last acute change, it may properly be called the pre-seismic change of the second stage. According to investigations of Prof. Ishimoto, it is more than likely that most earthquakes, whether moderate or slight, are preceded by earth-tiltings of the third stage. At all events, the occurrence of pre-seismic changes in connexion with such severe earthquakes as those mentioned above need not be regarded as in any way uncommon.

Precise levelling affords us the means of recognising the various characteristics of the topographical changes that take place accompanied by earthquakes, but one of the most remarkable revelations is that the changes consist in the main of a series of independent tiltings undergone by mosaic blocks, the movements of which when taken as a whole constitute what we call the earthquake district. Prof. N. Yamasaki was the first to point out this characteristic in connexion with the Etigo district. The writer has similarly called attention to the chronic tiltings now going on in the Kii Peninsula. That such characteristics are to be found in connexion with actual earthquakes or even with volcanic eruptions has been pointed out by Mr. C. Tsuboi[1] Seeing that a fault line is nothing but the gap-line of earth-tiltings occurring in consecutive blocks, the investigation of faults by means of precise levellings ought to yield results unattainable otherwise.

Hardly necessary is it to add that the topographical changes which we are now considering must also occur in the horizontal direction as well. The importance of investigating this component will be realized when one sees the results that were obtained by means of geodetic triangulations carried out repeatedly both before and after the great Kwanto earthquake of 1923, or the great Tango earthquake of 1927. While the importance of such investigations is fully appreciated, yet we must reluctantly own that they have rarely been attempted because of the great cost of the undertaking. In this country the only investigation of the kind made, in addition to those two just mentioned, was that carried out in 1914 in connexion with the Sakurazima eruption.

In the following paragraphs will be given detailed accounts of these earthquakes with special reference to the topographical changes which they accompanied, and which were revealed by means of precise levellings.

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1) C. Tsuboi: Bull. Earthq. Res. Institute, Vol. VII.

No. 15. The Mino-Owari earthquake of 1891.

This tremendous shock, which took place on Oct. 28 at 6.37 a.m., resulted in the loss of 7,273 lives and destruction of 142,177 houses. According to Prof. B. Koto[1], it was caused by a gigantic fault known as the Neo-valley (Neo-dani) fault. The track of the fault extended from Gongenyama (A) in the north to Katabira (a') in the south-east, though it was later proved to extend as far northwards as Hukui. The late Prof. F. Omori investigated another branch fault which was found to be essentially coincident in its northern part with the northern extension of the Neodani fault just mentioned, but differing from that of Prof. Koto in its southern part (B'), the latter running parallel to the Neodani fault proper as shown in Fig. 18.

Prof. Omori assigned the name Neodani fault to the main branch of the fault (Aaa'), and Kurotu-Atumi fault to the northern segment (BB'), having taken the two to form a single fault-system. The distance between the two segments where they run parallel to one another is about 4 km., while the total extension measures about 92 km.[2] The dislocation was seen to be most marked in the main branch at the hamlet of Midori, where the western side of the fault made a relative depression of as much as 6 m. and a relative shifting of as much as 2 m. towards S-by-E. A similar dislocation, though on a much smaller scale, occurred near the northern end of the northern segment. Besides what we have just mentioned, dislocations occurred in both segments in numerous ways, but they closely resembled each other consisting invariably of a relative depression on the eastern or north-eastern side with slight shearing relatively towards the north or to the north-west.

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1) B. Koto: Jour. Col. Sc. Imp. Univ. Japan, Vol. 5 (1893).
2) F. Omori: Rep. (in Japanese) Imp. Earthq. Inv. Comm., No. 88.

According to Prof. Omori, there was another segment of fault (A''), which when produced northwards formed one continuous line with the northern part of the main fault. No dislocation was apparent, but in view of the occurrencc of a tilting of the ground along this line, its existence is undoubted. A triangular block bounded by aa' and A'' was lifted up relatively to the surrounding blocks; a feature similar to that exhibited by the Senya and the Kawahune faults in connexion with the Riku-U earthquake of 1896.

Investigations of the three segments of the so-called Neodani fault have thus far been based on data as mentioned in the foregoing paragraphs. It will be noticed that these segments are arranged *en échelon* as we have seen in the case of the Gomura fault in connexion with the destructive Tango earthquake of 1927. The writer, however, is of the opinion that the fault was much more extensive than what Prof. Omori had found from his investigations. Besides the three segments already mentioned, there may have been involved one (C) lying near Maruoka, another (DD') lying to the west of the A''-fault and parallel to it, and a third (b) lying north-east of the south-eastern part of the main fault and parallel to it. Details are given in the following paragraphs.

Quite recently, through the courtesy of Major-General H. Omura, Director of the Military Land Survey Department, the writer was furnished with results of precise levellings repeatedly carried out, both before and after the great earthquake, over the different routes in the seismic area. These data, together with those that were published in 1903, proved extremely valuable in the present investigation. The routes and the years of survey are shown in Fig. 19, and the results in Table IV and Fig. 20.

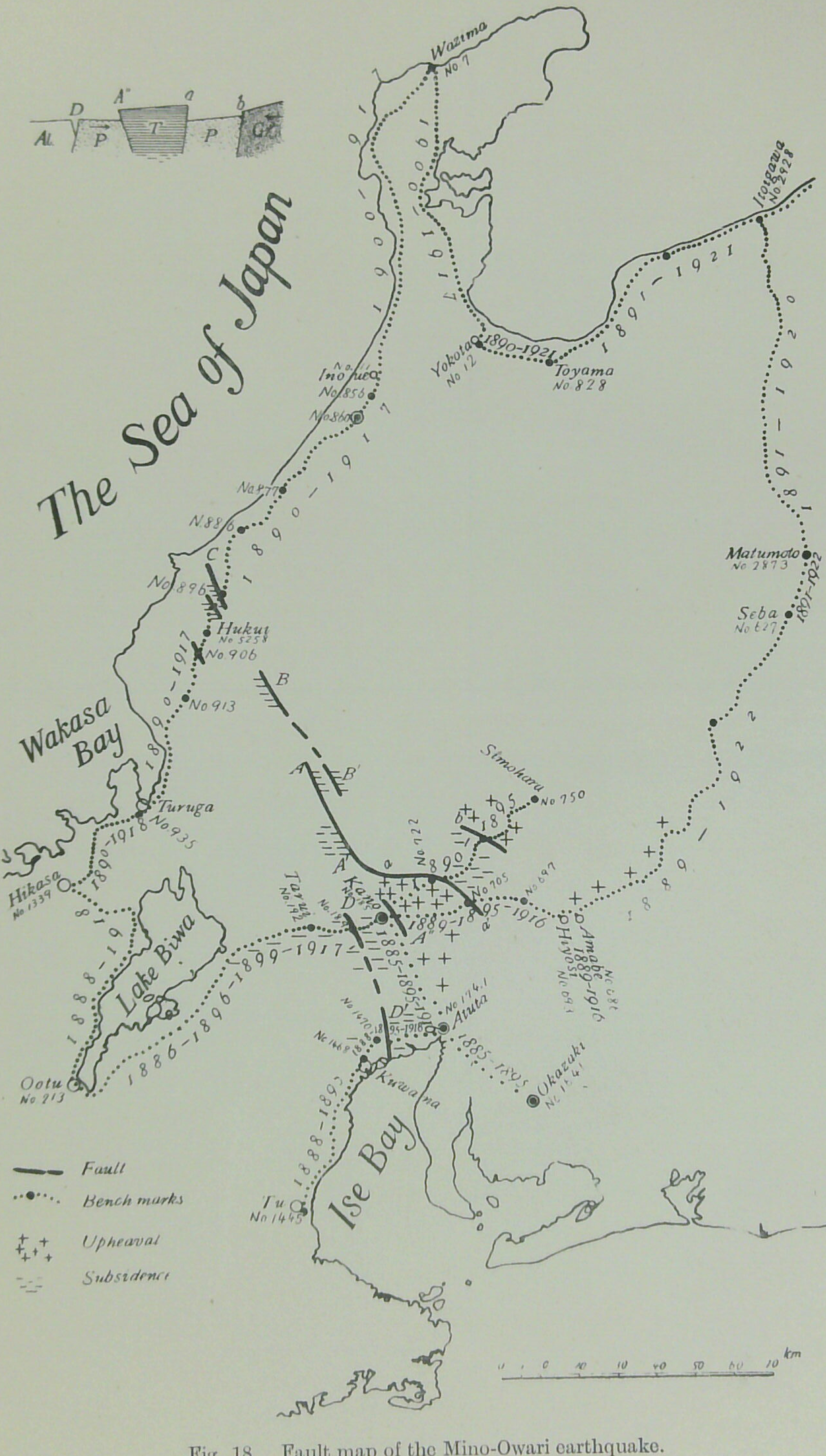

Fig. 18. Fault map of the Mino-Owari earthquake.

Fig. 19. Levelling routes in the northern part of Central Japan.

Table IV. Height differences of the bench-marks in the northern part of Central Japan.

(1) Section between Wazima and Hikasa.

B.M.	H. in 1917 − H. in 1900	B.M.	H. in 1917 − H. in 1900
	mm		mm
7 (Wazima)	0.0	9249	+ 6.9
9275*	—	9248	− 1.8
9274	− 2.9	9247	+ 8.6
9273	− 2.0	9246	+ 15.5
9272	− 6.2	9245	+ 6.3
9271	− 9.1	9244	+ 6.5
9270	− 12.8	9243	+ 14.6
9269	− 16.3	9242	+ 10.8
9268	− 8.8	9241	+ 1.2
9267	− 6.9	9240	+ 10.9
9266	− 20.9	9239	+ 11.7
9265	− 13.0	9238	+ 10.5
9264	− 12.4	9237	+ 5.2
9263	− 15.9	9236	+ 6.7
9262	− 7.3	9235	+ 0.1
9261	− 9.8	9234	+ 7.1
9260	− 23.8	9233	+ 11.5
9259	− 3.6	9232	+ 11.4
9258	− 5.8	9231	− 6.4
9257	− 3.1	9230	+ 3.0
9256	− 3.5	9229	+ 14.9
9255	− 5.2	9228	+ 12.3
9254	− 7.0	9227	− 52.0
9253	− 7.5	9226	+ 5.1
9252	− 9.6	9225*	—
9251	− 2.4	9224	+ 4.9
9250	+ 12.4	9223	+ 7.4

Table IV. (*continued*)

B.M.	H. in 1917 − H. in 1900
	mm
9222	+ 8.8
11 (Inoue)	+ 12.4

B.M.	H in 1917 − H. in 1890
	mm
11 (Inoue)	+ 12.4
855	+ 14.3
856	+ 14.1
857	+ 14.0
858	+ 16.4
859	+ 15.8
860	− 38.1
861	+ 3.2
862	+ 15.0
863	+ 23.5
864	+ 20.6
865	+ 14.4
866	+ 12.7
867	+ 14.8
868	+ 15.7
869	+ 17.7
870	+ 16.0
871	+ 14.8
872	+ 18.9
873	+ 20.2
874	+ 17.8
875	+ 18.8
876	+ 19.9

B.M.	H. in 1917 − H. in 1890
	mm
877	+ 20.9
878	+ 24.2
879	+ 19.2
880	+ 14.9
881	+ 11.4
882	− 8.0
883	− 8.8
884	+ 0.9
885	+ 6.4
886	+ 3.5
887	− 6.1
888	− 6.1
889	− 15.7
890	− 15.6
891	− 21.2
892	− 26.5
893	− 26.5
894	− 32.8
895	− 43.3
896	− 76.2
897	− 61.0
898	− 47.7
899	− 39.1
900	− 66.9
901	− 45.7
902	− 48.1
5258 (Hukui)	− 44.0
903	− 47.1

Table IV. (*continued*)

B.M.	H. in 1917 − H. in 1890	B.M.	H. in 1917 − H. in 1890
	mm		mm
904	− 40.8	932	+ 45.3
905	− 41.3	933	+ 41.2
906	− 49.6	934	+ 0.8
907	− 31.4	935 (Turuga)	+ 22.7
908	− 16.5	936*	—
909	+ 3.3	937*	—
910	− 3.5	938	+ 34.9
911	+ 0.7		
912	− 14.1	B.M.	H. in 1918 − H. in 1890
913	+ 7.5		
914	+ 11.9	938	+ 34.9
915	+ 17.4	939*	—
916	+ 35.3	940	+ 37.2
917	+ 39.8	941	+ 38.1
918	+ 39.7	942	+ 16.6
919	+ 43.4	943	+ 31.7
920	+ 42.7	944	+ 18.0
921*	—	945	+ 29.4
922	+ 7.9	946	+ 22.4
923	+ 38.9	947	+ 20.4
924	+ 23.5	948	+ 16.7
925*	—	949	+ 18.9
926*	—	950	+ 22.0
927	+ 39.6	951*	—
928	+ 32.9	952	+ 24.2
929	+ 40.0	953	+ 26.0
930	+ 34.5	954	+ 29.0
931	+ 52.0	1339 (Hikasa)	+ 36.0

Table IV. (*continued*)

(2) Section between Hikasa and Ootu.

B.M.	H. in 1918 − H. in 1888	B.M.	H. in 1918 − H. in 1888
	mm		mm
1339 (Hikasa)	+ 36.0	1318	+ 5.8
1338	+ 30.4	1317*	—
1337	+ 33.7	1316	+ 0.9
1336	+ 31.5	1315	+ 1.6
1335*	—	1314	+ 0.3
1334*	—	1313	− 0.9
1333	+ 29.2	1312	+ 4.9
1332	+ 27.9	1311	+ 7.3
1331	+ 26.6	1310*	—
1330	+ 17.6	1309	+ 7.9
1329*	—	1308	+ 14.5
1328	+ 6.9	1307	+ 4.5
1327	+ 7.0	1306	+ 6.9
1326	− 2.4	1305	+ 11.5
1325	− 3.4	1304	+ 15.7
1324	− 25.7	1303	+ 15.7
1323	+ 1.4	1302	+ 10.2
1322	− 5.0	1301	+ 10.7
1321	− 6.6	1300	+ 13.3
1320	− 2.7	213 (Ootu)	+ 17.6
1319	+ 2.8		

Table IV. (*continued*)

(3) Section between Ootu and Kanô.

B.M.	H. in 1896–1899 − H. in 1885	H. in 1899 − H. in 1896	H. in 1917 − H. in 1889–1899
	mm	mm	mm
214	− 2.4	—	—
213	—*	+ 0.0	+ 17.6
212.1	—	+ 3.0	+ 18.4
212	+ 7.5	+ 3.0	+ 14.7
211.1	—	+ 1.0	+ 7.4
211	− 5.2	+ 4.9	+ 27.7
210.1	—	+ 1.3	+ 32.6
210	− 5.9	+ 1.9	+ 30.6
209.1	—	+ 1.1	+ 28.6
209	− 10.0	− 1.6	+ 34.7
208.1	—	− 1.4	+ 29.7
208	− 22.0	− 3.0	+ 27.7
207.1	—	− 4.7	+ 27.9
207	− 14.3	− 8.3	+ 28.4
206.1	—	− 5.6	+ 27.0
206	− 20.1	− 5.6	+ 23.5
205.1	—	− 8.4	—*
205	− 10.5	− 6.0	+ 15.1
204.1	—	− 9.2	+ 6.7
204	− 8.9	− 10.3	+ 5.7
203.1	—	− 11.4	—*
203	− 8.0	− 11.0	+ 6.2
202.1	—	− 11.7	− 1.0
202	− 9.5	− 15.9	− 2.8
201.1	—	− 12.0	+ 1.6
201	− 29.9	− 11.2	+ 2.9
200.1	—	− 9.3	+ 5.0

Table IV. (*continued*)

B.M.	H. in 1896–1899 – H. in 1885	H. in 1899 – H. in 1896	H. in 1917 – H. in 1889–1899
	mm	mm	mm
200	—*	– 9.5	+ 1.4
199.1	—	– 10.7	+ 2.0
199	– 35.3	– 9.8	– 0.2
198.1	—	– 10.2	– 10.4
198	– 39.4	– 9.7	– 3.0
197.1	—	– 11.0	– 13 6
197	– 47.5	– 10.6	– 16.9
196.1	—	– 14.8	– 26.9
196	– 55.2	– 11.8	– 27.9
195.1	—	– 13.7	– 29.5
195	– 78.6	– 13.0	– 26.4
194.1	—	– 13.6	–120.5
194	– 83.4	– 11.8	+ 34.4
193.1	—	– 11.3	+ 18.2
193	– 92.5	– 7.7	+ 22.5
192·1	—	– 4.7	+ 6.9
192 (Tarui)	– 99.2	– 6.3	+ 10.5
191.1	—	– 8.8	– 2.7
191	–116.7	– 9.3	– 21.2
190.1	—	– 13.8	– 31.4
190	–178.2	– 10.9	– 51.9
189.1	–	– 16.4	– 50.1
189	–*	– 18.5	–153.4
188.1	–	– 15.3	–107.7
188	–308.3	– 11.5	– 58.5
187.1	—	– 12.3	– 39.3
187	–296.4	– 13.3	– 46.1
186.1	—	– 11.0	– 39.4
186	–130.4	– 9.2	– 22.7
185.1	—	– 14.9	– 16.0
185 (Kanô)	–149.7	– 13.3	– 22.4

Table IV. (*continued*)

(4) Section between Kanô and Hiyosi.

B.M.	H. in 1895 − H. in 1889	H. in 1916 − H. in 1889
	mm	mm
185 (Kanô)	−149.7	− 22.4
715	+128.4	− 34.8
714	+360.3	− 9.8
713	+613.6	+ 18.6
712	+750.2	+ 29.9
711	+767.3	—*
710	+757.6	+ 49.6
709	+673.3	—*
708	+598.3	—*
707	+585.5	+ 58.4
706	+696.6	+ 63.2
705	+663.6	+ 72.4
704	−162.7	+ 55.3
703	−118.2	+ 46.0
702	− 59.2	+ 59.0
701	− 32.7	+ 70.2
700	− 11.9	+ 74.8
699	− 4.9	+ 80.2
698	− 11.8	+ 87.6
697	− 4.3	+ 93.9
696	− 0.6	+101.4
695	− 4.3	—*
694	+ 1.0	+125.2

Table IV. (*continued*)

(5) Section between Hiyosi and Wazima via Matumoto and Itoigawa.

B.M.	H. in 1916 − H. in 1889
	mm
694	+125.2
693 (Hiyosi)	+137.7
692	+146.3
691	+152.3
690	+159.4
689	+168.7
688	+157.7
687	+170.1
686	+174.7

B.M.	H. in 1922 − H. in 1889
	mm
686	+174.7
685	+169.8
684	+181.1
683	+180.4
682	+183.3
681	+185.5
680*	—
679	+191.0
678	+191.3
677	+193.3
676*	—
675	+195.9
674	+197.4
673	+197.4

B.M.	H. in 1922 − H. in 1889
	mm
672	+202.2
671	+197.3
670	+205.9
669	+196.4
668	+184.6
667	+196.8
666	+176.4
665	+165.5
664*	—
663	+161.6
662	+158.5
661	+153.0
660	+154.5
659	+152.3
658	+151.0
657	+144.1
656	+151.5
655	+152.1
654	+144.7
653	+138.1
652	+141.9
651	+339.8
650	+130.5
649	+135.4
648	+132.2
647	+130.4

Table IV. (*continued*)

B.M.	H. in 1922 − H. in 1889
646	mm +126.7
645	+125.5
644	+130.8
643	+132.1
642	+126.6
641	+131.3
640	+129.6
639	+202.8
638	+136.3
637	+132.5
636	+144.0
635	+134.9
634	+133.1
633	+147.8
632	+129.4
631	+125.9
630	+129.3
629	+134.7
628*	—
627	+151.5

B.M.	H. in 1922 − H. in 1891
627	mm +151.5
2866	+130.8
2867	+129.0
2868*	—
2869	+129.9

B.M.	H. in 1922 − H. in 1891
2870	mm +125.9
2871	+122.1
2872	+110.1
2873	+100.6

B.M.	H. in 1920 − H. in 1891
2873	mm +100.6
2874	+106.5
2875*	—
2876	+105.8
2877	+109.2
2878	+ 99.9
2879	+ 93.3
2880	+ 89.8
2881	+138.2
2882	+ 96.0
2883	+ 90.1
2884	+ 93.4
2885	+100.3
2886	+ 87.9
2887	+ 84.3
2888	+ 80.1
2889	+114.4
2890	+258.3
2891	+288.8
2892	+245.0
2893	+164.6

Table IV. (*continued*)

B.M.	H. in 1920 − H. in 1891	B.M.	H. in 1920 − H. in 1891
	mm		mm
2894	+115.0	2922	− 38.4
2895	+102.6	2923	− 65.7
2896	+ 27.5	2924	− 62.1
2897	+ 15.3	2925	− 60.5
2898	+ 23.4	2926	− 82.6
2899	+ 29.5	2927	− 99.2
2900	+ 18.2	2928	− 94.2
2901	+ 31.3		
2902	+ 36.4	B.M.	H. in 1921 − H. in 1890–1891
2903	+ 8.1		mm
2904	+ 30.5	2928	− 94.2
2905	+ 14.6	2929	− 93.5
2906*	—	2930	− 92.1
2907	+ 38.2	2931	−112.9
2908	+ 70.9	2932	−292.6
2909	+ 60.7	2933	− 92.3
2910	+ 32.4	2934	− 83.2
2911	+ 56.1	2935	− 86.0
2912*	—	2936	− 85.1
2913*	—	2937*	—
2914*	—	2938	− 91.2
2915*	—	2939	− 87.7
2916*	—	2940	− 99.7
2917	+ 5.9	2941	− 86.1
2918	− 5.4	2942	− 83.8
2919*	—	2943	− 78.8
2920*	—	2944	− 75.4
2921*	—	2945	− 75.0

Table IV. (*continued*)

B.M.	H. in 1921 – H. in 1890–1891	B.M.	H. in 1921 – H. in 1890–1891
	mm		mm
2946	– 70.9	834	– 28.9
2947	– 59.7	835	– 24.0
2948	– 62.8	836	– 29.5
2949	– 61.4	837	– 12.7
2950	– 56.7	838	– 17.2
2951	– 50.8	12	– 18.2
2952	– 55.9	9326	– 15.8
2953	– 50.8	9325	– 21.5
2954	– 43.2	9324	– 35.9
2955	– 48.2	9323	– 15.2
2956	– 44.1	9322	– 15.2
2957	– 37.4	9321	+ 1.2
2958	– 36.2	9320	+ 2.0
2959	– 45.2	9319	– 16.3
2960	– 52.7	9318	+ 10.2
2961	– 44.5	9317	+ 0.9
2962	– 68.1	9316	+ 8.0
2963	– 64.0	9315	+ 7.3
2964*	—	9314	+ 10.2
2965	– 46.4	9313	+ 12.7
2966	– 46.2	9312	+ 12.9
2967	– 47.5	9311	– 8.3
828	– 48.0	9310*	—
829	– 44.2	9309	+ 3.8
830	– 42.9	9308	+ 11.0
831	– 39.5	9307	+ 9.1
832	– 38.1	9306	+ 12.1
833	– 30.6	9305	+ 6.7

Table IV. (*continued*)

B.M.	H. in 1921 −H. in 1890–1891	B.M.	H. in 1921 −H. in 1890–1891
9304	mm + 12.7	9289	mm − 13.3
9303	+ 15.1	9288	+ 14.5
9302	+ 17.7	9287	+ 6.2
9301	+ 18.4	9286	+ 12.6
9300	+ 8.6	9285	+ 11.3
9299	+ 8.0	9284	+ 11.1
9298	+ 13.6	9283	+ 1.1
9297	+ 15.0	9282*	—
9296	− 0.3	9281	+ 6.8
9295	+ 17.0	9280	− 2.7
9294	+ 10.8	9279	+ 1.3
9293	+ 4.3	9278*	—
9292	+ 9.1	9277	− 5.8
9291	+ 11.8	9276	− 0.1
9290	+ 9.6	7	+ 0.0

(6) Section between Kanô and Simohara.

B.M.	H. in 1894–1895 −H. in 1890	B.M.	H. in 1894–1895 −H. in 1890
185	mm −149.7	723	mm −416.9
716	+145.6	724	−335.6
717	+267.6	725	−277.8
718	+497.3	726	−227.9
719	+570.0	727	−182.5
720	+729.0	728	−166.5
721	+583.4	729	− 92.7
722	+491.6	730	− 68.4

Table IV. (*continued*)

B.M.	H. in 1894–1895 − H. in 1890	B.M.	H. in 1894–1895 − H. in 1890
	mm		mm
731	− 54.4	741	+ 30.1
732	− 61.1	742	+ 26.4
733	− 22.3	743	+ 12.6
734	− 0.3	744	+ 16.4
735	− 48.3	745	+ 17.8
736	+ 21.4	746	+ 16.2
737	+ 27.8	747	+ 15.6
738	+ 39.0	748	+ 8.9
739	+ 42.1	749	+ 7.2
740	+ 41.1		

(7) Section between Kanô and Okazaki via Atuta.

B.M.	H. in 1895 − H. in 1885	H. in 1916 − H. in 1895
	mm	mm
185	−149.7	+ 15.6
184.1	—	− 12.5
184	− 20.1	+ 7.5
183.1	—	− 75.1
183	—*	+ 7.1
182.2	—	− 55.7
182.1	—	+ 6.1
182	+ 80.5	+ 18.6
181.1	—	+ 27.3
181	+ 18.1	+ 32.3
180.1	—	+ 26.3
180	+ 88.0	+ 34.2
179.1	—	+ 41.2

Table IV. (*continued*)

B.M.	H. in 1895 −H. in 1885	H. in 1916 −H. in 1895
	mm	mm
179	+103.6	+ 46.1
178.1	—	+ 42.2
178	− 26.2	+ 17.1
177.1	—	+ 48.6
177	− 82.8	+ 33.2
176.1	—	+ 63.0
176	+ 24.2	+ 50.3
175.1	—	+ 78.9
175	− 12.2	+ 82.8
174.2	—	+ 91.1
174.1	—	+ 90.9

B.M.	H. in 1895 −H. in 1885	B.M.	H. in 1895 −H. in 1885
	mm		mm
174	− 37.3	169	− 8.0
173	− 28.7	168	− 2.6
172	− 20.9	167	− 40.5
171	− 19.6	166	+ 0.0
170	− 17.8		

(8) Section between Atuta and Tu via Kuwana.

B.M.	H. in 1895 −H. in 1888	H. in 1918 −H. in 1895
	mm	mm
174.1	—	+ 90.9
1480	− 92.3	—*
1479	− 37.3	+ 78.4

Table IV. (*continued*)

B.M.	H. in 1895 −H. in 1888	H. in 1918 −H. in 1895
	mm	mm
1478	− 43.2	+ 69.7
1477	− 74.3	+ 58.7
1476	− 62.0	+ 63.3
1475	−126.9	—*
1474	− 97.6	+ 45.3
1473	−101.0	+ 41.3
1472	−208.3	− 90.6
1471	—*	+ 0.5
1470	—*	− 92.1
1469	—*	+ 48.4
1468	− 81.0	+ 57.3
1467	− 66.5	+ 68.3
1466	− 77.9	—
1465	− 53.4	—
1464	− 50.7	—
1463	− 38.3	—
1462	− 33.7	—
1461	− 44.0	—
1460	− 45.1	—
1459	− 42.5	—
1458	− 40.5	—
1457	− 34.5	—
1456	− 30.0	—
1455	− 23.0	—
1454	− 18.3	—
1453	− 26.2	—
1452	− 12.2	—
1451	− 42.7	—
1450	− 7.1	—
1449	− 3.4	—
1448	− 13.5	—
1447	− 4.4	—
1446	− 1.4	—
1445	+ 0.0	—

* Original identity uncertain.

Upon close examination the intersection of the main fault, or its branch lines, and the levelling routes came out as follows:

Table V. Intersections of faults and levelling routes.

Curve No.	Route	B.M. No.	Changes in height	Dates of survey
1	Hikasa-Hukui-Inoue	986	− 76 mm	1890, 1917
2	Tarui-Kano-Mikasa	188	− 308	1886, 1896
3	do.	189	− 153	1896, 1917
2	do.	185–715	278	1889, 1895
2	do.	705–704	827	do.
4	Kano-Simohara	722–723	909	1890, 1895
4	do.	735–736	69	do.
5	Kano-Atuta-Kuwana	1472	− 208	1888, 1895
6	do.	do.	− 91	1895, 1918
6	do.	1470	− 92	do.

Thus the northern extension of the Kurotu-Atumi fault is indicated by a sharp depression of 7.6 cm. at B.M. No. 896 near Maruoka (see Curve 1); the region to the west of it experiencing subsidence as in the other parts of the fault-system, namely, segments *B*, *A A* and *A''*. (The curve also shows the presence of another fault at B.M. No. 860, which is in the epicentral area of the Kaga earthquake of 1799, and suggests earth-tilting in that locality, be it chronic or acute.) The outstanding feature of Curve 2 is the indication of an out-bulge of as much as 83–90 cm. of the block bounded by the two segments *aa'* and *A''* which cross the levelling route at B.M. Nos. 185 and 704. Another indication is a subsidence at B.M. No. 189, which, though missed in the earlier survey of 1886, was revealed

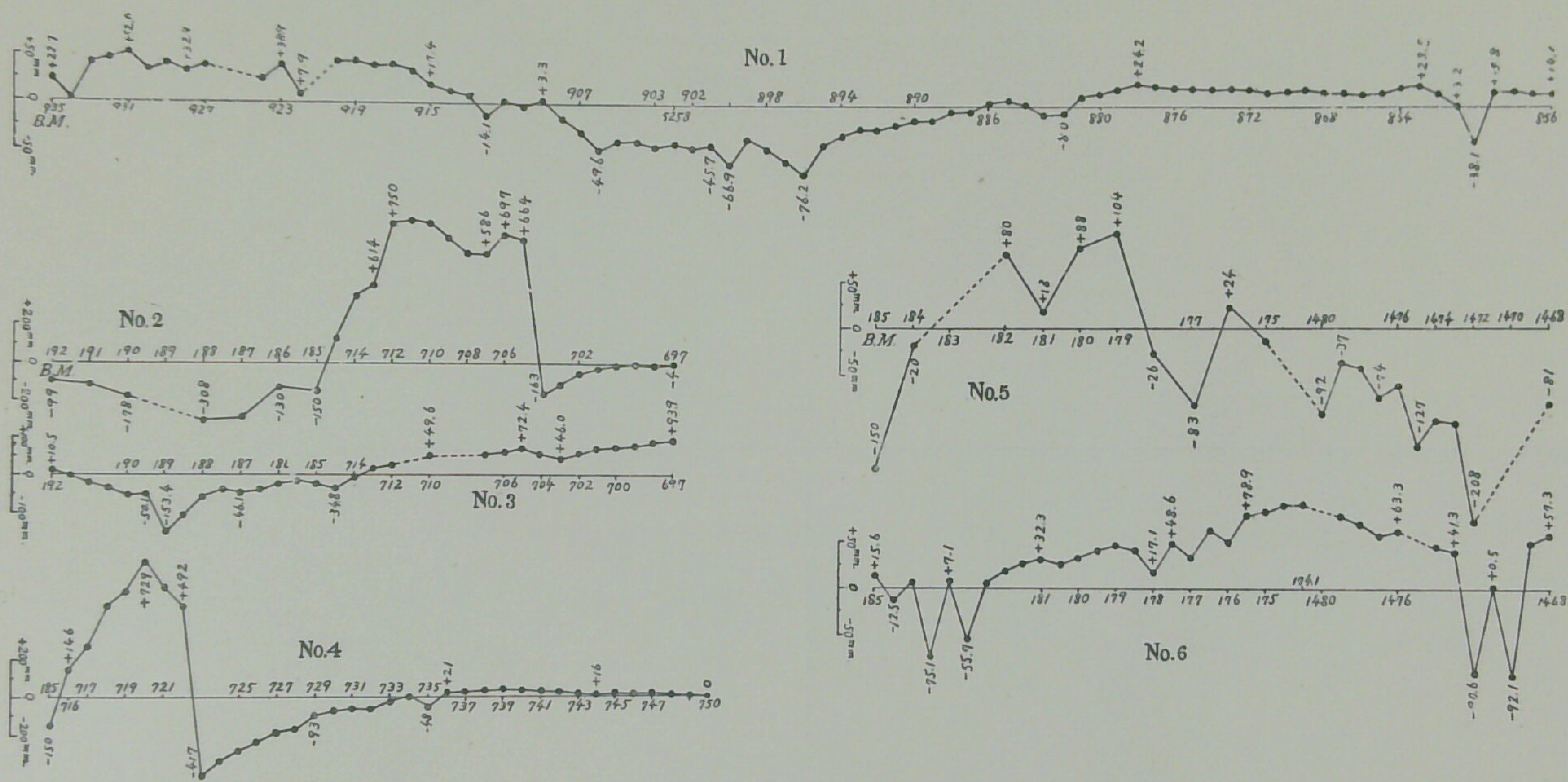

Fig. 20.

by the two later surveys of 1896 and 1917. The close resemblance of the earth-tiltings as indicated by the pair of curves Nos. 2 and 3 is rather interesting; they show results of surveys made in 1886 and 1896 and those made in 1896 and 1917. Turning now to curve No. 4 it will be seen that this also shows an out-bulge of as much as 115 cm. of the block just mentioned as being bounded by segments A'' and aa', with moreover traces of a very steep fault at B.M. No. 723 and another less so at No. 735; the region to the east of the latter having gradually upheaved as is shown also in another levelling route that runs parallel to it. Lastly, curve No. 5 indicates a gentle depression but extending as much as 21 cm. and lying eastwards of Kuwana at B.M. Nos. 1470–1472. Here again a close resemblance of earth-tiltings is noticeable in curves Nos. 5 and 6, the former of which indicates in the main the change associated with the 1891 earthquake, and the latter the chronic change undergone during some 21 years after the occurrence of that great earthquake.

These results lead the writer to believe that the fault which occurred with the 1891 earthquake crossed the island from the head of Ise Bay in the south, trending NNW up to the Sea of Japan in the north. The track of this cross-fault consisted of three or four detached segments arranged *en échelon* with the southern segments in the tract of tension. The region to the west of the track underwent, in general, subsidence with a southward shift relatively to the eastern side, although the appearance of two branches (aa' and b) on the latter side forms an exception.

It is now easy to imagine how that gigantic force which caused the tremendous 1891 earthquake was brought to bear on each side of the cross-fault. Let us consider such a force as having been exerted on the western side. It might then have been exerted there from the W or NW towards the E or SE, the force being compressional on both sides of the northern part of the fault and tensional on those of the southern part so that the effect would be to widen out Ise Bay like an imaginary fan with the pin holding the ribs together lying somewhere near the centre of the cross-fault. With the sudden destruction of equilibrium, displacements occurred along the cross-fault with the western side downwards towards the south, at the same time lifting the high land of the so-called Japan-Alps in the east by as much as 20 cm. and lowering the low Wakasa-Biwa Lake-Ise Bay line in the west by as much as 4-10 cm.

The reason for the apparent insignificance near its northern and southern extremities of the cross-fault connected with the 1891 earthquake, the full nature of which was brought to light only by means of precise levellings carried out in this region, may be attributed to the fact that a part of the seismic forces which had been accumulating there for centuries had already been relieved, first by the Kuwana earthquake of 1819, and secondly by the Etizen earthquake of 1858. The former of these earthquakes took place on the 2nd of August and was semi-destructive over a region forming a narrow belt trending N-S from Kuwana in the south to Kanazawa in the north, the shaking having been worse in the former city than in the latter. The earthquake disaster of April 9, 1858, in the provinces of Hida, Etizen, Kaga and Ettyû was due to two earthquakes, of which the first (1858-a) took place at about 1 a.m., and the second (1858-b) two hours later. The former was responsible for the disaster in Hida, where the causalties were 209 people killed and 711 houses destroyed. The earthquake having special bearing on our present study, however, is the one that occurred after the two hours interval and in the northern corner of the province of Etizen. It played havoc in the towns of Maruoka, Kanatu and Daisyôzi, causing the collapse of about 200 houses in the two first-named towns and 100 houses in the last. Needless to say, these places were also severely shaken by the first earthquake, but the second was much stronger, whereas in the towns of Katuyama and Oono both shocks were felt almost alike. As the seismic activity of Central Japan is likely to recur with a period of 300-500 years, or an average of 382 years and as the last culmination prior to the earthquake under discussion took place in 1586, the 1854-b earthquake might well have been foreseen as a shock, the visit to this region of which was threatened by the Hida earthquake (1858-a) two hours earlier on the same day, as the inevitable result of the sudden release of pent-up forces.

No. 16. The Tokyo earthquake of 1894.

The probable origin of this earthquake, which took place on June 20 at 14 h 4 m 10 s, was a weak zone trending NNW-SSE with its epicentre about 40 km. north of Tokyo. It shook Tokyo so severely that the maximum acceleration of the earth-particles was as high as 444 mm. per sec. per sec. at the University grounds. Many brick walls and chimneys were shaken down and a number of people were killed. The total casualties were 26 persons killed and 90 houses thrown down.

Levelling routes in Tokyo and its environs were first laid down in 1883, the surveys having been repeated in the years 1892, 1895, 1898, 1902, 1909, 1914, 1918, 1923 and 1925. Of these surveys those carried out up to 1902 are here adopted as being comparatively important in working out the topographical changes directly connected with the 1894 earthquake.[1] The results are shown in Table VI and Figs. 21-24.

1) Data deducible from later surveys are especially important for working out the changes connected with the destructive Kwanto earthquake of 1923. The surveys have been completed by the Millitary Land Survey Department, although the results have not yet been published.

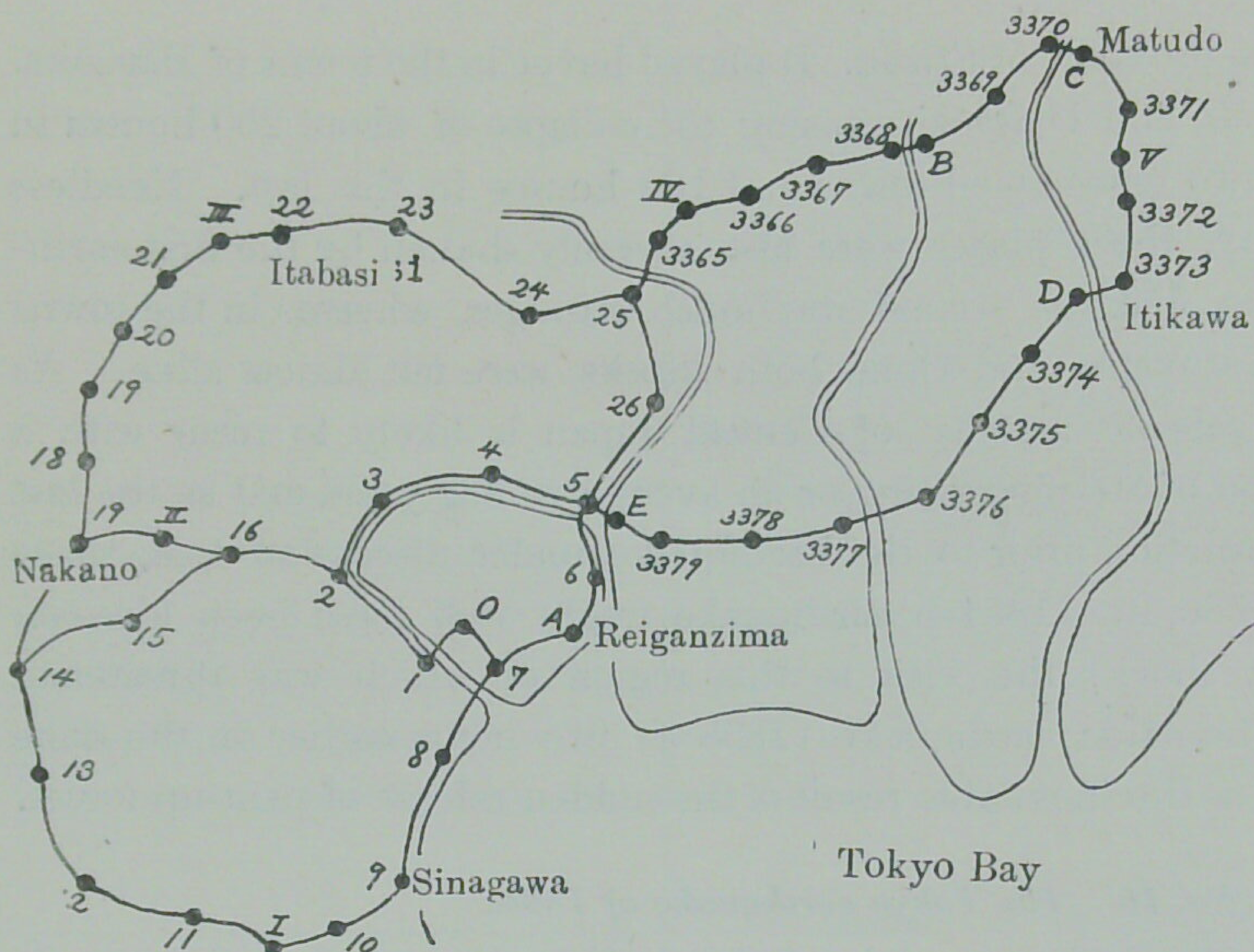

Fig. 21. Bench-mark routes in Tokyo and its environs.

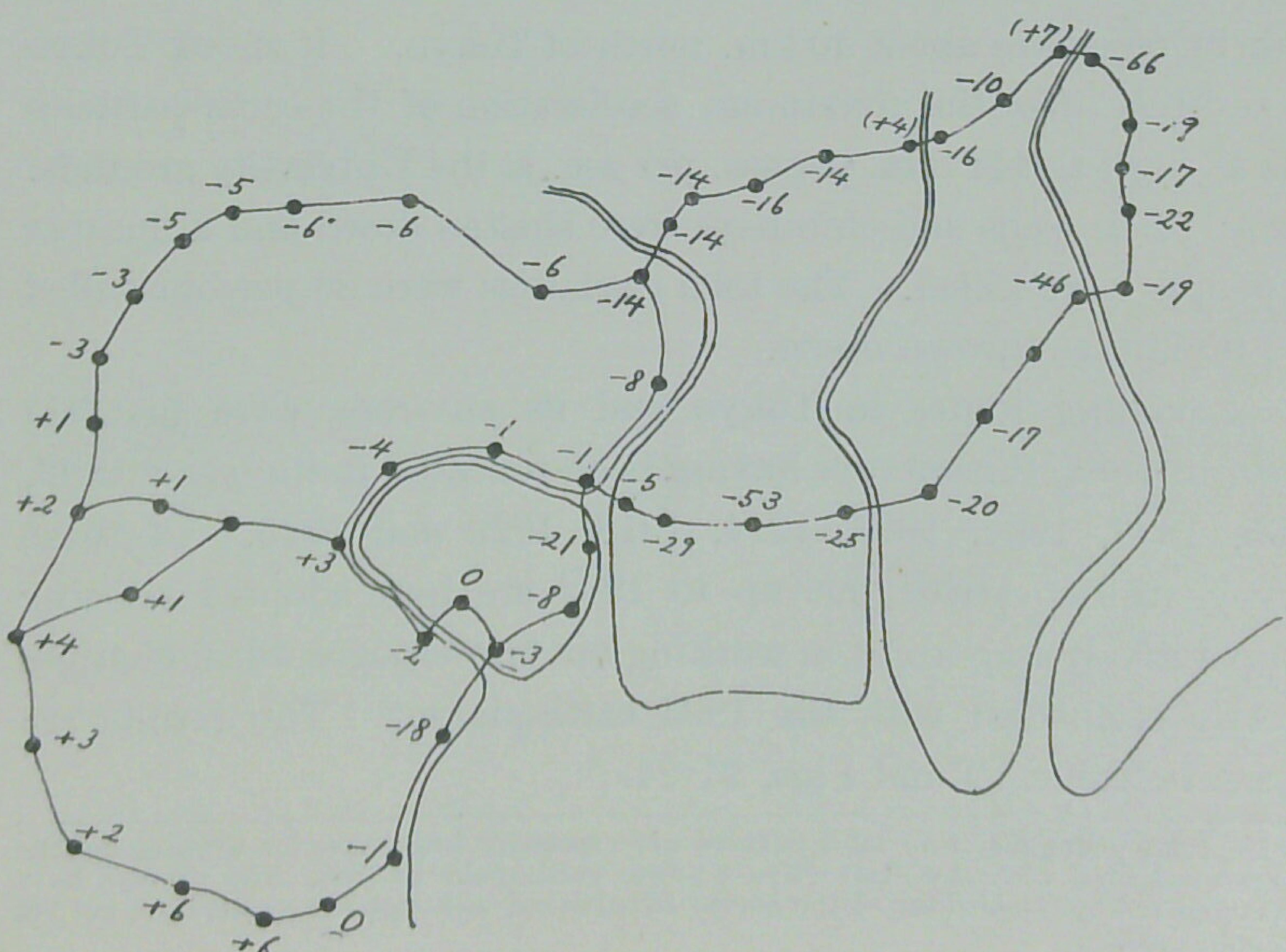

Fig. 22. Height differences of the bench-marks in Tokyo and its environs in 1892 and the mean heights in 1895, 1898 and 1902.

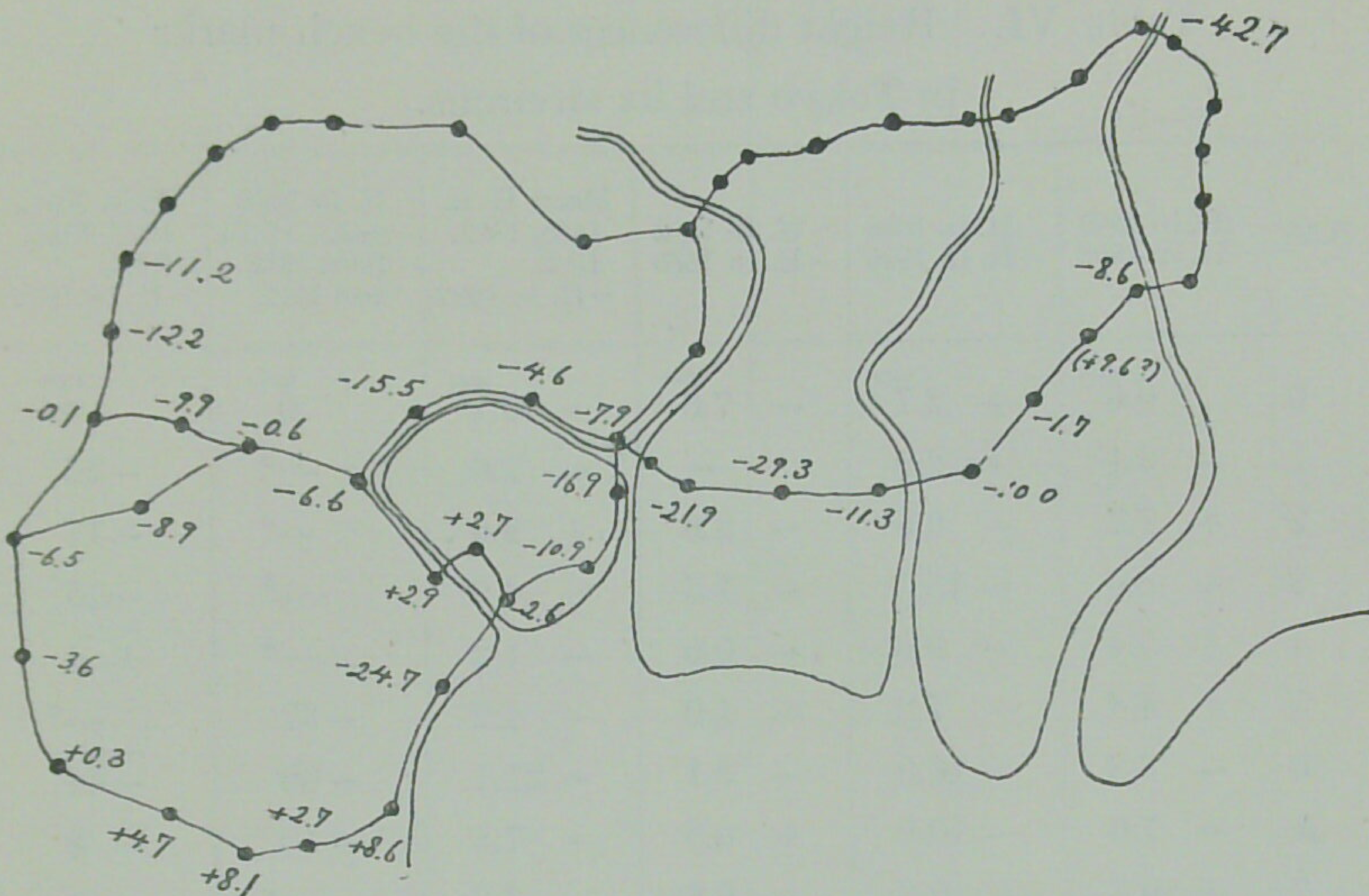

Fig. 23. Height differences of the bench-marks in Tokyo and its environs between 1895 and 1898.

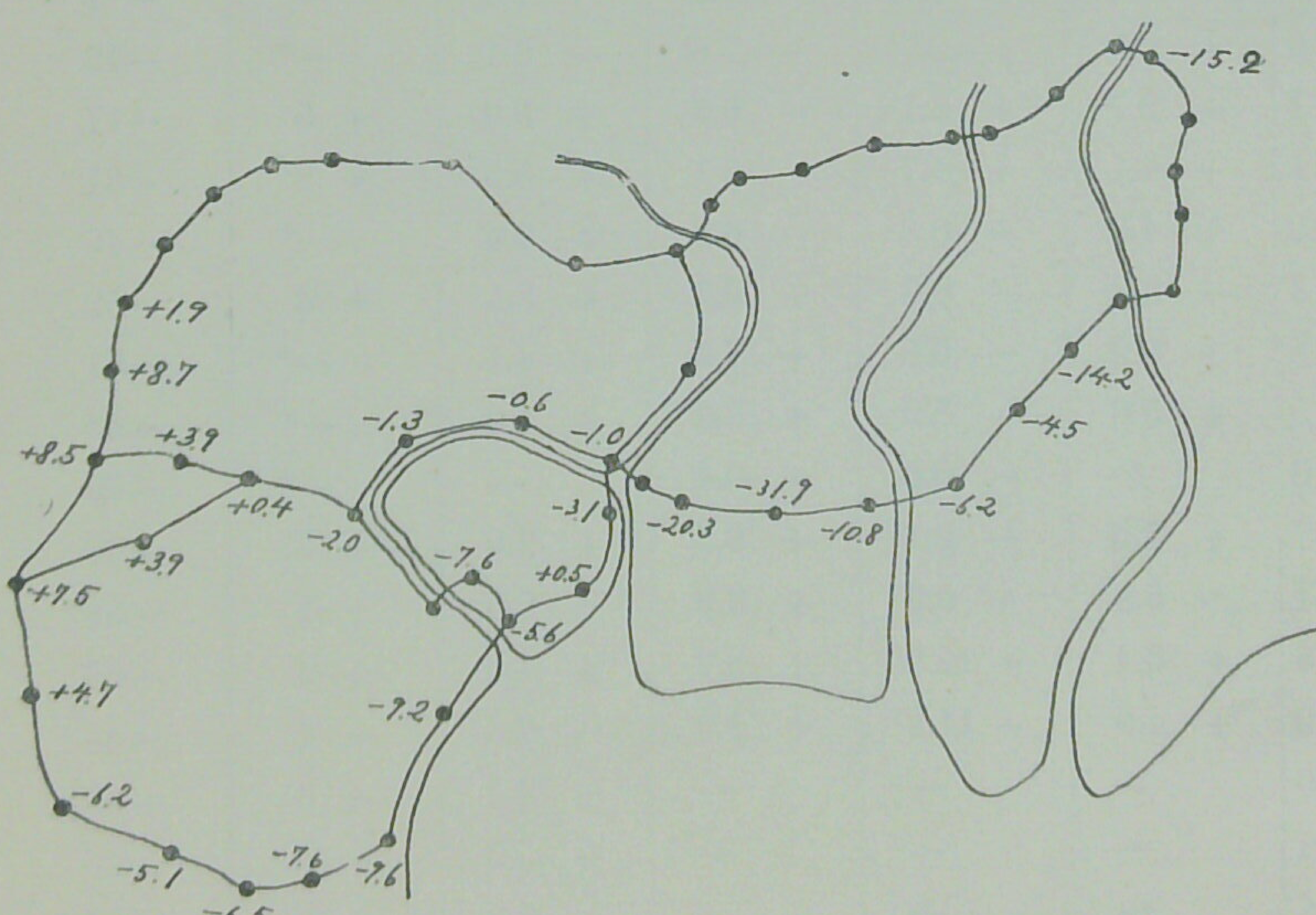

Fig. 24. Height differences of the bench-mark sin Tokyo and its environs between 1898 and 1902.

Table VI. Height differences of the bench-marks in Tokyo and its environs.

B.M.	H. in 1895 −H. in 1892	H. in 1898 −H. in 1895	H. in 1902 −H. in 1898	Mean H. in 1895, 1898, 1902 −H. in 1892	H. in 1918 −mean H. in 1895, 1898 and 1902	H. in Nov., 1923,-Feb., 1924, −H. in 1918
	mm	mm	mm	mm	mm	mm
0	0.6	+ 2.7	− 7.6	− 0.1	0	0
1	− 3.1	+ 2.9	—	− 1.6	—*	−15
2	+ 7.7	− 6.6	− 2.0	+ 2.6	—*	−11
3	+ 6.6	− 15.5	− 1.3	− 4.2	—*	−15
4	+ 5.4	− 9.6	− 0.6	− 1.2	—*	+ 4
5	+ 4.4	− 7.9	− 1.0	− 1.2	−37	—*
6	− 8.8	− 16.9	− 3.1	− 21.1	−69	−44
A	− 7.0	− 10.9	+ 0.5	− 7.8	−10	− 3
7	+ 0.3	− 2.6	− 5.6	− 3.3	—*	− 1
8	+ 1.3	− 24.7	− 9.2	− 18.2	−25	− 1
9	− 3.9	+ 8.6	− 9.6	− 1.4	—*	− 7
10	+ 0.6	+ 2.7	− 7.6	− 0.1	—*	−19
I	+ 2.7	+ 8.1	− 6.5	+ 5.9	+ 5	−17
11	+ 4.1	+ 4.7	− 5.1	+ 5.5	+ 8	−31
12	+ 4.3	+ 0.3	− 6.2	+ 2.4	—*	−49
13	+ 3.9	− 3.6	+ 4.7	+ 3.1	+ 8	−52
14	+ 5.9	− 6.5	+ 7.5	+ 4.1	—*	−51
15	+ 5.6	− 8.9	+ 3.9	+ 1.0	—*	−45
16	—	− 0.6	+ 0.4	—	—*	−55
17	+ 5.9	− 0.1	+ 8.5	+ 2.0	+ 4	−48
II	+ 5.9	− 9.9	+ 3.9	+ 0.6	+ 1	−38
18	+ 6.4	− 12.2	+ 8.7	+ 1.2	+ 2	−55
19	+ 4.9	− 11.2	+ 1.9	− 2.6	− 4	−48
20	—	—	—	− 3.1	− 6	−43
21	—	—	—	− 5.0	−16	−40
III	—	—	—	− 5.2	−17	−35

Table VI. (*continued*)

B.M.	H. in 1895 −H. in 1892	H. in 1898 −H. in 1895	H. in 1902 −H. in 1898	Mean H. in 1895, 1898, 1902 −H. in 1892	H. in 1918 −mean H. in 1895, 1898 and 1902	H. in Nov., 1923,-Feb., 1924, −H. in 1918
	mm	mm	mm	mm	mm	mm
22	—	—	—	− 5.6	− 20	− 30
23	—	—	—	− 5.9	—*	− 8
24	—	—	—	− 6.5	—*	+ 8
25	—	—	—	− 13.8	− 81	− 61
26	—	—	—	− 7.6	− 52	− 23
3365	—	—	—	− 13.7	− 54	− 5
IV	—	—	—	− 14.2	− 59	− 44
3366	—	—	—	− 15.6	—*	− 55
3367	—	—	—	− 13.5	—*	+ 19
3368	—	—	—	+ 3.9	—*	− 10
B	—	—	—	− 16.0	− 66	− 2
3369	—	—	—	− 10.5	− 41	+ 27
3370	—	—	—	+ 7.2	—*	+ 48
C	− 33.0	− 42.0	− 15.2	− 66.5	—	—
3371	—	—	—	− 18.7	—*	+ 54
V	—	—	—	− 17.3	− 9	+ 56
3372	—	—	—	− 21.7	− 15	+ 55
3373	—	—	—	− 19.0	− 12	+ 57
D	− 41.5	− 8.6	—	− 45.8	—*	+ 55
3374	− 15.3	+ 9.6	− 14.2	− 10.3	− 23	+ 38
3375	− 12.0	− 1.7	− 4.5	− 14.6	− 34	0
3376	− 11.4	− 10.0	− 6.2	− 20.1	−209	−179
3377	− 11.1	− 15.3	− 10.8	− 24.9	−255	−246
3378	− 22.5	− 29.3	− 31.9	− 52.7	−323	−115
3379	− 7.9	− 21.9	− 20.3	− 29.3	−143	−156
E	—	—	—	− 4.6	− 25	+ 13
9831	—	—	—	—	—	−166

Table VI. (*continued*)

B.M.	H. in 1895 −H. in 1892	H. in 1898 −H. in 1895	H. in 1902 −H. in 1898	Mean H. in 1895, 1898, 1902 −H. in 1892	H. in 1918 −mean H. in 1895, 1898 and 1902	H. in Nov., 1923,-Feb., 1924, −H. in 1918
	mm	mm	mm	mm	mm	mm
9832	—	—	—	—	—	−380
9833	—	—	—	—	—	−105
9834	—	—	—	—	—	−276
9835	—	—	—	—	—	− 55
9836	—	—	—	—	—	− 1
9837	—	—	—	—	—	+ 2
9838	—	—	—	—	—	+ 1
9839	—	—	—	—	—	+ 54
9840	—	—	—	—	—	+ 47
9841	—	—	—	—	—	+ 56
9842	—	—	—	—	—	+ 69
9843	—	—	—	—	—	+ 71
3822	—	—	—	—	—	+ 61
3823	—	—	—	—	—	+ 67
3824	—	—	—	—	—	+ 77
3825	—	—	—	—	—	+ 80
3826	—	—	—	—	—	+ 85

0......Kôzimati, A......Reiganzima, No. 9......Sinagawa, No. 17......Nakano, No. 22......Itabasi, C......Matudo, D......Itikawa, No. 3378......Honzyo.

*......Uncertain.

A close examination will make it evident that earth-tiltings, either acute or chronic, occurred with the 1894 earthquake. Briefly, the change seems to have consisted of tiltings, all dipping westwards, of three consecutive blocks lying west of the lines represented by the Itabasi-Sinagawa line and the courses of the rivers Sumida-gawa and Edo-gawa. This characteristic will be found most accentuated in Fig. 22 or Fig. 23, and may thus be regarded as a general indication of the sudden change which the earthquake had accompanied. It may be worth while to add that the changes which have kept on in the same district since the earthquake (see Fig. 24) point to similar characteristics. Another fact worth noting is that the manner in which the extreme eastern block tilted in connexion with the earthquake under discussion is similar to that in which it tilted at the time of the great Kwanto earthquake of 1923.

The topographical changes mentioned thus far relate to a region somewhat remote from the epicentral area. One would naturally expect changes on a far larger scale to have taken place in the epicentral area, and this is just what has happened according to the bench-mark situated at the north-eastern corner of the present levelling routes which indicated a subsidence of as much as 3.3 cm. during the interval between 1892 and 1895.

No. 17. The Susaka earthquake of 1897.

The Susaka earthquake, which took place on Jan. 17 at 5 h 36 m, originated about 7 km. east of the City of Nagano, its meizoseismic area being 12 km. in length and 6 km. in width. (See Fig. 25.) Within this area some houses and bridges were badly damaged, coarse plaster walls shaken down and unstable grave-stones and stone lanterns overturned. Fissures were also produced in the ground, from some of which mud and water were ejected. Many aftershocks took place, and at Susaka 38 of them were recorded during the subsequent month. But much more noteworthy was the occurrence of another big shock, though less severe than the first, on the 30th of April of the same year with the epicentral zone at AA about 3 km. to the east[1]. B.M. Nos. 3646–3650 stand just at the boundary of the January earthquake, while Nos. 3639–3645 are in the area which was rather severely disturbed by both shocks. Precise levellings were carried out over this route first in 1894 and later in 1927 (Table XII). The diagram showing the changes in height of B.M. Nos. 3639–3660 (see Fig. 26)

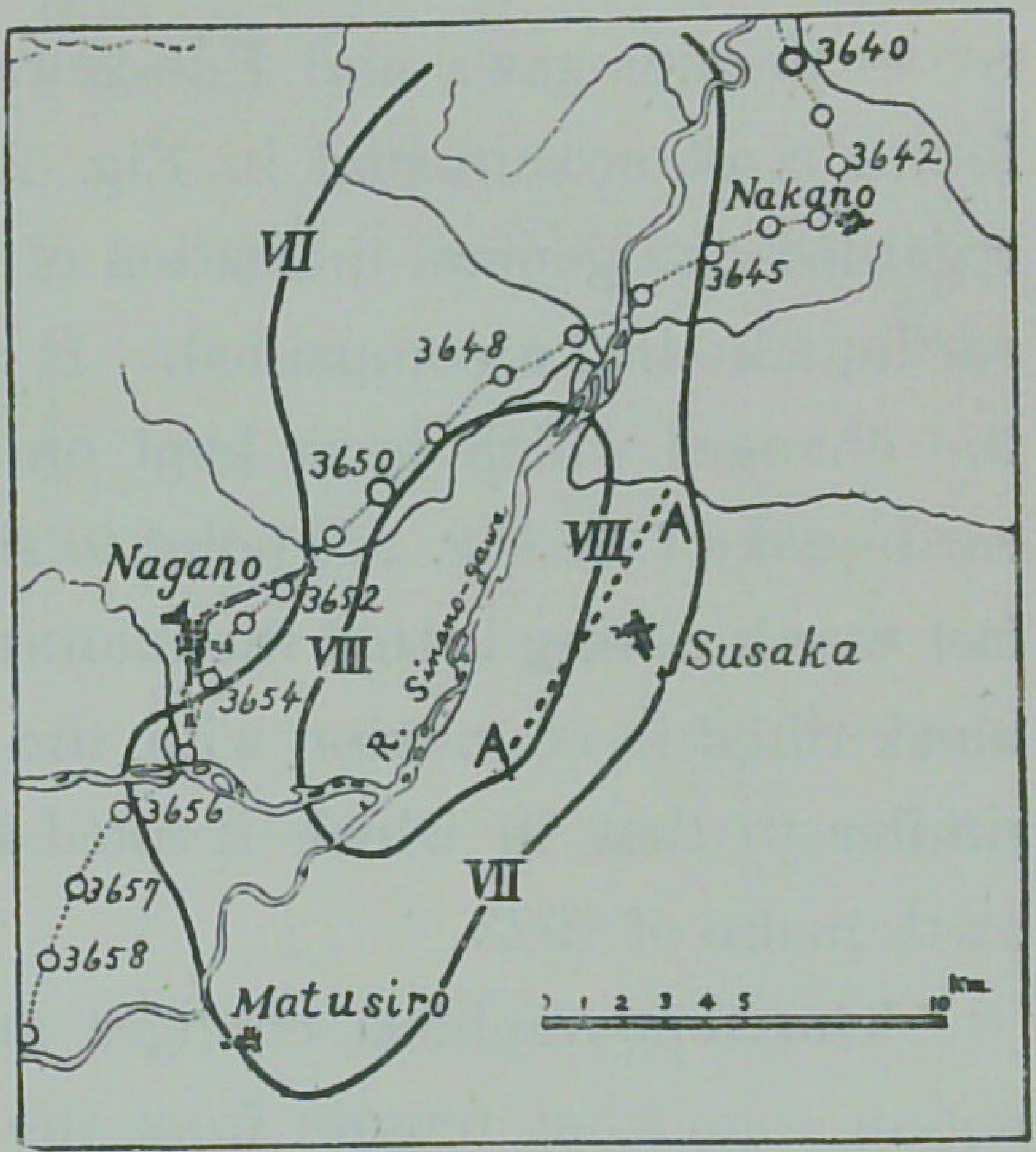

Fig. 25. Map showing the seismic area of the Susaka earthquake.

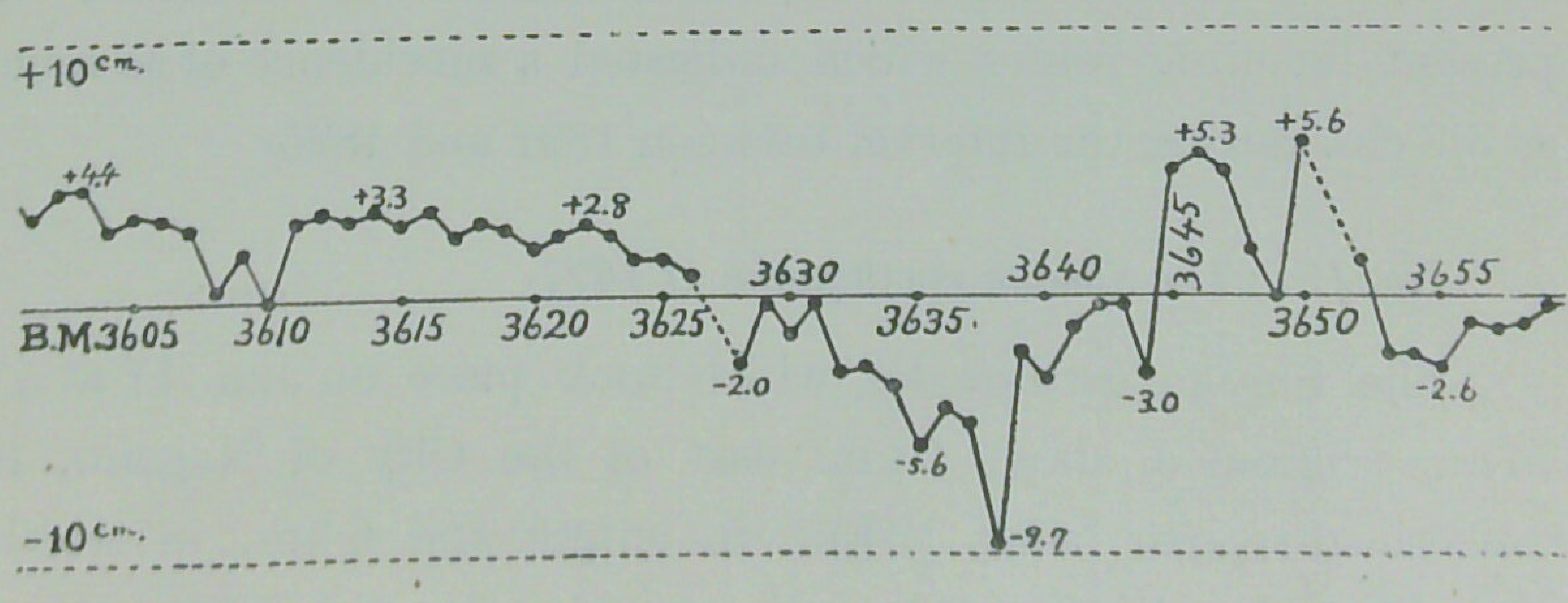

Fig. 26. Diagram illustrating the change of land-level associated with the Susaka earthquake.

1) For details, see Rep. Imp. Earthq. Inv. Comm., No. 21, pp. 71–95.

indicates a very characteristic change of topography with an upheaval of about 6 cm. in the meizoseismic area and subsidences on both sides of it. The change would involve the so-called secular variation of land-level, but there is good ground for assuming that it was in the main due to the Susaka earthquakes of 1897, especially the first one. On the other hand, a tilting indicated by B.M. Nos. 3595–3638, standing along the lower course of the Sinano-gawa River, may be accepted as being due wholly to secular variation and identical with the chronic tilting of the Kariha-Higasikubiki block as pointed out elsewhere by Prof. N. Yamasaki[1)]

No. 18. The Anegawa earthquake of 1909.

The Anegawa earthquake, which occurred on Aug. 14 at 15 h 31 m in the drainage area of the upper course of the Anegawa River, Oomi Province, resulted in the loss of 41 lives and destruction of 2,233 buildings of which 976 were dwelling-houses. Prof. B. Koto, who investigated the earthquake from the stand point of geology, assigned its seismogenic line, as far as the writer understands, to a locality somewhere not far from the Asai fault and to the east of it[2)]. (See Fig. 27.) The writer however placed the epicentre at the point which is marked with a cross. This place again is in a seismic zone, through which pass epicentres of rather conspicuous earthquakes that have shaken the district during the 10 years preceding the present earthquake[3)]. It must be noted, however, that none of the field workers were able to find any faults accompanied by shifts, either horizontal or vertical.

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1) N. Yamasaki: Proc. Imp. Acad., Vol. 4 (1928), p. 60.
2) B. Koto: Rep. Imp. Earthq. Inv. Comm., No. 69.
3) A. Imamura: Rep. Imp. Earthq. Inv. Comm., Nos. 70 & 95.

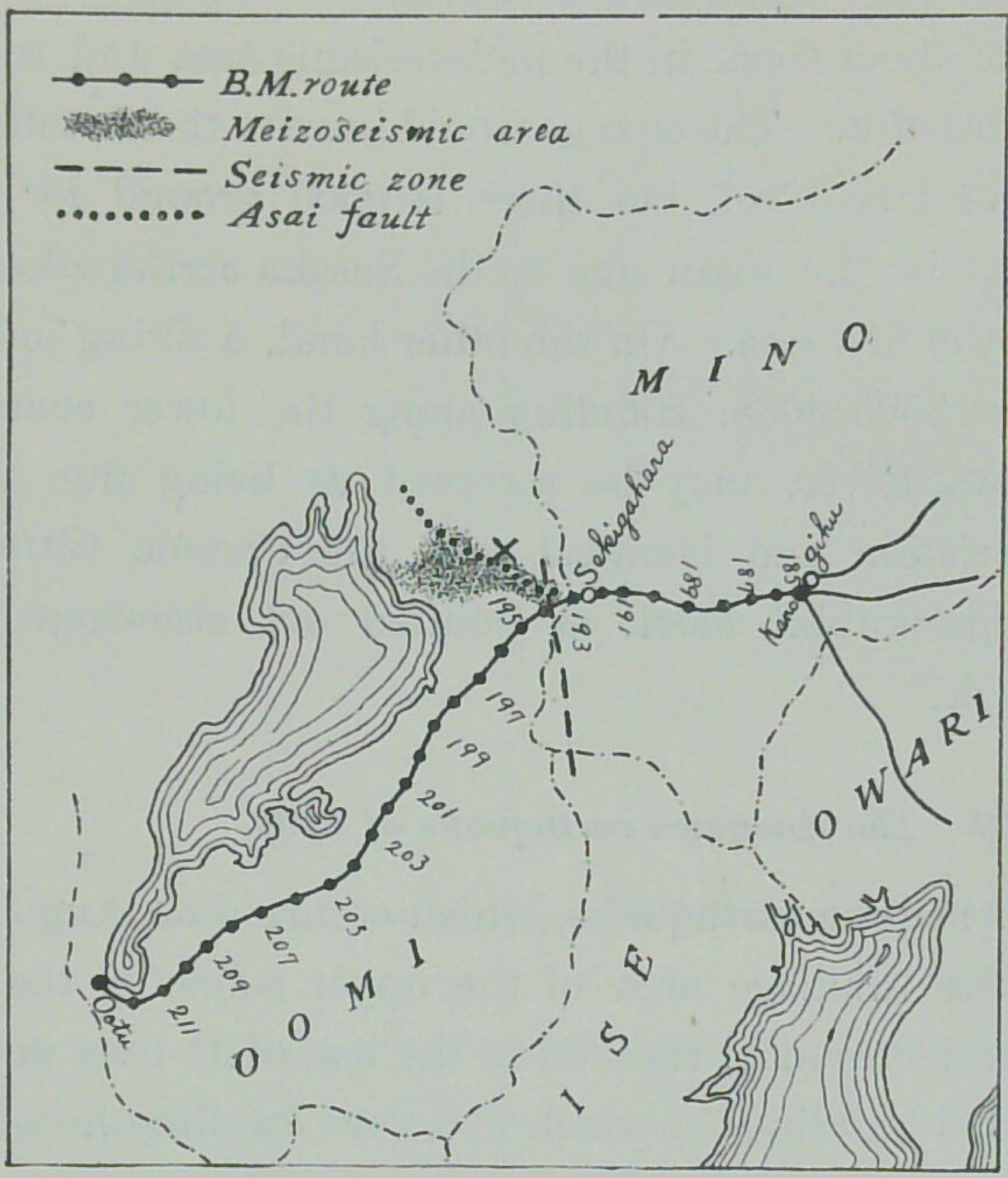
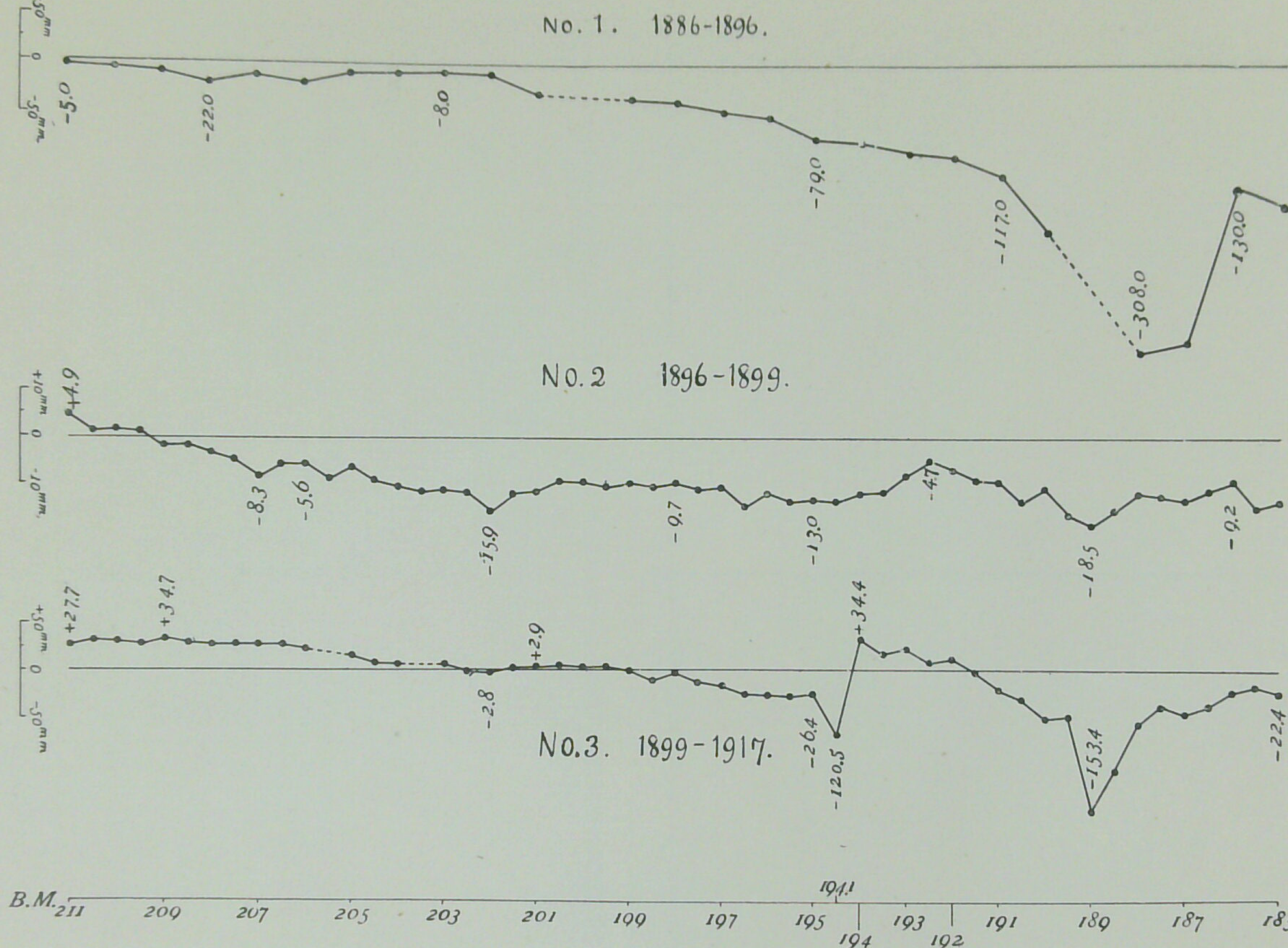


Fig. 27.

Not long ago, through the courtesy of Major-General H. Omura, Director of the Military Land Survey Department, the writer was supplied with the results of precise levellings repeatedly carried out over the route that almost touches the south-eastern extremity of the meizoseismic area. (See Table IV.) Results of the surveys are shown in Fig. 28, curves Nos. 1–3 indicating the differences in height of the bench-marks undergone during the periods 1886–1896, 1896–1899 and 1899–1917, respectively.

Evidently the topographical change represented by the first curve was due to the great Mino-Owari earthquake of 1891, and although it shows a gentle subsidence, dipping eastwards in the



No. 1. 1886-1896.
+50mm
0
-50mm
-5.0
-22.0
-8.0
-79.0
-117.0
-308.0
-130.0
No. 2 1896-1899.
+10mm
0
-10mm
+4.9
-8.3
-5.6
-15.9
-9.7
-13.0
-4.7
-18.5
-9.2
No. 3. 1899-1917.
+50mm
0
-50mm
+27.7
+34.7
-2.8
+2.9
-26.4
-120.5
+34.4
-153.4
-22.4
B.M. 211
209
207
205
203
201
199
197
195
194.1
194
193
192
191
189
187
185

Fig. 28.

region to the west of the famous Neodani fault caused by the earthquake of 1891, apart from a sharp subsidence at B.M. No. 188 (probably No. 189), it does not show any particular change in B.M. Nos. 192–199, whereas in the third period a very conspicuous one is noticeable. This last-mentioned change, which between the two consecutive marks Nos. 194 and 194.1 is as much as 15.5 cm., was undoubtedly due to the earthquake of 1909. In fact, the site coincides approximately with the intersection of the levelling route and either the Asai fault, or the seismic zone, or the south-eastern protuberance of the meizoseismic area caused by producing it slightly forward. The country to the west, moreover, underwent a slight depression, while that in the east experienced a little elevation, the change as a whole differing in nowise from those we have been accustomed to associate with faults on a much larger scale. Such a change of topography was not unexpected in a severe earthquake which may be regarded in the wider sense as one of the aftershocks of the great Mino-Owari earthquake. There is another sharp change shown by B.M. No. 189, which is nothing but a further advance of the depression produced at the same place on the occassion of the great earthquake of 1891.

Turning now to the second period which covered only 2 years and 10 months, it will be observed that there occurred at the spot, which was to suffer dislocation later, a very characteristic tilting, similar in character to that which took place later in the third period, although differing in magnitude. It must be noted, however, that in the figure, the vertical scale of the second curve is taken 5 times larger than that of the others.

Those who can see in the characteristic earth-tilting which took place at Sekihara before the earthquake of October 27, 1927, a harbinger of that earthquake, would doubtless find no difficulty in acknowledging with the writer that the present case is a similar phenomenon. While it is true that the change above described is small, it is by no means insignificant, for supposing the change to have gone on at the same rate during the subsequent 10 years up to the time when the earthquake actually took place, the total change would have amounted to as much as 4 cm. in the immediate neighbourhood of the centre of change, an amount large enough to be seized by a student of practical seismology as the portent of a coming earthquake.

No. 19. The Horisya earthquake of 1917.

Horisya and its vicinity in the Nantô district, Formosa, which were severely shaken by two large earthquakes in 1916, namely on Aug. 28 and on Nov. 15, respectively, were visited by another much bigger earthquake on Jan. 5, 1917, at 1 h 50 m. Owing to the fact that most of the inhabitants were in the midst of their slumbers, and that their heavy-roofed, unsubstantial houses collapsed so quickly that few could escape, the casualty list was comparatively heavy, being 1,700 houses thrown down and 138 people killed and wounded.

As usual, aftershocks were frequent in the epicentral region, 39 of them having been recorded during the subsequent 5 days at Taityû situated some 50 km. NW of the epicentre. Among these, the one which took place on Jan. 7 at 2 h 8 m was the worst and caused some damage.

The epicentral area was on the seismic zone that is known to cross Formosa from west to east with Kwarenkô as its eastern extremity. The epicentre may be regarded as having been in the mountainous district south-east of Horisya, though the shaking was much severer in Horisya and vicinity than in the epicentral

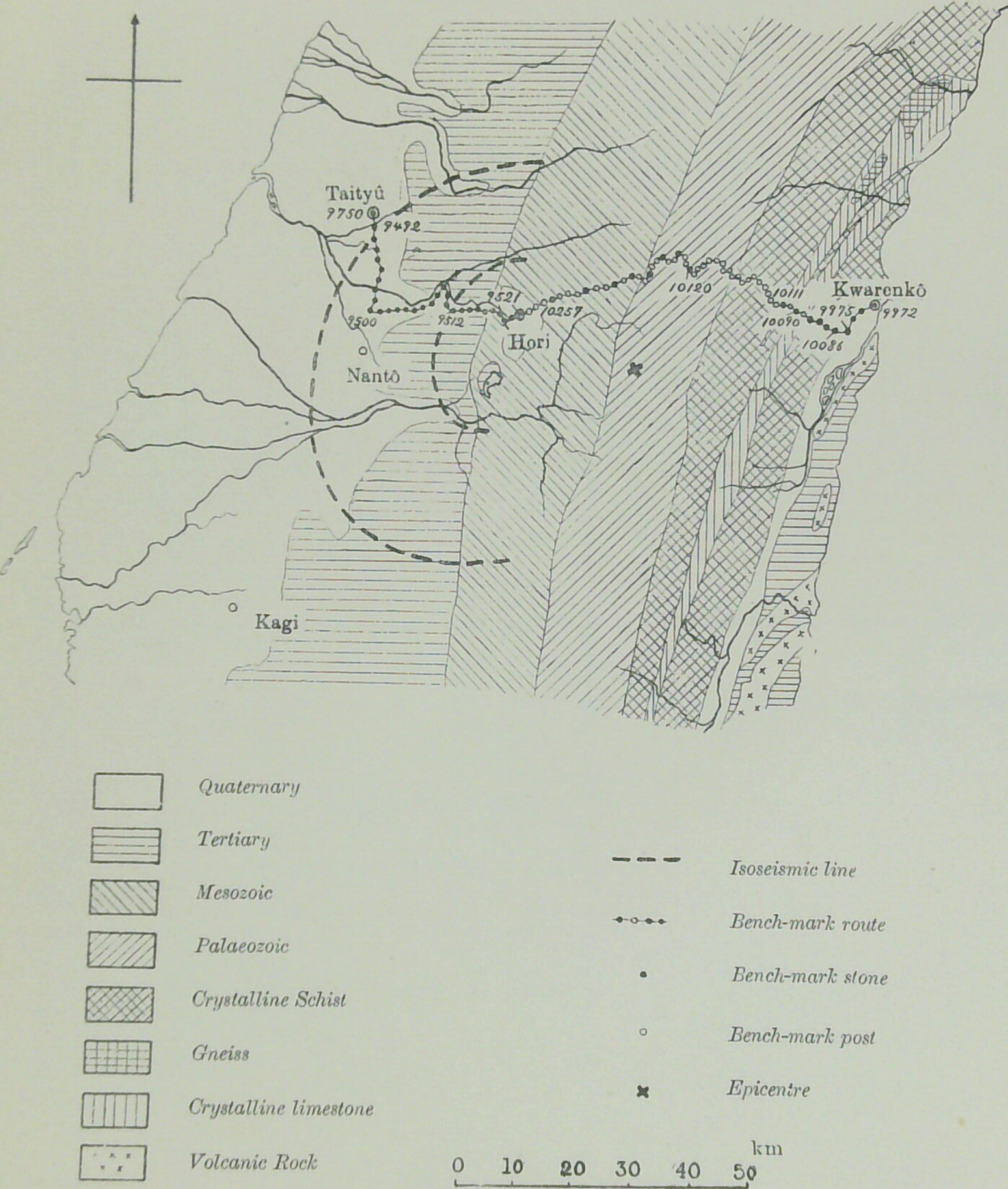


Fig. 29. Map showing the seismic area of the Horisya earthquake with the bench-mark routes.

area itself. This anomaly is to be explained by differences in the physical characters of the respective localities; Horisya and vicinity being Alluvium or Diluvium in formation, while the mountainous district is Tertiary or pre-Tertiary.

The levelling route across this area was first laid down in 1914 from Taityû up to Horisya, and again in 1924 from Horisya up to Kwarenkô, thus traversing the island almost completely from west to east. The second survey, however, was carried out

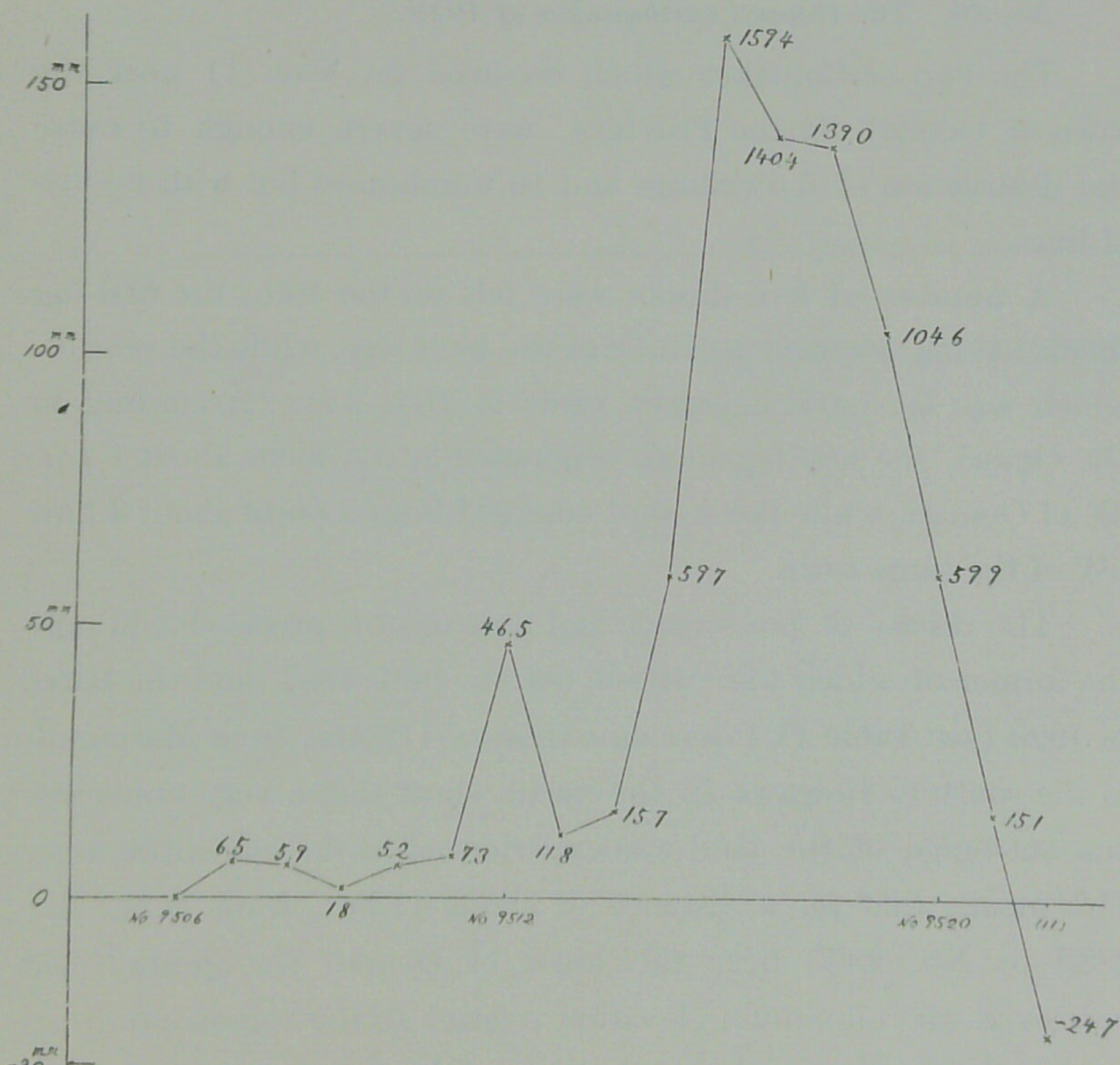


Fig. 30. Diagram showing the change of land-level associated with the Horisya earthquake.

in 1924 from B.M. No. 9506 up to No. (11), the route surveyed traversing the western half of the disturbed area. The changes in height of the bench-marks from No. 9515 to No. (11) show an out-bulge of the land amounting in height to as much as 16 cm. for a distance of nearly 16 km., pointing to the possible existence of a more conspicuous topographical change; at the least, a subsidence of the pre-Tertiary district lying further to the south-east.

No. 20. The Oomati earthquakes of 1918.[1]

The two earthquakes which occurred on Nov. 11 near the town of Oomati, Sinano Province, were severe enough to cause the destruction of 6 dwellings and 16 warehouses but with no loss of lives.

A number of fore-shocks were felt on the 10th, the first big shock having occurred at 2 h 58 m the next day, while the second, which was far more energetic came at 16 h 3 m. According to Dr. Omori, the first big shock originated at the focus about 2 km. SE of Oomati, while the second emerged from a point about 4 km. SW of the same town.

The results of pre-seismic and post-seismic precise levellings, the former of which was carried out in 1891–1893, and the latter in 1920 (see Table IV) over an extent of 112 km. from Matumoto in the south to Itoigawa in the north, show that a very conspicuous out-bulge of the land was experienced in the epicentral area. This means that for a distance of about 14 km. from B.M. No. 2889 to No. 2895 near the town of Oomati the ground had upheaved, the maximum elevation relative to the region adjoining the southern part being about 19 cm. In contrast to this, B.M.

1) For details see F. Omori: Bull. Imp. Earthq. Inv. Comm., Vol. X, No. 1.

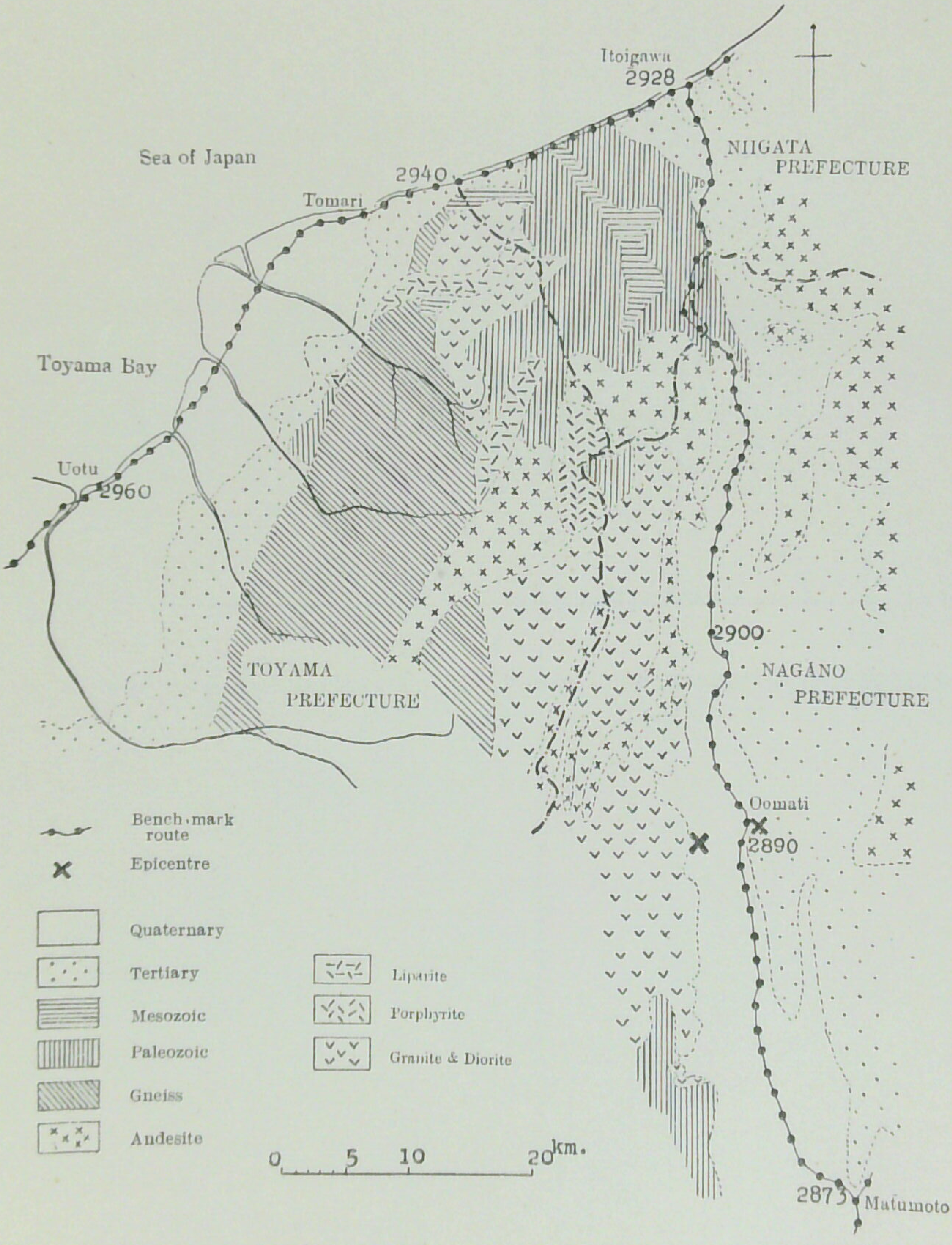


Fig. 31. Geological map of the Oomati district and vicinity with bench-mark routes.

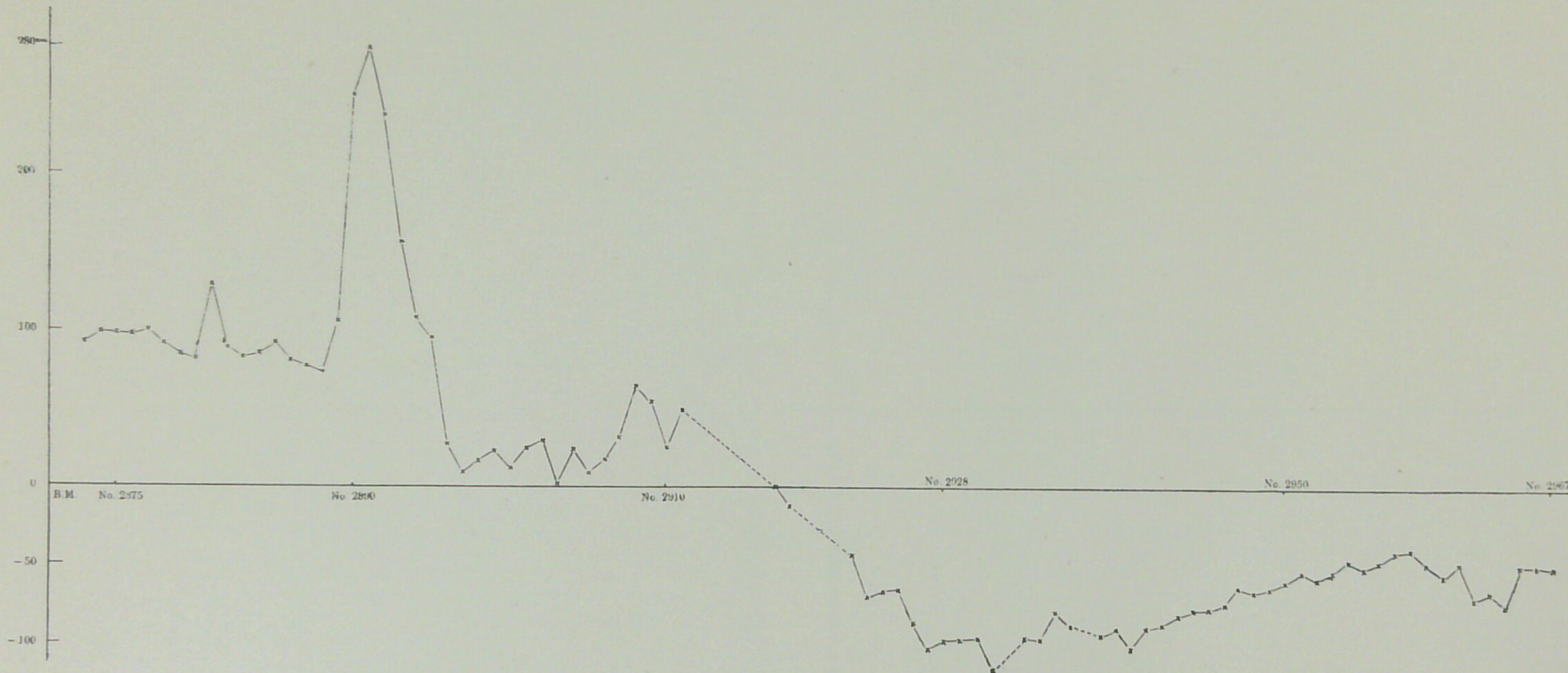


Fig. 32. Vertical displacements of the bench-marks in the Oomati district and vicinity.

Nos. 2896–2907, for a distance of 26 km. to the north of the above-mentioned elevated area suffered a depression with a maximum amount of 6.6–8.7 cm. when referred to the 30 km. tract lying to the north of Matumoto.

We must not, however, overlook another conspicuous tilting of the pre-Tertiary block lying to the north of the depression area just mentioned. The tilt consists of a dip northward for close on to 40 km. at a uniform rate of 4 mm. to the km. Whether secular variation had to do with it, or whether it was brought about cataclysmically on the occasion of the earthquake under discussion, is more than can be answered at present.

No. 21. The Miyosi earthquake of 1919.

This earthquake, which originated, according to Prof. S.T. Nakamura, in a mountainous region some 4 km. NE of the town of Miyosi in the province of Bingo, took place on Nov. 1 at 8 h 36 m. Miyosi and environs were rather badly shaken, but there were no damages. It was followed by some twenty or thirty aftershocks—some of which were strong enough to alarm the inhabitants.

Even with an earthquake of such magnitude, we may well assume the occurrence of topographical changes measurable by means of precise levellings, provided the levelling route passes through, or approaches within a few km. of, the epicentral area. These conditions were actually fulfilled in the present earthquake. Very fortunately, a levelling route linking Hirosima with Hamada via Sindi, which passes through Miyosi, had been laid down in 1891–1892. (See Table VII and Figs. 33 and 34.) The re-survey of the route was carried out for the section between

Table VII. Heights of bench-marks in the prefectures of Hirosima and Simane.

(1) Section between Hirosima and Sindi.

B.M.	Height in 1921	Height in 1891	Change
	m	m	mm
1669*	2.9213	2.9426	—
2364	4.2855	4.2855	0.0
2363	6.2023	6.1995	+ 2.8
2362	6.5230	6.5255	− 2.5
2361	10.5236	10.5141	+ 9.5
2360	10.8422	10.8226	+19.6
2359	16.2924[1)]	16.2724	+18.3
2358	20.5598	20.5931	−33.3
2357	21.6030	21.5867	+16.3
2356	41.5270[2)]	41.5075	+18.9
2355	62.3487	62.3291	+19.6
2354	97.7821	97.7606	+21.5
2353*	130.4291	130.4644	—
2352	181.6142	181.5970	+17.2
2351	268.0637	268.0476	+16.1
2350	263.5587	263.5439	+14.8
2349	246.7662	246.7393	+26.9
2348	227.0518	227.0223	+29.5
2347	216.1684	216.1327	+35.7
2346	211.4202	211.3859	+34.3
2345	206.7330	206.6938	+39.2
2344	201.7316	201.6921	+39.5
2343	199.9848	199.9454	+39.4
2342	197.8912	197.8403	+50.9
2341	197.0794	197.0235	+55.9

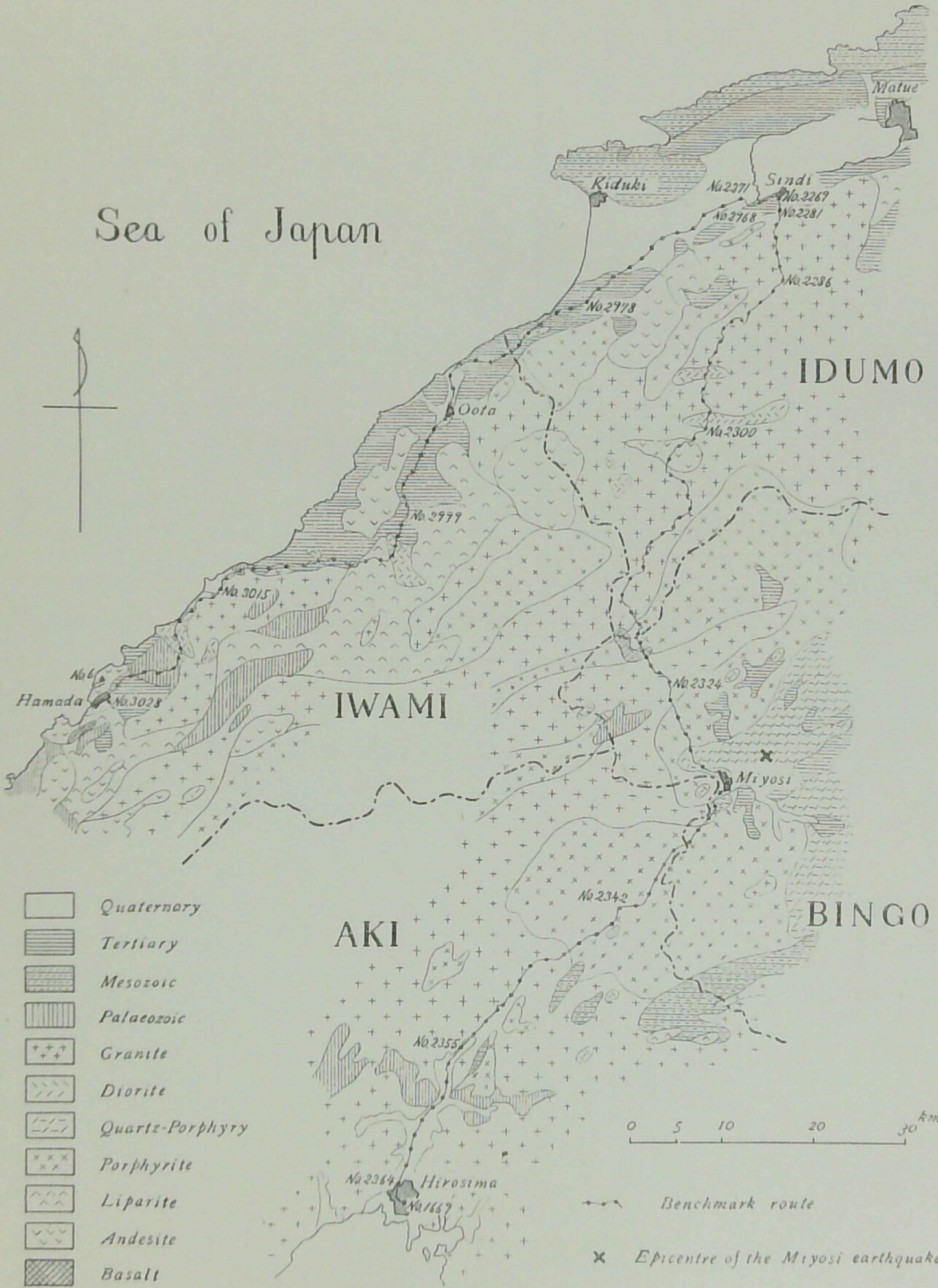


Fig. 33. Geological map and levelling route connected with the Miyosi earthquake.

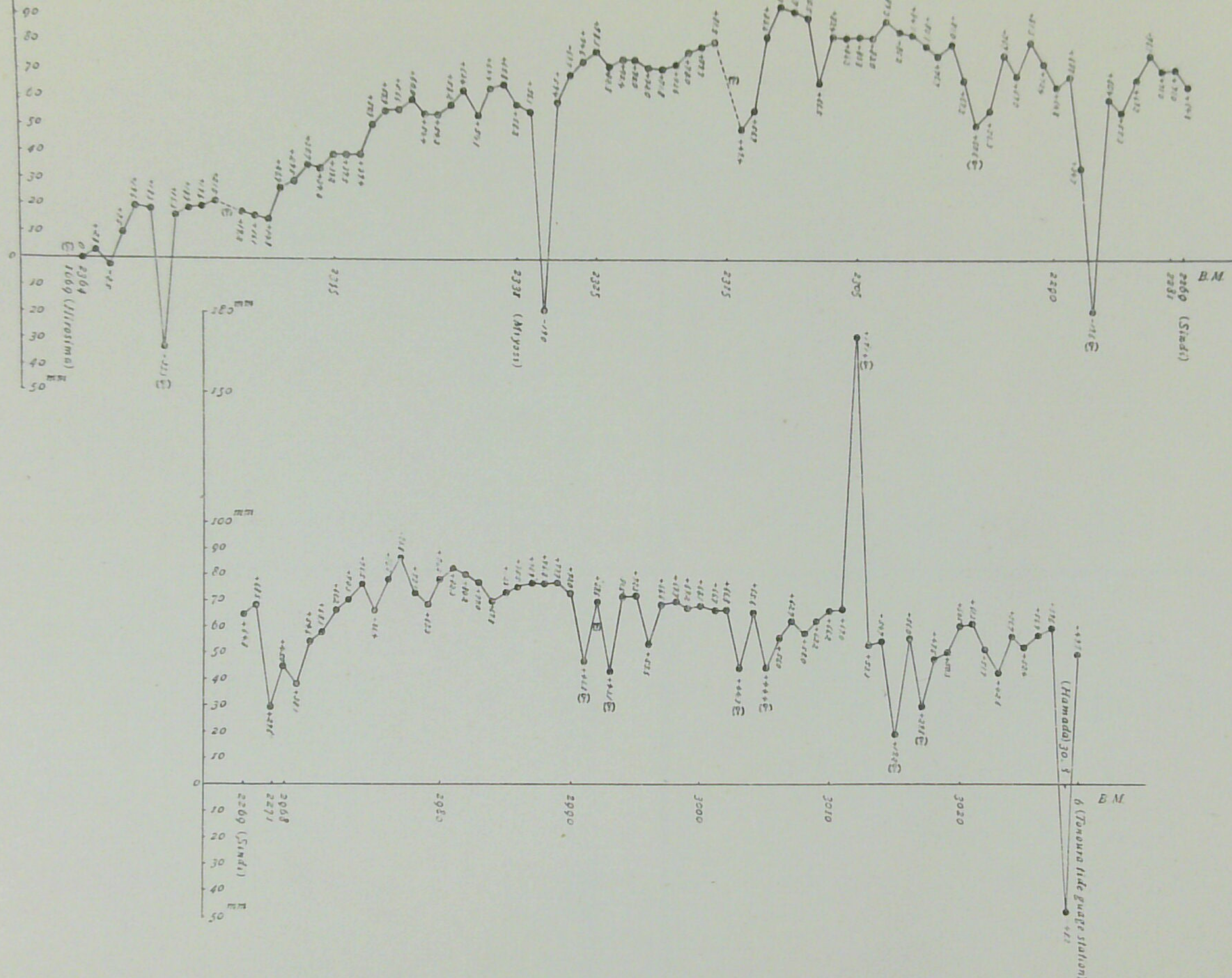


Fig. 34. Height differences of the bench-marks in the levelling route linking Hirosima with Hamada.

Table VII. (*continued*)

B.M.	Height in 1921	Height in 1891	Change
2340	205.4194 m	205.3628 m	+56.6 mm
2339	188.7008	188.6408	+60.0
2338	179.7760	179.7216	+54.4
2337	176.6569	176.6026	+54.3
2336	173.7096	173.6514	+58.2
2335	187.5324	187.4690	+63.4
2334	164.8642[3)]	164.8071	+54.1
2333	160.2535	160.1891	+64.4
2332	156.5604[4)]	156.0799	+65.8
2331	156.2571	156.1989	+58.2
2330	166.2441[5)]	170.5518	+56.1
2329	152.5920	152.6110	−19.0
2328	162.7440	162.6846	+59.4
2327	170.6083	170.5386	+69.7
2326	188.5318	188.4572	+74.6
2325	210.6874	210.6093	+78.1
2324	242.2302	242.1574	+72.8
2323	291.0964	291.0210	+75.4
2322	335.3418	335.2668	+75.0
2321	404.2949	404.2229	+72.0
2320	456.3707	456.2989	+71.8
2319	524.5941	524.5205	+73.6
2318	579.5863	579.5083	+78.0
2317	511.5484	511.4685	+79.9
2316	467.7318	467.6503	+81.5
2315*	444.3255	444.3777	—
2314	425.1316	425.0822	+49.4
2313	407.6954	407.6387	+56.7

Table VII. (*continued*)

B.M.	Height in 1921	Height in 1891	Change
	m	m	mm
2312	390.7368	390.6535	+83.3
2311	425.4284	425.3341	+94.3
2310	414.6729	414.5802	+92.7
2309	449.6003	449.5098	+90.5
2308	421.8737	421.8072	+66.5
2307	479.3400	479.2566	+83.4
2306	558.8746	558.7914	+83.2
2305	564.2316	564.1478	+83.8
2304	530.8808	530.7978	+83.0
2303	456.3065	456.2172	+89.3
2302	380.4982	380.4130	+85.2
2301	332.2403	332.1562	+84.1
2300	276.9113	276.8312	+80.1
2299	246.0305	245.9538	+76.7
2298	219.0145	218.9335	+81.0
2297	199.4357	199.3684	+67.3
2296*	179.9081[6]	179.8696	+50.6
2295	160.2818	160.2225	+56.3
2294	140.1288	140.0519	+76.9
2293	120.4624	120.3934	+69.0
2292	106.9178	106.8365	+81.3
2291	76.9904	76.9170	+73.4
2290	62.5680	62.5032	+64.8
2289	52.5199	52.4511	+68.8
2288	38.7909	38.7562	+34.7
2287*	39.9381	39.9577	−19.6
2286	81.7225	81.6621	+60.4
2285	37.0532	36.9979	+55.3

Table VII. (*continued*)

B.M.	Height in 1921	Height in 1891	Change
	m	m	mm
2284	30.3086	30.2414	+67.2
2283	65.9362[7]	65.8722	+76.1
2282	28.5534	28.4824	+71.0
2281	7.6380	7.5670	+71.0
2269	2.5542	2.4894	+64.8

*......Original identity uncertain.

Correction in mm. for new mark......1) −1.7, 2) −0.6, 3) −3.0, 4) −414.7
5) 4363.8, 6) 12.1, 7) 12.1.

(2) Section between Sindi and Hamada.

B.M.	Height in 1922	Height in 1892	Change
	m	m	m
2269	2.5542	2.4894	+.0648
2270	6.5782	6.5097	+.0685
2271	3.2240	3.1944	+.0296
2968	3.1762	3.1312	+.0450
2969	7.0540	7.0159	+.0381
2970	10.0530	9.9984	+.0546
2971	10.7528	10.6947	+.0581
2972	8.9662	8.9000	+.0662
2973	8.6959	8.6256	+.0703
2974	8.5353	8.4588	+.0765
2975	5.2605	5.1941	+.0664
2976	8.8788	8.8003	+.0785
2977	13.0078	12.9210	+.0868
2978	36.0718	35.9987	+.0731
2979	8.8199	8.7516	+.0683

Table VII. (*continued*)

B.M.	Height in 1922	Height in 1892	Change
	m	m	m
2980	17.9699	17.8914	+.0785
2981	34.4567	34.3744	+.0823
2982	26.8513	26.7711	+.0802
2983	10.4823	10.4053	+.0770
2984	70.1012	70.0314	+.0698
2985	110.4154	110.3421	+.0733
2986	50.0286	49.9531	+.0755
2987	5.1404	5.0635	+.0769
2988	3.6182	3.5414	+.0768
2989	7.7464	7.6687	+.0777
2990	27.2944	27.2214	+.0730
2991*	32.2323	32.1855	+.0468
2992*	14.0766	14.0070	+.0696
2993*	22.1960	22.1529	+.0431
2994	50.7805	50.7090	+.0715
2995	86.9959	86.9236	+.0723
2996	123.9220	123.8684	+.0536
2997	173.7092	173.6406	+.0686
2998	187.6348	187.5651	+.0697
2999	235.1432	235.0760	+.0672
3000	241.0474	240.9793	+.0681
3001	214.9594	214.8927	+.0667
3002	260.1730	260.1062	+.0668
3003*	243.9766	243.9323	+.0443
3004	283.1015	283.0359	+.0656
3005*	245.6173	245.5729	+.0444
3006	180.8913	180.8353	+.0560
3007	145.6497	145.5870	+.0627

Table VII. (*continued*)

B.M.	Height in 1922	Height in 1892	Change
	m	m	m
3008	84.6338	84.5758	+.0580
3009	35.9380	35.8758	+.0622
3010	18.4456	18.3794	+.0662
3011	27.6576	27.5906	+.0670
3012*	6.4744	6.3030	+.1714
3013	68.4604	68.4071	+.0533
3014	7.3126	7.2579	+.0547
3015*	4.9250	4.9058	+.0192
3016	12.5242	12.4682	+.0560
3017*	5.5245	5.4947	+.0298
3018	6.0203	5.9728	+.0475
3019	3.0635	3.0132	+.0503
3020	17.7809	17.7204	+.0605
3021	48.5655	48.5042	+.0613
3022	65.6325	65.5808	+.0517
3023	28.0335	27.9909	+.0426
3024	17.9591	17.9024	+.0567
3025	9.9665	9.9141	+.0524
3026	21.3314	21.2745	+.0569
3027	40.7884	40.7288	+.0596
3028	6.1936	6.2418	−.0482
6	2.8412	2.7915	+.0497

* .....Original identity uncertain.

Hirosima and Sindi in 1921 and for one between Sindi and Hamada in 1922, the change in height of every bench-mark having been estimated with the assumption that B.M. No. 2364 which stands at Hirosima underwent no change during the intervening 29 years, though there is ground for suspecting that it suffered a depression to the extent of about 5 cm. (See Fig. 42, curve for Tonoura, a terminus of the present route.)

In the first section of the route, the most conspicuous change was experienced by B.M. No. 2329 which is situated about 6 km. WSW of the epicentre. The topographical change thus revealed by that mark as well as the adjoining ones consisted of a very characteristic subsidence of as much as 7.8 cm. when referred to one of the next two marks; but 9.7 cm. when referred to B.M. Nos. 2324–2333.

As regards the second section, the area through which the route passes experienced no change after all, excepting the spots where stand B.M. Nos. 3028, 2271 and 2968–2977.

Bench-mark No. 3028 stands in the town of Hamada, the scene of an acute upheaval of from 30 to 60 cm. in connexion with the 1872 earthquake, so that there need be no hesitation in ascribing the change indicated by this bench-mark to what we call the secular or chronic variation. Similarly, the change indicated by B.M. Nos. 2271, 2968–2977 may also be regarded as chronic tilting undergone by a Tertiary or post-Tertiary crustal block.

No. 22. The Simabara earthquakes of 1922.[1]

Earthquakes began to be felt from about 16 h 15 m of Dec. 7, 1922, and though they were all fore-shocks, a vigorous one was felt at about 1 h 50 m of the following day succeeded by another

1) For details see Bull. Imp. Earthq. Inv. Comm., Vol. X, No. 2.

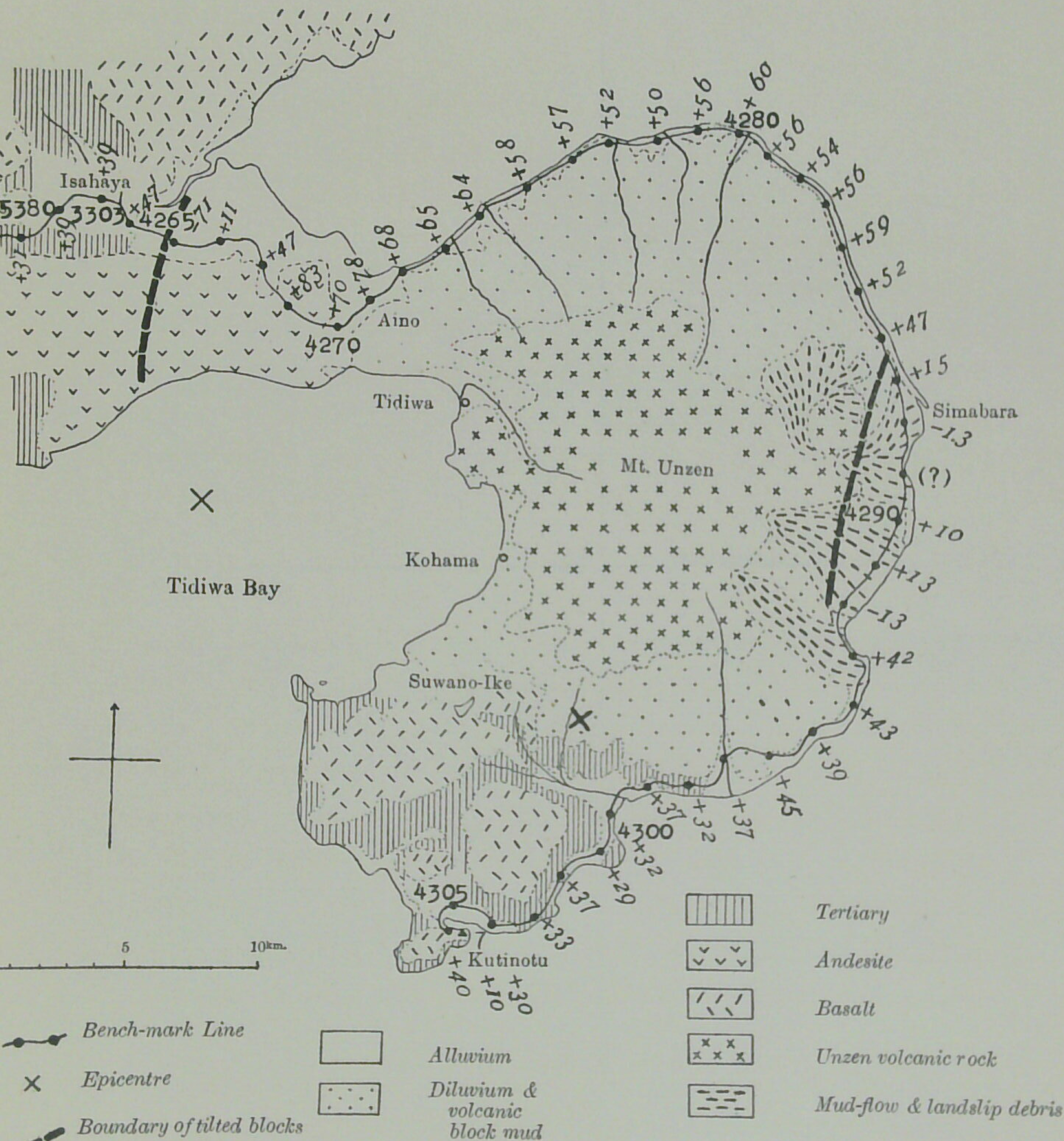


Fig. 35. Geological map of the Simabara Peninsula and vicinity with bench-mark route.

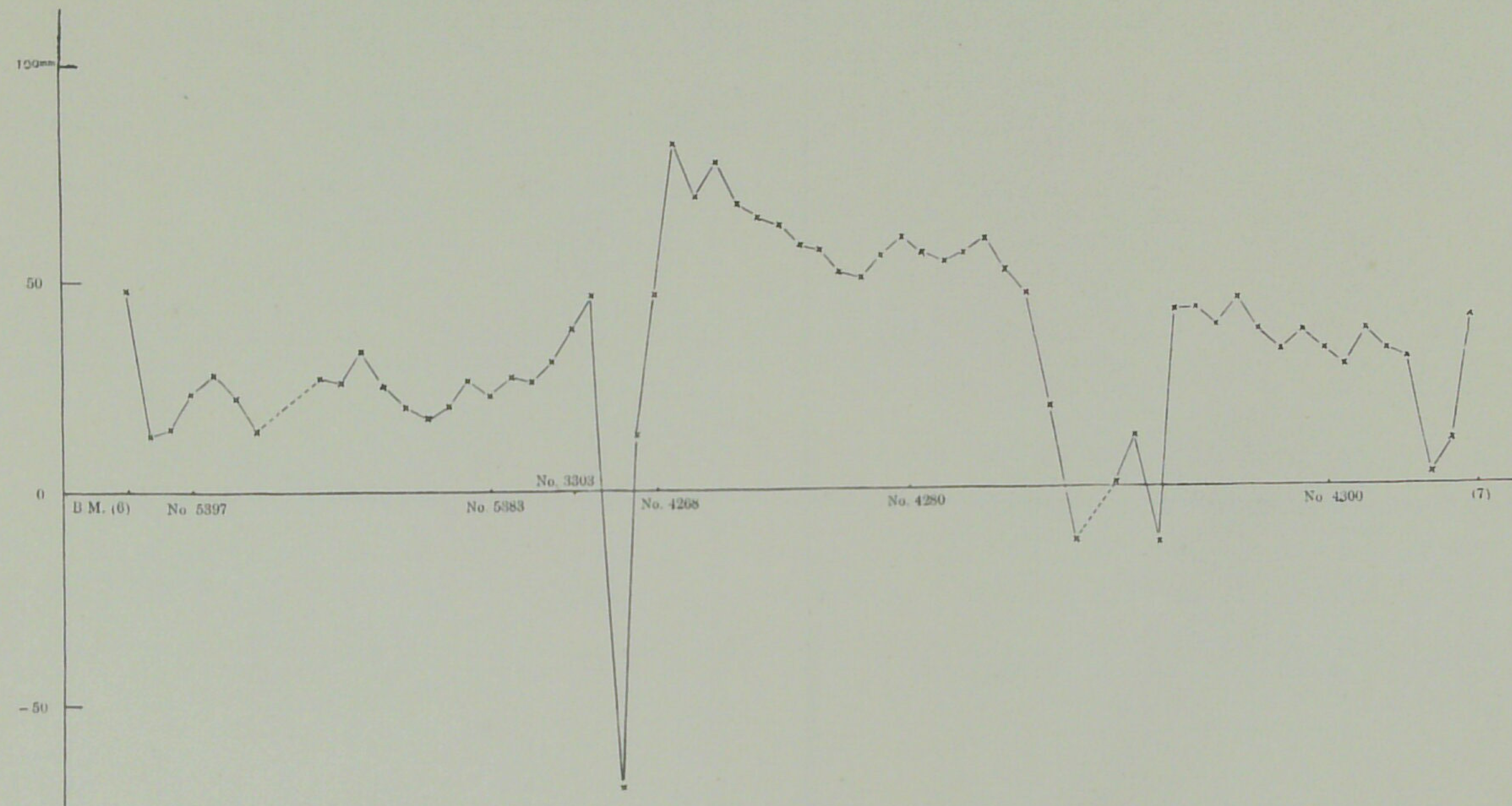


Fig. 36. Change of land-level of the Simabara Peninsula and vicinity accompanied by the Simabara earthquake.

strong shock at about 11 h 3 m of the same day. While the first of these overthrew houses, killed people and caused other damage in the villages lying in the SE part of Simabara Peninsula, the havoc wrought by the second strong shock throughout the district lying between Obama hot springs in the western as far as Kitamura in the northern part of the peninsula was much more serious.

That the two shocks affected different areas is explained by the fact that their seismic centres were not coincident; the former in the writer's opinion having originated beneath the base of Hugendake (volcano) whereas the latter originated in Tidiwa Bay near the Isthmus of Simabara. The number of killed and wounded was 27 and 35 respectively, while 131 dwellings and 295 warehouses were levelled.

Re-levelling of the route which terminates at Hukabori, a mareograph station near Nagasaki, and at Kutinotu, a port in the southern end of the peninsula, was undertaken in 1923. It must be noted, however, that the earlier surveys were made as far back as 30 years ago; the section between Isahaya and Kutinotu in 1894 and that between Isahaya and Hukabori in 1897. While in the circumstances, some changes more or less during the interval must be expected, the annual mean sea-level at the Hukabori mareograph station showed a rise of only 2 or 3 cm., which difference, when compared with results of surveys made before and after the interval in question, is altogether negligible in the first approximation. The outstanding changes observed in the land-level were as follows:

(i) Between B.M. Nos. 4265 and 4270, that is between Isahaya and Aino, the maximum elevation was 8.3 cm., and the maximum depression 7.1 cm.

(ii) Leaving Aino and following the eastern coast of the Simabara Peninsula, we reach at its southern extremity the small sea-port of Kutinotu. In this section of country, with the exception of the eastern extremity of the peninsula between B.M. Nos. 4287 and 4292, there was an all-round uplift of from about 3 cm. to 6 cm., whereas no elevation at all could be detected about Kutinotu. On the other hand, the eastern extremity of the peninsula showed a slight depression as compared with adjacent lands.

While it is a matter for regret that this survey covered only the southern and eastern coast-lines, leaving out the western coast-line, still when it is considered that the latter section had never been previously surveyed, it was unavoidable. Another matter to which attention may be called is the fact that the change in sea-level during a period of more than 23 years as observed at Hukabori, and just referred to, would seem to suggest subsidence of as much as 2–3 cm., rather than an elevation.

At all events, there appears to have occurred a slight upheaval of land for the greater part of the peninsula; or, more precisely, an earth-tilting with depression on the extreme east of the peninsula and elevation on its northern part. Such a change could be expected with an earthquake occurring in a locality consisting of a Tertiary layer covered with younger eruptive rocks. In addition to the foregoing, there occurred at the isthmus, connecting the peninsula with the main land, a much more conspicuous topographical change which may be regarded as an accompaniment of the present earthquakes. The occurrence of this fault-like change together with the earth-tilting above cited would seem to suggest that there were two seismic centres, one at the bottom of Tidiwa Bay and another in the heart of the peninsula. As the former accompanied more conspicuous changes than the latter, we shall not be far wrong in concluding that the most active centre was at the bottom of Tidiwa Bay.

No. 23. The Kwanto earthquake of 1923.

If the great Tango earthquake of 1927 can be called a twin earthquake, that is to say, an earthquake of double source, then the non-local destructive earthquake of Sept. 1, 1923, which devastated almost the entire Kwanto district may well be called an earthquake of multiple source. The seismic waves responsible for the wide-spread destruction emerged from different points on a weak zone, which crosses the bottom of Sagami Bay from NW to SE and measuring some 60 km. in length, as well as other weak zones distributed in the Kwanto district. Indeed, the writer was able to distinguish in the initial portion of the seismograms obtained at Tokyo three different phases—a phenomenon suggesting different sources of origin. Of these, the initial phase which reached Tokyo at 11 h 58 m 44 s emerged from the centre of the first-said zone (Fig. 41, I); the second that came 3 sec. later and which was much bigger than the initial phase, originated near Tanzawayama (II); whilst the third which came 7.5 sec. later than the first and was the biggest of the three phases, originated again from the central part of the zone (III). It is highly probable that the same process repeated itself afterwards, although they were completely masked by the exceptionally large earth-movements that lasted more than a minute.[1] Fortunately the direction in which our Institute is situated is such that it is able to command a fair side view of the migration of origin, whereas those stations so situated as to command an endwise view of the zone were unable to observe the migration. We have here an explanation of why investigators,

1) A. Imamura: Proc. Imp. Acad., Vol. II (1926), No. 2.

adopting for the most part data obtained at stations situated on the NW side of the seismic zone, and who, quite ignoring those obtained from the four or five pairs of seismographs installed at our Institute, insist on assigning the origin of this earthquake to a point near Odawara or Tanzawa district, the very locality which to us is the origin in interpretation of the *second* phase of our seismograms. It scarcely needs to be added here that from the aspect of world-wide seismic wave transmission, the Kwanto region itself may be regarded as the seismic focus.

In the matter of magnitude and other characteristics, this earthquake had much in common with the earthquake of 1703. For instance, in their charts for the distribution of seismic intensities, in the upheavals of land, and in the distribution of the heights of the *tunamis*, they resembled each other quite closely; although the *tunamis* and the changes brought about in the topography were on a smaller scale in the 1923 earthquake than in the older earthquake. But when we come to the damage and the death roll, they reached astounding proportions in the 1923 earthquake. Official returns set forth 99,331 killed, 103,733 injured, besides a large number missing; 128,266 houses levelled, 447,128 houses reduced to ashes, and 868 houses washed away.

The topographical changes that came about in the Kwanto district in connexion with the 1923 earthquake assumed various forms, such as upheavals and subsidences of land, or more generally earth-tiltings; horizontal displacements; dislocations, either primary or secondary; landslides etc. Of these changes, the landslides, the outstanding example of which was the Nebukawa mudflow, are least concerned with our present study. The dislocations promptly received the able attentions of Prof. Yamasaki, who has put down the so-called primary dislocations to the

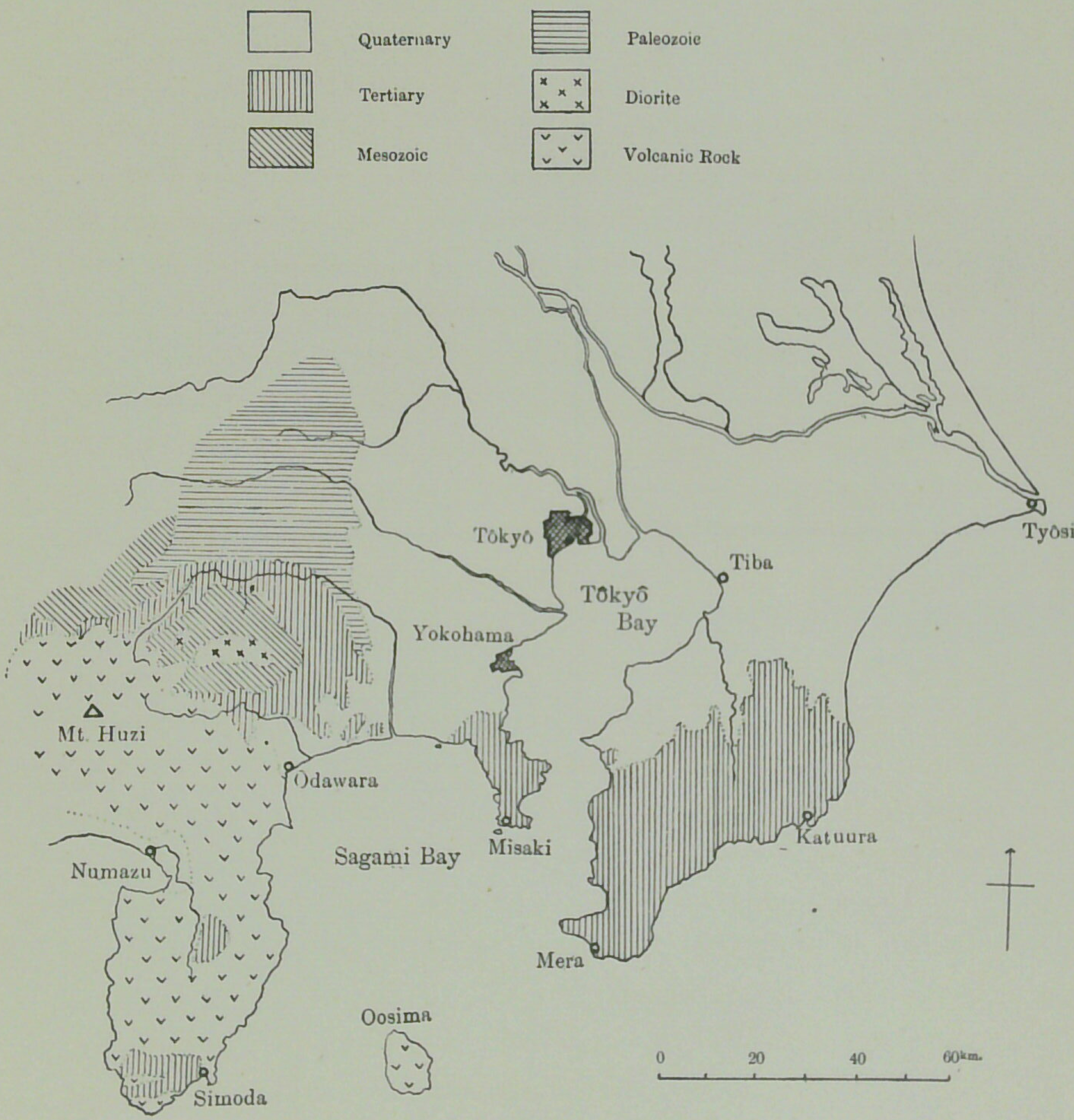


Fig. 37. Geological map of the Kwanto district.

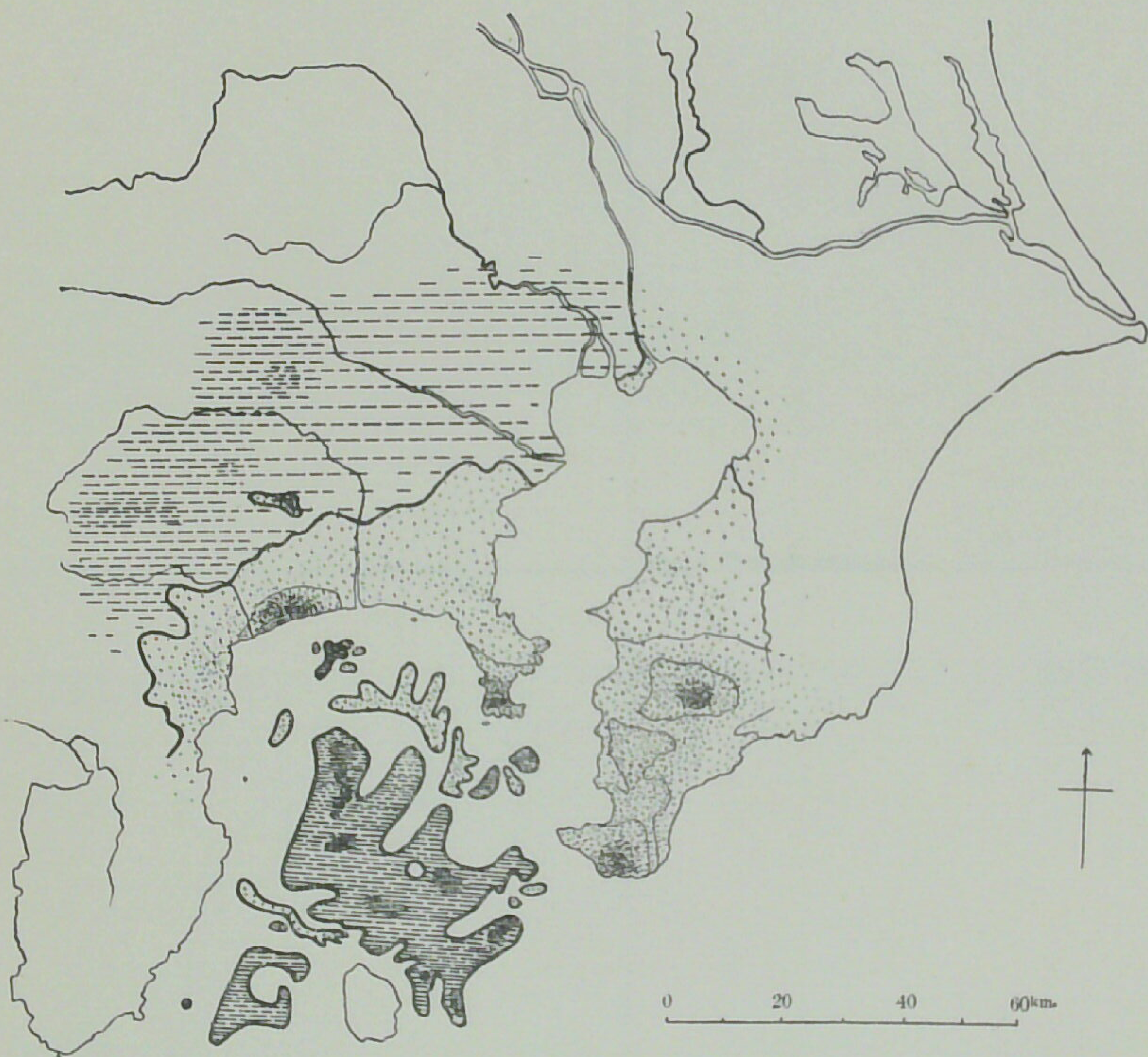


Fig. 38. Map showing the distribution of upheaval and subsidence accompanied by the great Kwanto earthquake of 1923.

deep trench that crosses the bottom of Sagami Bay in a NW to SE direction, and the secondary dislocations to different localities such as Nako in the province of Awa, Sitaura and Sinkawa in the province of Sagami, etc.[1] The belt along which the primary dislocation occurred is identical with what the writer has just referred to under the term *weak zone*. Bounded by this line, the sea-bottom on the SW side underwent a tremendous depression, whilst that on the other side experienced a corresponding elevation, thus suggesting the possible formation in this place of a gigantic fault with a vertical dislocation of as much as 100 metres. It is estimated that the area and volume of depression amount to 700 sq. km. and 50 cu. km. respectively, and those of elevation to 240 sq. km. and 20 cu. km. These results are based on careful soundings carried out by the Imperial Naval Hydrographers at 83,286 points distributed in the area between Tyôsi in the east and Suruga Bay in the west, and between Tokyo Bay in the north and Miyake Island in the south. As to the horizontal shear of the submarine fault, the writer and Mr. F. Kishinouye, adopting the results of geodetic triangulations carried out by the Imperial Military Land Survey Department before and after the earthquake (see Table VIII and Fig. 39), calculated it as not being less than 8 metres.[2]

The geodetic triangulation of the Kwanto district and its surrounding regions was carried out first in 1884–1889 and later in 1924–1925. For the sake of convenience, the northernmost point Teruisi-yama and the azimuth of Tukuba-san from this point were assumed unchanged for the intervening years, after which the changes, or to put it more concretely, the horizontal displacements

1) N. Yamasaki: Jonr. Fac. Sc., Tokyo Imp. Univ., Sec. II.

2) A. Imamura & Kishinouye: Proc. Imp. Acad., Vol. IV (1928), No. 3 and Bull. Earthq. Res. Inst., Vol. V.

Fig. 39.

relatively to the said standard of other points were worked out, the results thus obtained being shown in the accompanying table.

The data would involve, besides the cataclysmic change associated with the 1923 earthquake, a secular variation which had been going on at each triangulation point during some 40 years preceding the earthquake. There are, however, good grounds for assuming that those conspicuous changes undergone by points situated within a short distance, say 50 km., from the epicentral zone, were brought about mostly at the time that the earthquake took place. Instead of the standard at Teruisi-yama and Tukuba-san, another pair of trigonometrical points could be selected, or we

Table VIII.

Triangulation point	Displacement		Triangulation point	Displacement	
	Azi-muth	Mag-nitude		Azi-muth	Mag-nitude
	°	m		°	m
Teruisi-yama	0	0.00	Takane	68	0.45
Tukuba-san	292	0.43	Hongô	90	0.55
Dôhira-yama	62	0.41	Tokumaru	111	0.39
Kokusi-dake	56	1.60	Tokyo	170	0.17
Kumotori-yama	57	1.43	Renkôzi-mura	127	0.84
Koganesawa-yama	73	1.29	Kaminumabe	140	0.71
Gosyôtai-yama	75	1.84	Sengen-yama	112	2.75
Tanzawa-yama	93	1.28	Hutago-yama	141	2.73
Kamuriga-take	47	1.56	Nokogiri-yama	145	2.57
Kenasi-yama	32	2.29	Bôno-Oo-yama	146	1.14
Asitaka-yama	34	2.13	Ookawa	34	1.20
Manziro-dake	9	2.86	Mineoka	95	0.82
Oosima	8	3.78	Kano-san	128	1.50
Simomizo-mura	116	1.36	Kuranami	108	0.55
Zama-mura	117	1.64	Ootani	100	0.77
Tobio-yama	114	1.37	Nonoduka	109	0.82
Nagatuda-mura	120	1.52	Rokudizô	63	0.49
Hôten-mura	349	0.20	Itinomiya	86	0.34

may proceed to find out the movement of each of the mosaic blocks that constitute the Kwanto district as a whole. Whichever way we may choose, there remains to acknowledge the fact that, broadly speaking, the whole Kwanto district partook of a clockwise twist about a vertical axis somewhere in Sagami Bay, the bottom of the bay itself along the above-cited great fault having suffered, probably, a horizontal displacement of not less than 8 metres as has already been mentioned.

The writer now proposes to deal with the results of precise levellings, together with results of triangulations of the second- and third-order triangulation points that were also carried out by the Imperial Military Land Survey Department for the purpose of investigating, amongst other things, the changes in height of the area concerned. Only two triangulations were carried out, one before and another after the earthquake. Re-levellings of the different routes in and around the Kwanto district, however, were made several times, so that the level changes of each bench-mark could be deduced not only for the period including the 1923 earthquake, but also for the periods preceding as well as following it.

The levelling routes and the years of survey for every section of the route are given in the accompanying charts, though details for the routes in Tokyo and vicinity are here omitted. (See earthquake No. 16.) Let us first examine the changes directly connected with the present earthquake.

As will be seen from Fig. 40, the post-seismic survey was held in the period 1923–1924, but the pre-seismic survey was carried out in periods which differ not only from each other for adjacent sections but also for adjacent marks within the same section, as for instance in the section between Tokyo and Hudisawa. Notwithstanding these drawbacks, the curve expressing the height changes are found to connect fairly smoothly the sections to sections and the points to points although no allowance has been made for differences in the years of survey, all of which go to suggest that the secular variations of the land-level in the disturbed area had been negligibly small when compared with the cataclysmic changes of 1923. The outstanding features are as follows:

(i) Generally speaking, the Kwanto district upheaved in its SE part and subsided in its NW parts with the neutral axis lying

Fig. 40. Levelling routes in the Kwanto district and vicinity.

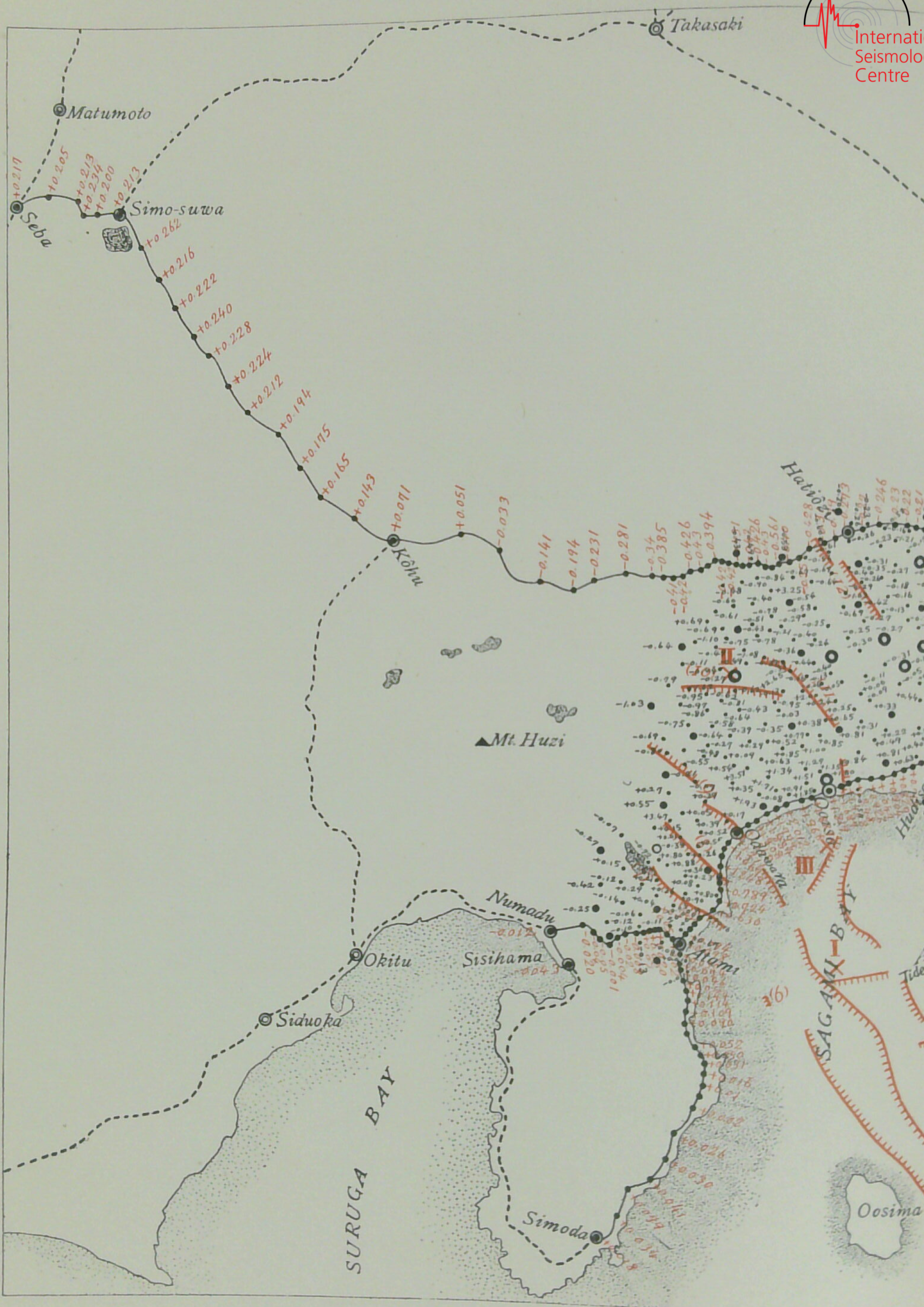


Fig. 41. Map showing the change of land-level

in the Kwantô district and vicinity.

somewhere along a line passing through Atami, Matuda, Atugi, Kawasaki and the lower course of the Edo-gawa River. This may be called an acute, onward tilting of the Kwanto block.

(ii) Roughly speaking, maximum elevations occurred at three different places, namely, on the coast between Ooiso and Odawara, in the southern part of the Miura Peninsula, and in the southern part of the Bo-So Peninsula, the maximum elevations attained at the respective places having been 2.0, 1.4 and 2.0 metres. It is well to note that all these places are situated in close proximity to the upheaved sea-bottom of Sagami Bay. In the Bo-So Peninsula the elevation is found to diminish towards the eastern coast. This fact together with the anomalous deviation of the horizontal displacements at such points as Nonoduka, Mineoka and especially Ookawa, seem to agree in suggesting that the south-eastern limit of the upheaved area may not be so far from the coast-line as it may appear.

(iii) The area of maximum depression occurred in a mountainous district, predominantly pre-Tertiary, and lying between Hatiôzi in the north-east and Gotenba in the south-west. The maximum depression was traced to a place near Tanzawayama where it amounted to 1.6 metres.

As above stated, Prof. N. Yamasaki has investigated secondary faults, though his investigation was limited to the four faults, namely, the Bôsyû faults (the western segment of No. 1 in Fig. 41), the Sitaura fault (the eastern segment of No. 5), the Sinkawa fault (the southern segment of No. 13) and the Hatusima fault (No. 6). The results of precise levelling and geodetic triangulation as shown in Fig. 41, however, enabled the writer to make, on one hand, the extended study of the faults discovered by Yamasaki, and, on the other hand, a new study of the faults or flexures, which may be regarded as occurred in the disturbed area associated directly or indirectly with the great earthquake of Sept. 1, 1923. For instance, taking No. 1, Yamasaki investigated only its western segment for an extent of about 3 km. in length. The result of levelling, however, shows a topographical change in B.M. Nos. 3880–3887, which shows that there occurred a fault somewhere between B.M. Nos. 3884 and 3885 with dropping of its northern side of not less than 67 cm.[1] It may be said that the fault appeared as a relative tilting of the blocks adjacent to the fault, the southern one making a tilt dropping westwards relatively against the northern one, so that Yamasaki, who made an excellent study of the western segment, halted at the *hinge* or *node* of the dislocation without searching for the further extension of his Emmyôzi fault.

The faults, though some of them may be no more than mere flexures, thus worked out, have been found, for the most part, to run along with the preexisting tectonic lines. They may be summarised as follows:

No. 1. The Emmyôzi f.—total extension 8 km., maximum dislocation 1 m.

No. 2. The Yatuka f. consists of two segments—total extension 22 km., maximum vertical displacement 40 cm. in the W segment and 15 cm. in the E segment.

No. 3. The Hota f.—total extension 12 km., maximum vertical displacement 30 cm.

No. 4. The Kamogawa f. consists of two segments—total extension 20 km., maximum vertical displacement 40 cm. in the W segment and 60 cm. in the E segment.

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1) Actually ascertained lately by Mr. Y. Otsuka.

No. 5. The Sitaura f.—total extension 3 km., maximum vertical dislocation 1.5 m.

No. 6. The Hatusima f.—total extension 1 km., maximum vertical dislocation 1 m.

No. 7. The Hakone f.—total extension 11 km., maximum vertical displacement 40 cm.

No. 8. The Nebukawa f.—total extension 5 km., maximum vertical displacement 1 m.

No. 9. The Sakawa f. consists of two segments—total extension 20 km., maximum vertical displacement 80 cm. in the NW segment and 20 cm. in the SE segment. It may possibly be a continuation of the main fault; but some doubted the relationship for the reason that the dislocation was manifested there very meagrely, though it is immaterial if we assume the place to correspond to the hinge of the relative tilting of the blocks adjacent to the tectonic zone.

No. 10. The Tanzawa f.—total extension 15 km., maximum vertical displacement 1 m.

No. 11. The Susugatani f.—total extension 14 km., maximum vertical displacement 2 m.

No. 12. The Sakaigawa f.—total extension 14 km., maximum vertical displacement 30 cm.

No. 13. The Sinkawa f.—total extension 6 km., maximum vertical dislocation 1 m.

No. 14. The Negisi f.—total extension 11 km., maximum vertical displacement 40 cm.

No. 15. The Renkozi f.—total extension 9 km., maximum vertical displacement 20 cm.

Some of these faults or flexures may be regarded as direct accompaniments of the great shock, while others may be those associated with its aftershocks. Thus No. 7 would correspond to the Hakone earthquake which took place on Sept. 1, 1923, at 16 h 38 m., while either No. 9, No. 10 or No. 11 may be identified to that which the writer presumably takes as the second source of the great earthquake of multiple origin.

As to the pre-seismic topographical changes undergone by the Kwanto district, it will be convenient to begin with the strand line noticed by some old fishermen on the southern coasts of the Bô-Sô and Miura Peninsulas. We understand that the mean sea-level gradually lowered itself during the 60 or 70 years that preceded the 1923 earthquake by about 80 cm. in the former place and by about 50 cm. in the latter. Some such change, but in a horizontal plane, seems also to have occurred—very probably in the form of a twist about a vertical line, for Mr. Niemon Hirano, the owner of an islet near Kamogawa in Awa Province popularly known by the name of Niemon-zima, had made it a practise for some 60 years invariably to watch on the day of the winter solstice the accurate position of sunset with reference to certain objects in the distant landscape, but had been noticing for some time a gradual, northward displacement of the objects relative to the position of sunset. To his amazement, however, the earthquake had replaced his landmarks to where he was accustomed to find them in his boyhood days.

The first reliable measurements, however, were begun in 1896 with the establishment of the Aburatubo Mareograph Station near the southern promontory of the Miura Peninsula. The annual mean sea-level since worked out showed the occurrence there from 1900 to 1920 of a gradual subsidence of land at the rate of about one cm. per annum, and thence forward up to the time of the great earthquake a gradual upheaval at the rate of about 3 cm. per annum.[1] This result is in good accordance with that of the precise levellings carried out over the route between Kôhu and Hino in the three periods of 1883–1884, 1895 and 1903. The differences in heights of B.M. in the first two periods point to a

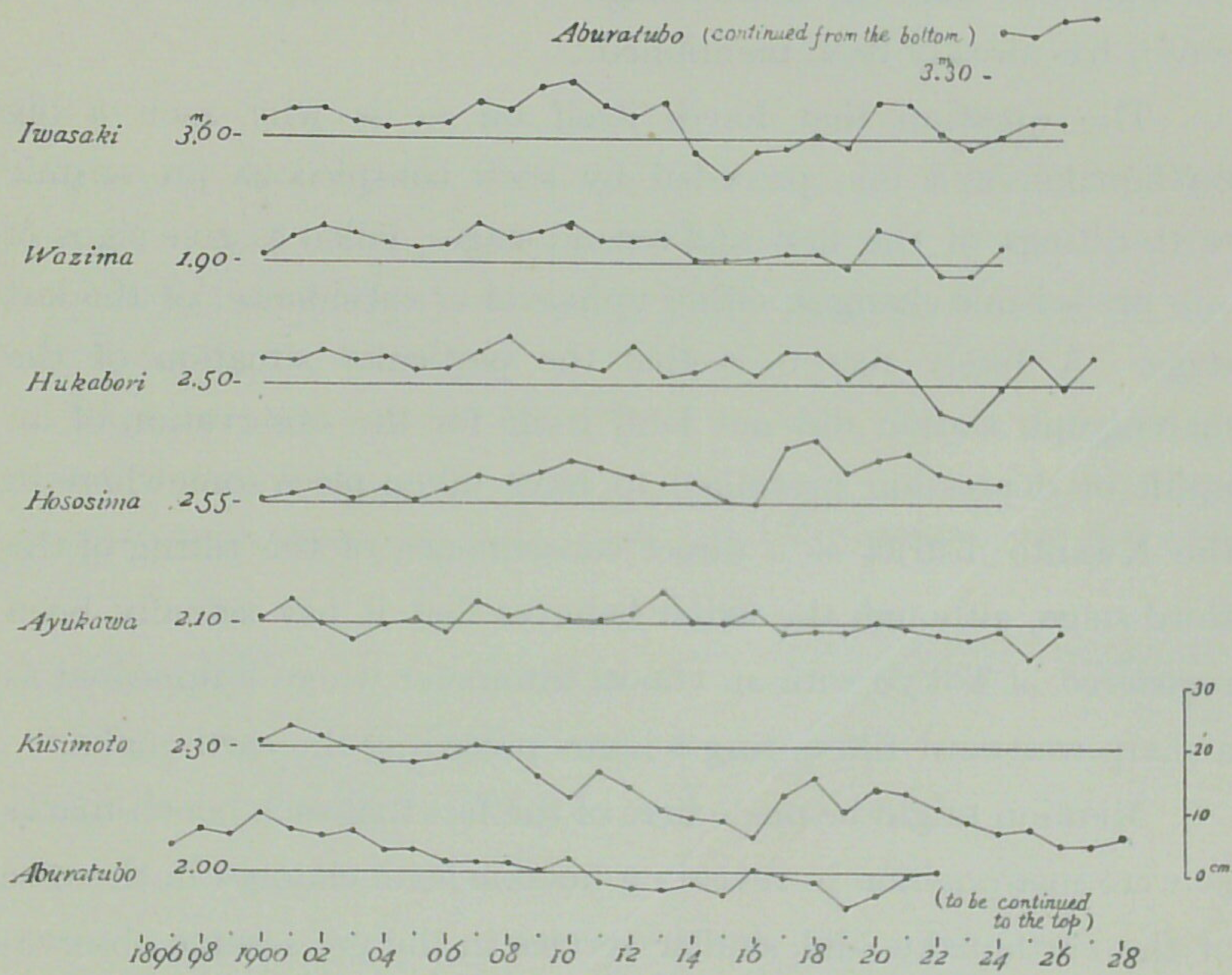

Fig. 42. Diagram showing the variation of annual mean sea-level at the different mareograph stations. (Ordinate indicates the height of the standard bench-mark above the mean sea-level.)

general subsidence of land with a maximum of 14.5 cm. near Sasago, whereas the same covering the remaining two periods shows a general upheaval with a maximum of 6.3 cm. for this

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1) See also A. Imamura: Jap. Jour. Astr. & Geop., Vol. V (1928), No. 3, pp. 133–135.

region.[1] These facts coupled with the results of mareographic observations at Aburatubo force us to the conclusion that in the beginning of the century the tilting of the Kwanto block was in the backward sense. That this change of the earliest stage was followed in 1920 by the change of the second stage, which can be distinguished from the former stage by its occurring in the onward sense, has already been mentioned.

The question that forces itself on us is why such a big earthquake, and one preceded by such conspicuous pre-seismic earth-tiltings of the first and second stages, failed to give signs of any pre-seismic changes, either upheaval or subsidence, of the last stage. A likely reason is that the particular situation of the mareograph station did not lend itself for the observation of an uplift or depression presumed to have taken place somewhere in the Kwanto district as a direct consequence of the tilting of the third stage, although the writer believes that it has actually been registered at Tokyo with an Omori tiltometer where it appeared as a sharp westward tilt during 8 hours preceding the earthquake.[2]

Mention might be made here of the fact that such bench-marks as were instrumental in revealing notable level changes in the case of the earthquake, did similar service in the pre-seismic observations. For instance, the route between Totuka and Atami, which showed a general elevation with a maximum of as much as 197 cm. at B.M. No. 42.1 in the case of the earthquake, showed at the same mark a gentle depression in the period between 1883 and 1895 with a maximum of as much as 2.8 cm.

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1) Investigated by Captain Atumi and Mr. Muto of the Military Land Survey Department, but results not yet published.

2) A. Imamura: Proc. Imp. Acad., Vol. IV (1928), No. 4.

Table IX. Height differences of the bench-marks in the route linking Tokyo with Aburatubo, Misaki, and Atami.

(1) Section between Tokyo and Aburatubo.

B.M.	H. in Oct., 1923, -Jan., 1924, −H. in 1883–1918.		H. in Jan.-Mar., 1925, −H. in Oct., 1923 -Jan., 1924.	H. in Jan.-Feb., 1927, −H. in Jan.-Mar., 1925.
	mm		mm	mm
0	0		0	—
7	− 1		− 2	—
8	− 1		− 1	—
9	− 7	(5)	− 2	—
9.1	+ 5	(2)	− 8	—
27	− 6	(4)	− 7	—
27.1	− 11	(2)	− 7	—
28	− 1	(4)	+ 5	—
28.1	− 7	(2)	+ 4	—
29	− 12	(1)	− 1	—
29.1	− 18	(2)	− 11	—
30	+ 43	(1)	+ 1	—
30.1	—*	(2)	− 2	—
31	+ 72	(1)	− 2	—
31.1	+ 95	(4)	− 2	—
32	+ 100	(1)	− 4	—
32.1	+ 145	(4)	− 7	—
33	+ 153	(4)	+ 1	—
33.1	+ 221	(2)	0	—
34	+ 170	(1)	− 3	0
34.1	+ 230	(2)	− 15	0
35	+ 392	(1)	− 5	+ 2
35.1	+ 479	(2)	− 12	+ 5

Table IX. (*continued*)

B.M.	H. in Oct., 1923, -Jan., 1924, –H. in 1883–1918.	H. in Jan.-Mar., 1925, –H. in Oct., 1923-Jan., 1924.	H. in Jan.-Feb., 1927, –H. in Jan.-Mar., 1925.
36	+ 569 mm (1)	–14 mm	+ 5 mm
36.1	+ 697 (2)	–22	+ 4
5360	+ 746 (3)	–25	0
5360.1	—* (3)	–31	+ 5
5361	+ 541 (3)	–53	+ 4
5361.1	+ 850 (3)	–43	+ 4
5362	—* (3)	–46	+ 8
5362.1	+ 898 (3)	–47	+ 5
5363	—* (3)	–48	+ 4
5363.1	+ 942 (3)	–58	+ 5
5364	—* (3)	–57	+10
5364.1	+1057 (3)	–55	+ 8
5365	+1048 (3)	–49	+16
5365.1	+1066 (3)	–48	+14
5366	+1147 (3)	–48	+13
5366.1	+1230 (3)	–49	+20
5367	+1301 (3)	–44	+26
5367.1	+1370 (3)	–50	+26
5367.2	+1409 (3)	–50	+24
2	+1390 (3)	–46	+24

Earlier survey......(1) in 1883–1884, (2) in 1896, (3) in 1898, (4) in 1908, (5) in 1918.

(2) Section between Hudisawa and Atami.

B.M.	H. in Nov., 1923,-Mar., 1924, –H. in 1884–1896.	H. in Mar.-May., 1925, –H. in Nov., 1923,-Mar., 1924.
36.1	+ 697 mm (2)	–22 mm
37	—* (1)	–13

Table IX. (*continued*)

B.M.	H. in Nov., 1923,-Mar., 1924, –H. in 1884–1896.	H. in Mar.-May., 1925, –H. in Nov., 1923,-Mar., 1924.
37.1	+ 768 mm (2)	–14 mm
38	+ 820 (1)	–16
38.1	+ 904 (2)	–14
39	+1047 (1)	–18
39.1	+ 926 (2)	–42
40	+1248 (1)	–10
40.1	+1408 (2)	–17
41	+1689 (1)	–21
41.1	+1819 (2)	–19
42	+1889 (1)	–25
42.1	+1966 (2)	–31
43	+2012 (1)	–22
43.1	+1979 (4)	–23
44	+1884 (1)′	–34
44.1	+1808 (2)	–24
45	+1560 (4)	–24
45.1	+1211 (2)	–22
46	+1069 (1)	0
46.1	—* (5)	+ 8
47	+1248 (4)	+ 7
47.1	—* (2)	+14
48	—* (4)	+ 9
48.1	+ 789 (2)	+ 1
49	+ 725 (4)	+ 2
49.1	+ 630 (2)	+ 8
50	+ 242 (1)	+13
50.1	—* (2)	+17
51	—* (1)	+16
51.1	+ 94 (2)	+17
52	+ 98 (3)	+15

Earlier survey......(1) in 1884, (1)′ in 1888, (2) in 1896, (3) in 1903, (4) in 1908, (5) in 1919.

*......Uncertain.

Re-levellings from which the post-seismic topographical changes could be deduced were carried out as follows:

The route from Tokyo to Atami during Sept.-Dec., 1923, and during Jan.-May, 1925.

The route from Hudisawa or Totuka to Aburatubo during Sept.-Dec., 1923, and during Jan.-March, 1925, and during Jan.-Feb., 1927.

The results are given in Table IX and illustrated diagrammatically in Fig. 43. A glance will show that the Miura Peninsula which had tilted conspicuously with a northward dip in connexion with the 1923 earthquake, recovered its original position somewhat with the result that the peninsula itself had sunk as much as 5.0 cm. on the average. We have grounds for believing that a recovery of this nature was in rapid progress directly after the great earthquake. We learn that a subsidence of not less than 50 cm. occurred at Misaki during the month that followed the catastrophe (a similar phenomenon was noted in Awa immediately after the great Kwanto earthquake of 1703). Manifestations of much the same sort were observed on the Totuka-Atami route, the average subsidence here being as much as 2.0 cm. But the most unexpected change was that experienced in the period between 1925 and 1927. Instead of recovering still more of its old position, a tilt though very slight, had taken place in the onward sense, the bench-mark at Aburatubo having risen as much as 2.4 cm.

Greatly feeling the desirability of tracing further changes of this kind, the writer, through the generosity of the Imperial Academy, was able with the kind assistance of the Military Land Survey Department to institute in 1926 a new levelling route

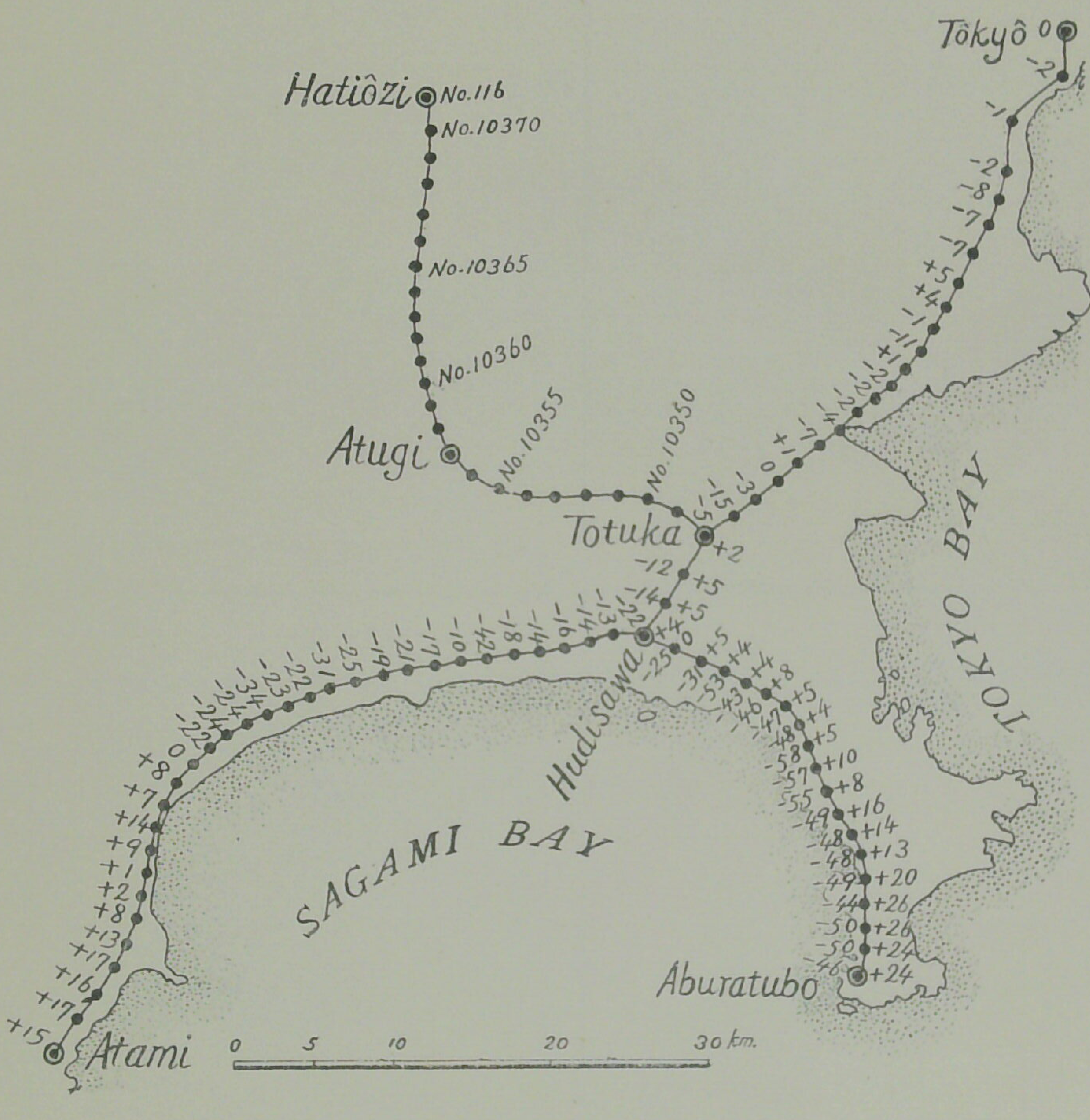

Fig. 43. Map showing the post-seismic variation of land-level.
(Figures inscribed on the left hand side of the route indicate the variation in mm. during the earlier epoch and those on the other side during the later epoch.)

linking Hatiôzi with Totuka, which, together with the Totuka-Aburatubo route, may be regarded as of fundamental importance in the investigation of any future tilting of the Kwanto block. The new route extends for a distance of 47.2 km. with 22 bench-marks, of which 4 have been specially designed and constructed with the view of withstanding earthquake shocks and other disturbances. Neither have precautions been neglected for ensuring that the route shall traverse hard ground, keeping clear of tectonic lines of whatsoever nature. A re-levelling of the Aburatubo-Hatiôzi route is expected to be undertaken in the not distant future. (See Table X and Fig. 43).

Table X. New levelling route linking Hatiôzi with Totuka.

B.M.	Height referred to B.M. No. 0.	B.M.	Height referred to B.M. No. 0.
116	m 109.5715	10359	m 52.8949
10370	135.3904	10358	28.2508
10369	143.8075	10357*	21.6117
10368	152.7260	10356	18.1686
10367*	139.9872	10355	17.0672
10366	126.6481	10354	15.9308
10365	102.1565	10353	43.7622
10364*	59.6406	10352	37.9280
10363	52.7427	10351	39.1543
10362	112.0764	10350	39.0092
10361	83.5847	10349	46.5480
10360*	68.8488	35	14.4864

*......Of special construction.

The writer desires to take this opportunity for expressing his warmest thanks to the shop-proprietors of the Marunouti-Building, whose timely generosity in the form of contributions rendered possible our investigations of the post-seismic topographical changes of the Kwanto district for the period between 1923 and 1925.

No. 24. The Tazima earthquake of 1925.[1]

The earthquake, which shook the northern part of the province of Tazima at about 11 h 10 m on the morning of May 23, 1925, resulted in the destruction of 3,400 houses with a death roll of 428 lives. The meizoseismal area was comparatively small, for on following the lower reaches of the Maruyama River, it embraced an area no larger than 16 km. E–W by 20 km. N–S. The origin was in all likelihood near the cove of Tuiyama situated at the outlet of this river where it discharges into the Sea of Japan, so that another meizoseismal area of equal extent must have extended to the northward of this place.

The shaking was severest in the hamlet of Tai, situated on the east bank of the Tuiyama Cove, 82 out of a total of 83 dwellings having been thrown down. It was in this region that the so-called Tai fault was discovered. It is on the top of a Tertiary hill, the highest part of which is 231 metres, and lying to the north of the village of Tai. There were formed two fault lines almost parallel to each other and running in a direction SW to NE for a distance of nearly 1,500 metres, the distance separating the two being about 400 metres at the widest part. The fault was not so conspicuous so that some ascribed it to nothing more than a mere fissure formed in the surface soil, but its occurrence in the Tertiary

1) For details see Bull. Imp. Earthq. Inv. Comm., Vol. X, No. 3.

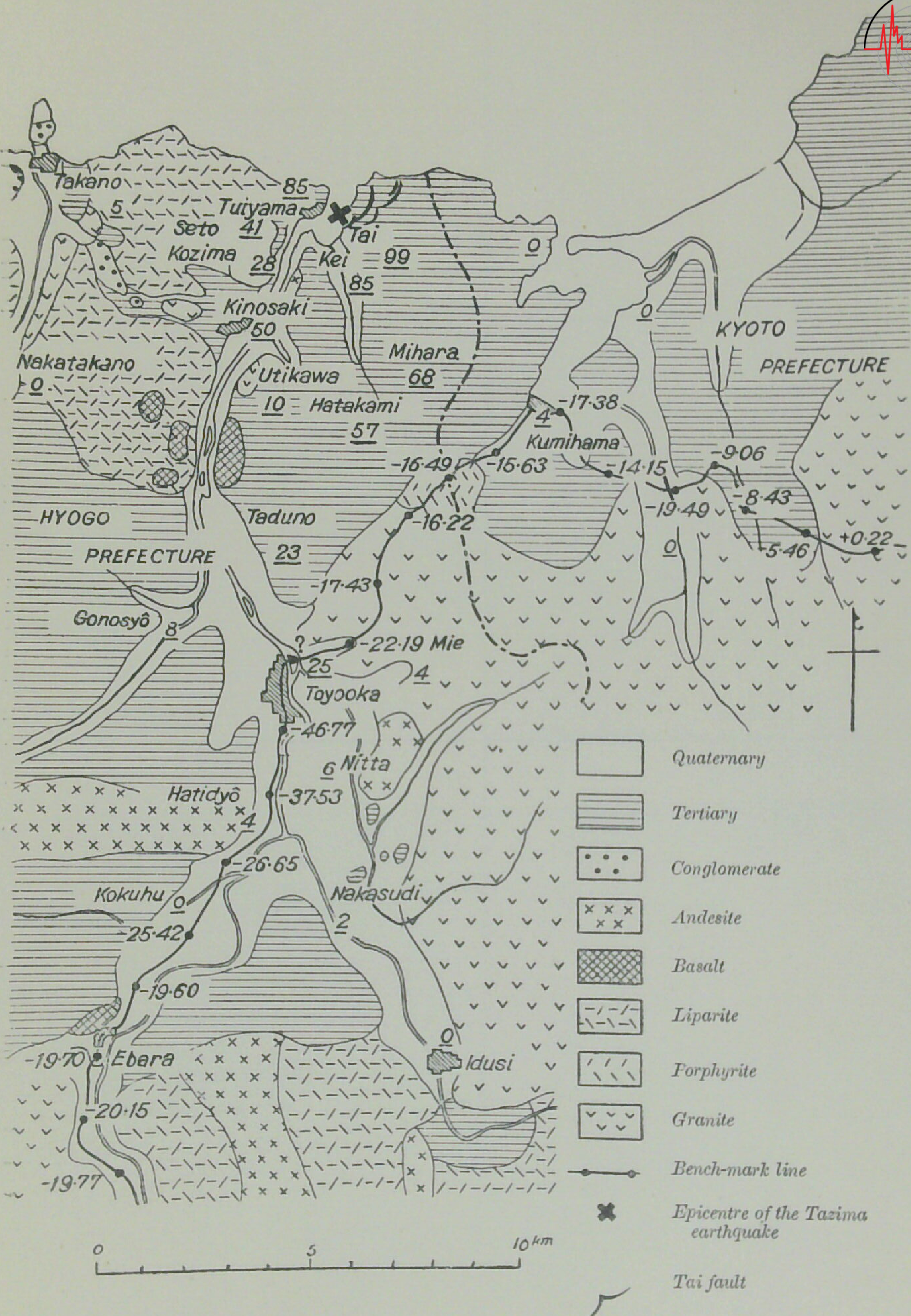

Fig. 44. Map showing the seismic area of the Tazima earthquake of 1925. (Numerals underlined denote percentage of houses collapsed. Numerals along the B.M. route denote the height change in cm.)

rock underneath was beyond doubt. As it traverses a grove of willow trees, which are so much cultivated in this part of country—the making of willow wicker basket being an important industry here—it afforded glimpses here and there of a typical fault. Indeed, it might be called a miniature fault.

After the earthquake, prospects seemed favourable for a careful re-survey by the Land Survey Department of the levelling route passing through the affected districts, but it failed to materialize, although even if it did, it is a cause for regret that the route extending from the direction of Miyadu, passing through Kumihama and Toyooka and then proceeding southwards through mountains, links only distant Tottori without approaching at all the meizoseismal area. In addition to this drawback there is the unfortunate fact that bench-marks at several important points have lost their original identity, not only through the action of the elements but also through the perversity of ignorant people.

We are pleased to be able to say that nearly two years after the present earthquake, a survey was started as a result of the severe Tango earthquake which followed the Tazima earthquake, and what was most fortunate, the survey took in the latter district as well. The results of this survey have enabled us to deduce changes in the land-level which took place in the regions concerned with the present earthquake, and from which it seems that in Toyooka and vicinity there was a depression of some 30 cm. in the level districts and about 10 cm. in the hilly sections (see Fig. 44). From this it is quite natural to conceive of considerable changes having occurred in and around the neighbourhood of the lower Maruyama River, besides the changes exhibited by the Tai fault.

Lastly, it may be stated that the Naval Hydrographers sounded the seas bordering the epicentral zone, but no change of depth greater than one foot could be found.

No. 25. The Tango earthquake of 1927.

The destructive Tazima earthquake of 1925 was followed by another shock, which resembled it in many ways but caused far greater loss in life and property. It took place on March 7, 1927, at 18 h 27.6 m in 135° 1′ E, 35° 39′ N, about 19 km. to the east of the epicentre of the former shock. Fig. 45 shows the area of greatest disturbance in Tango Province, Kyoto Prefecture, areas in which the number of houses that were levelled exceeded 1 and 10% of the total being enclosed within the dotted and the full lines respectively. The actual casualties were 10,633 houses thrown down, 4,961 houses burned and 3,017 killed.

In this earthquake, two independent faults were produced along the old tectonic lines. One in the north (the Go-mura fault) consisting of 5 or 6 segments arranged *en échelon* has a track 18 km. long, trending NNW–SSE, with an upthrow (maximum 60 cm.) and southward shift (maximum 270 cm.) of the west side, while the other in the south (the Yamada fault) has one 7 km. long, trending almost at right angles to the former, with upthrow (maximum 40 cm.) and eastward shift (maximum 80 cm.) of the north side. In the area within one km. or two from each fault the seismic intensity was as high as one-half or two-fifth of gravity with the percentage of houses destroyed reaching as much as 90.

A permanent maximum upheaval of nearly as much as 80 cm. occurred along the coast of the Sea of Japan to the west of Gomura fault and as far westwards as Tuiyama Cove. Temporary elevation, which is a manifestation of earth-tilting of the last stage,

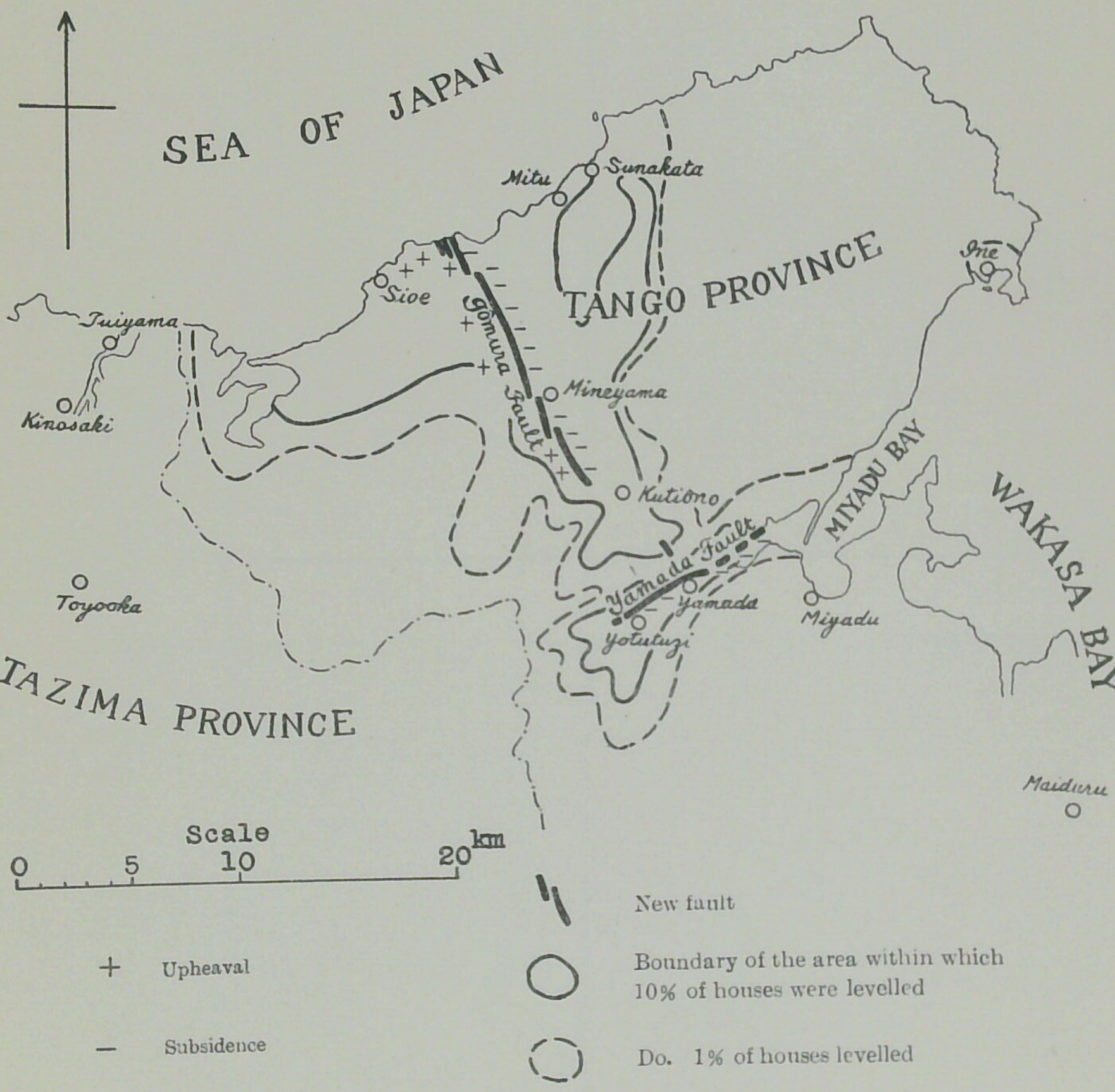

Fig. 45. Map showing the seismic area with the isoseismals and new fault lines.

seems also to have taken place during the two and half hours immediately before the earthquake. This was observed by a number of fishermen at Mitu and Sunakata, where the sea during that interval made an unseasonable ebb reducing the depth of the water by 70–130 cm. in the former place and by 100 cm. in the latter. The two places lie 4.6 km. and 6.1 km. respectively east of the Gomura fault. Reports were received at the time that to the west of Mitu as far as Sioe, and to the east of Sunakata up to Kyôgamisaki, the sea-level temporarily sank from 30 to 20 cm.

These are results obtained by field workers without the aid of instruments of precision during the first week or two after the earthquake. Immediately afterwards, however, parties equipped with the necessary instruments for observation were despatched by the Earthquake Research Institute of the Tokyo Imperial University to the disturbed areas. Besides the precise levellings which were repeated four times over the old as well as the newly laid routes, three geodetic triangulations of points of the first and second orders were made, together with a seismic triangulation with a network consisting of four stations spaced at suitable distances from one another. In addition to these we had the cooperation of the Naval Hydrographers, with their very careful and elaborate system of soundings of the seas bordering the whole of the disturbed area, and which required five months for completion. As may be judged from the following paragraphs, the post-seismic investigations may indeed be claimed as having been carried out in a satisfactory manner: the one lingering regret in the writer's mind being the non-realization of the precise levelling over this region, which it was hoped would be undertaken in 1925 immediately after the great Tazima earthquake, and, which, if accomplished, would have been the pre-seismic levelling for the earthquake under discussion that came two years later.

The precise levellings were carried out as follows:

(1) Over the pre-existing route. The pre-seismic survey was carried out in 1887–1888, and the first post-seismic re-levelling in the period April 19–May 30, 1927 (Fig. 46 and Fig. 49, A). At the same time, new routes extending over the region, where considerable topographical changes had apparently occurred in connexion with the present earthquake, were laid down (see Fig. 47).

(2) Over all of the routes in the disturbed area during the period June 1–July 31, 1927. The changes in height of bench-marks are shown in Fig. 47 and Fig. 49, B.

(3) Over all of the routes as above during the period March 3–April 20, 1928. The changes in height of bench-marks are shown in Fig. 48 and Fig. 49, C.

The changes in height of bench-marks based on the first re-levellings (Figs. 46 & 49, A) were estimated with the assumption that B.M. No. 1232 (Kutiôno) had not been affected, though it seems to be better to regard B.M. Nos. 1363–1370, which are the ones in the south-eastern extremity of the route, as unchanged. The topographical changes thus revealed would involve both secular and cataclysmic variations, but in the present case the former variation seems to have been negligibly small when compared with the sharp changes in the curves representing the Gomura and the Yamada faults. The changes indicated by B.M. Nos. 1228–1229 and 1235–1236 go to prove that the vertical dislocation of the Gomura fault at Mineyama was 75 cm. and that of the Yamada fault at Yamada 114 cm. Besides the above-mentioned changes, there occurred at Toyooka and vicinity in the western part of the disturbed area a considerable subsidence, which as already pointed out is the change associated with the Tazima earthquake of 1925.

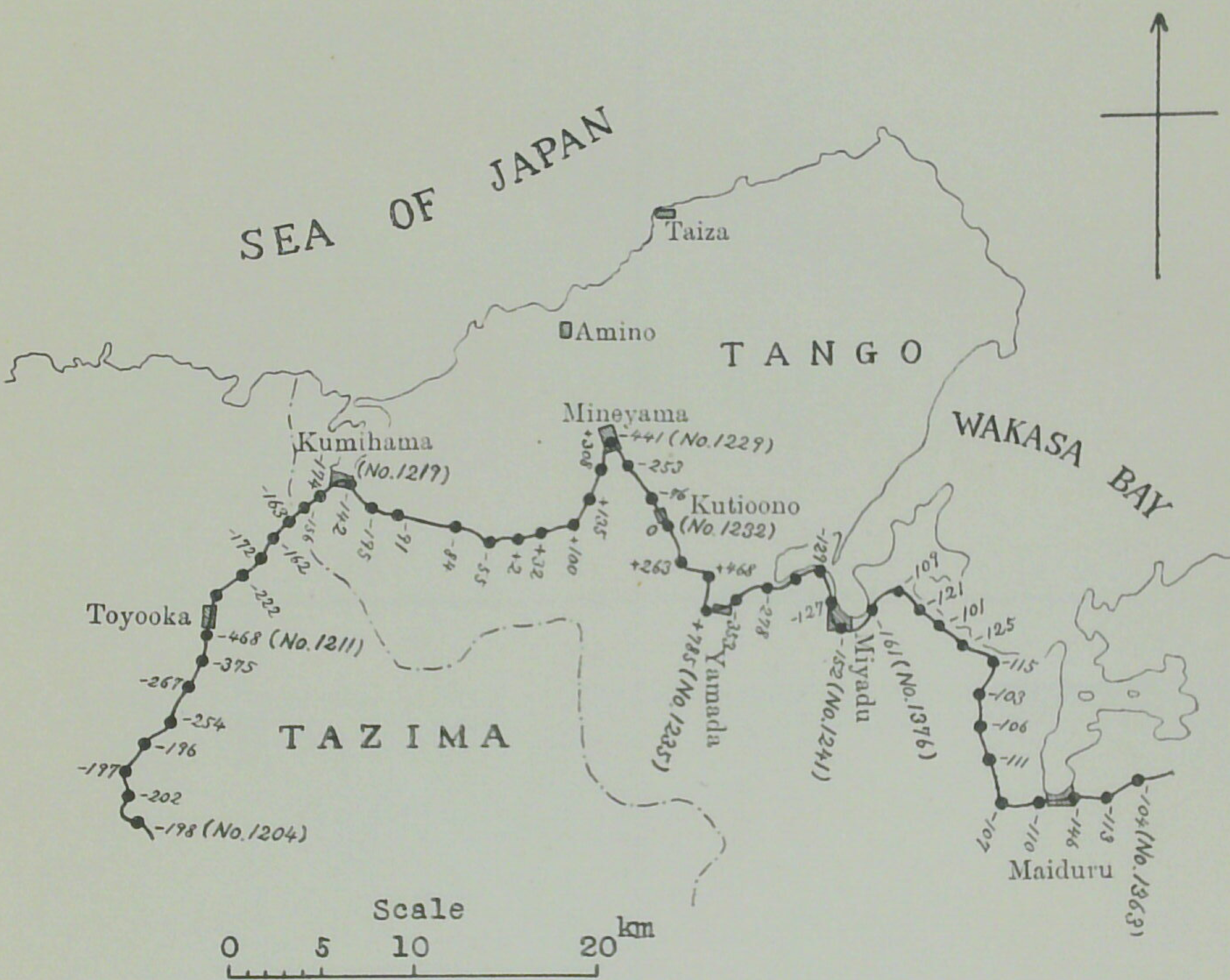

Fig. 46. Map showing the level changes associated with the Tango earthquake of 1927.

(Figures indicate the amount of height change in mm.)

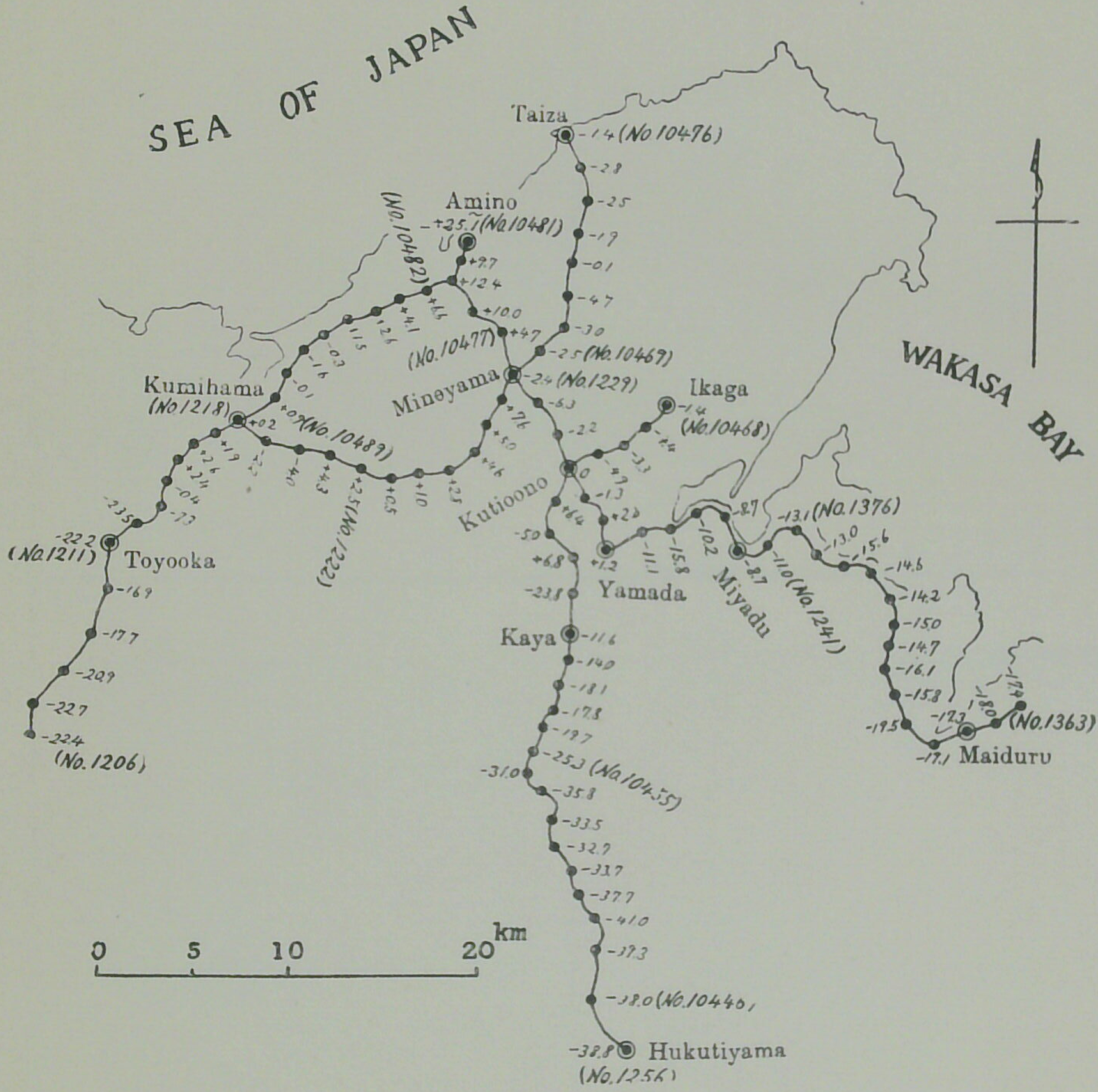

Fig. 47. Map showing the post-seismic veriation of land-level in mm. during the period between April 13–June 24 and June 1–July 31, 1927.

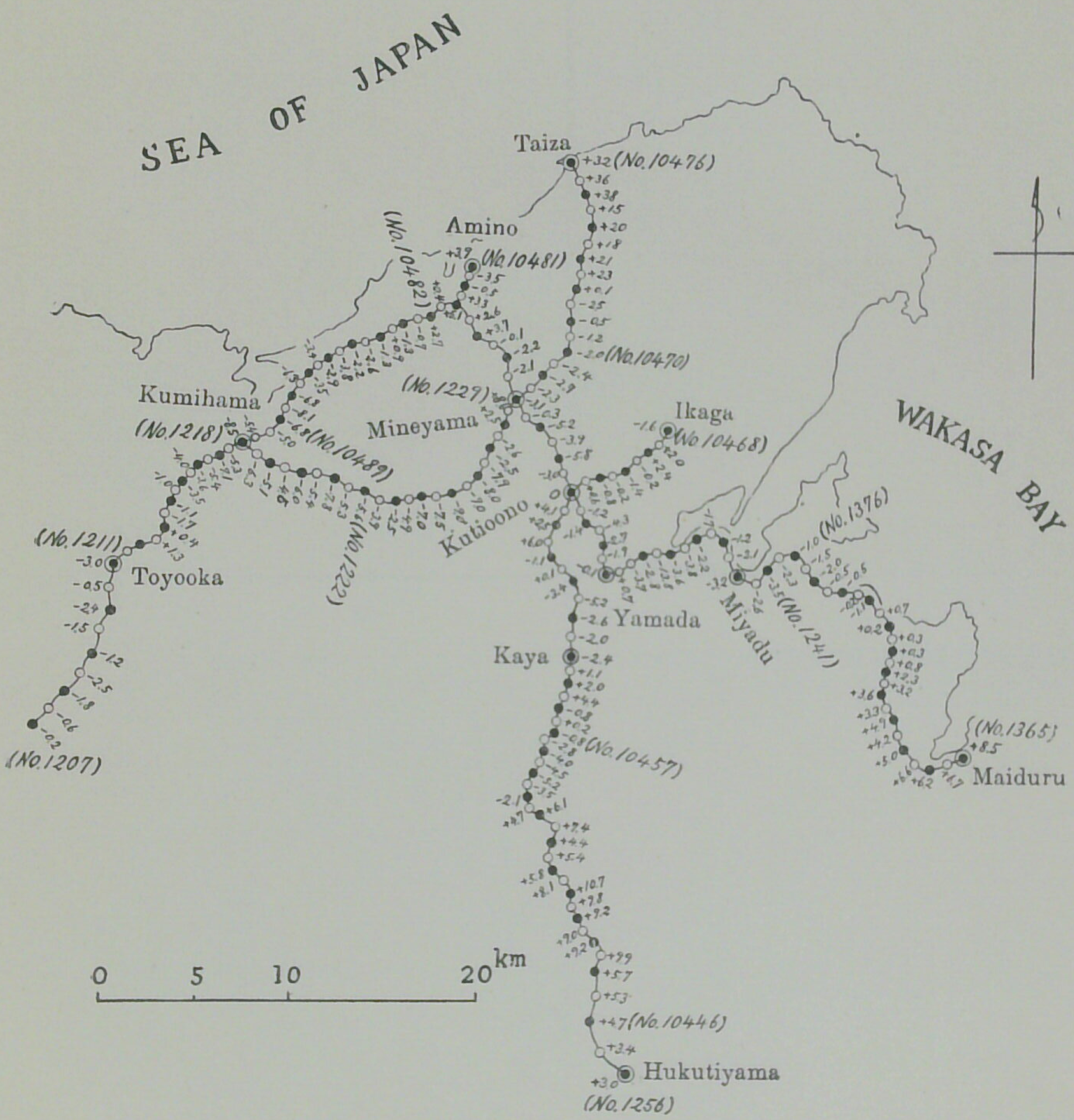

Fig. 48. Map showing the post-seismic variation of land-level in mm. during the period between June 1–July 31, 1927, and March 3–April 20, 1928.

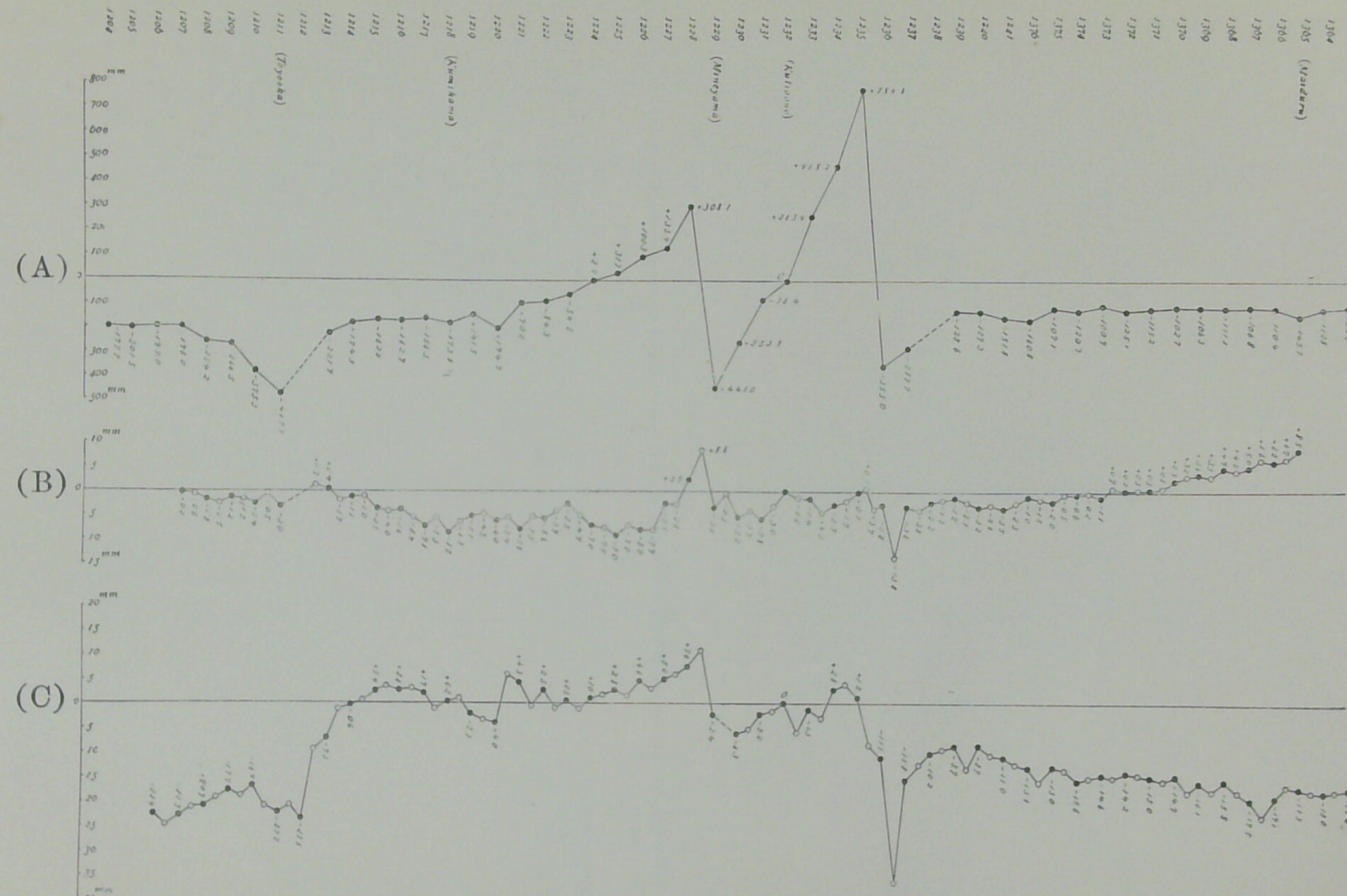

Fig. 49. **Diagram illustrating the changes of level accompanied by the Tango earthquake of 1927.**

Upon close examination of the change of land-level undergone by the disturbed area during approximately 50 days between the first and second post-seismic surveys (see Figs. 47 & 49, B), it was noticed that the earth-tilting had continued in the same sense as it did at the time of the catastrophe. The change, though slight, is well defined and may be said to have been on a scale of one-hundredth of the change that was accompanied by the great earthquake. In this relationship, the present earthquake differed from the great Kwanto earthquake, where the post-seismic tilting occurred at first in a backward sense.

The change undergone by the same district during the subsequent 9 months (see Figs. 48 & 49, C) is quite similar to what had been experienced in the previous period, that is to say, the earth-tilting kept on in the same onward sense. It must, however, be remarked that the changes which occurred along the Yamada fault at two places, one near Yotutuzi and the other in the east of Yamada, were comparatively great, showing a change of 3 cm. in the latter.

On comparing the changes exhibited thus far in the forgoing two periods, Prof. C. Tsuboi noticed that they were composed of a series of discontinuous tiltings suffered by the respective contiguous mosaic blocks, which in turn constitute the whole disturbed block.[1] This may be regarded as further evidence of those characteristic block movements pointed out by Prof. N. Yamasaki in connexion with the precise levellings carried out over the littoral of Etigo Province.

Soundings over the extensive seas bordering the disturbed district were promptly taken in hand by the Naval Hydrographers, who beginning the work in May finished it in

1) C. Tsuboi: Bull. Earthq. Res. Inst., Vol. VII.

August of the same year.[1] On examining the results thus obtained, it will be seen that, unlike the Tazima earthquake of 1925, there were some deformations of the sea-bed, the outstanding features of which, according to Prof. T. Terada and Mr. S. Higasi, are as follows:

(i) The remarkable discontinuity in the vertical displacement observed in the land area on both sides of the Gomura fault may be seen to have extended into the sea-bed for a considerable distance with rather bigger vertical displacement than on land.

(ii) A conspicuous zone of depression (above 3 m.) is seen encircling the entire coastline at a distance of some 1–3 km. from it, beyond which comes a broader zone of upheaval.

(iii) The NE side of the Oku-Tango Peninsula has undergone a general upheaval which corresponds with the general tendency of this peninsula to show an upward movement as judged from the distribution of the coastal erosion terraces.[2]

Geodetic triangulations of the trigonometrical points of the first and second orders in Central Japan were first carried out in 1884–1888. Immediately after the earthquake, a plan for successive revisions of these points likely to be most concerned with the present earthquake was launched by the Earthquake Research Institute in conjunction with the Military Land Survey Department. The work was carried on as follows:—

(1) The first post-seismic revision of the trigonometrical points of the first order during the period May to June, 1927.

(2) The second post-seismic revision of the trigonometrical points of the first order, with the addition of favourably situated points of the second order, during August to September, 1927.

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1) See ditto Vol. IV.
2) See T. Terada & S. Higasi: Proc. Imp. Acad., Vol. IV (1928), No. 6.

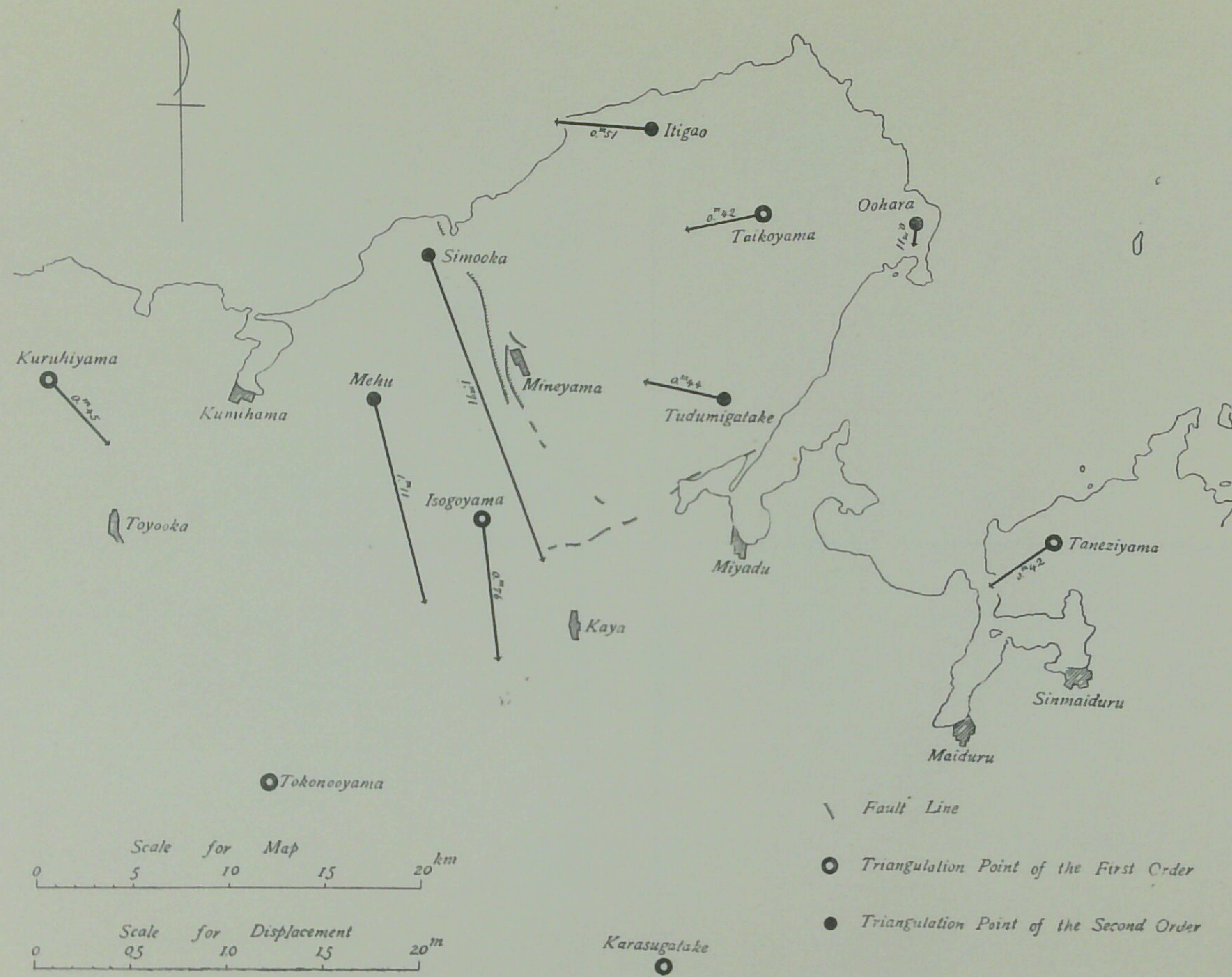

Fig. 50. Displacements of triangulation points during the period between 1884 and June, 1927.

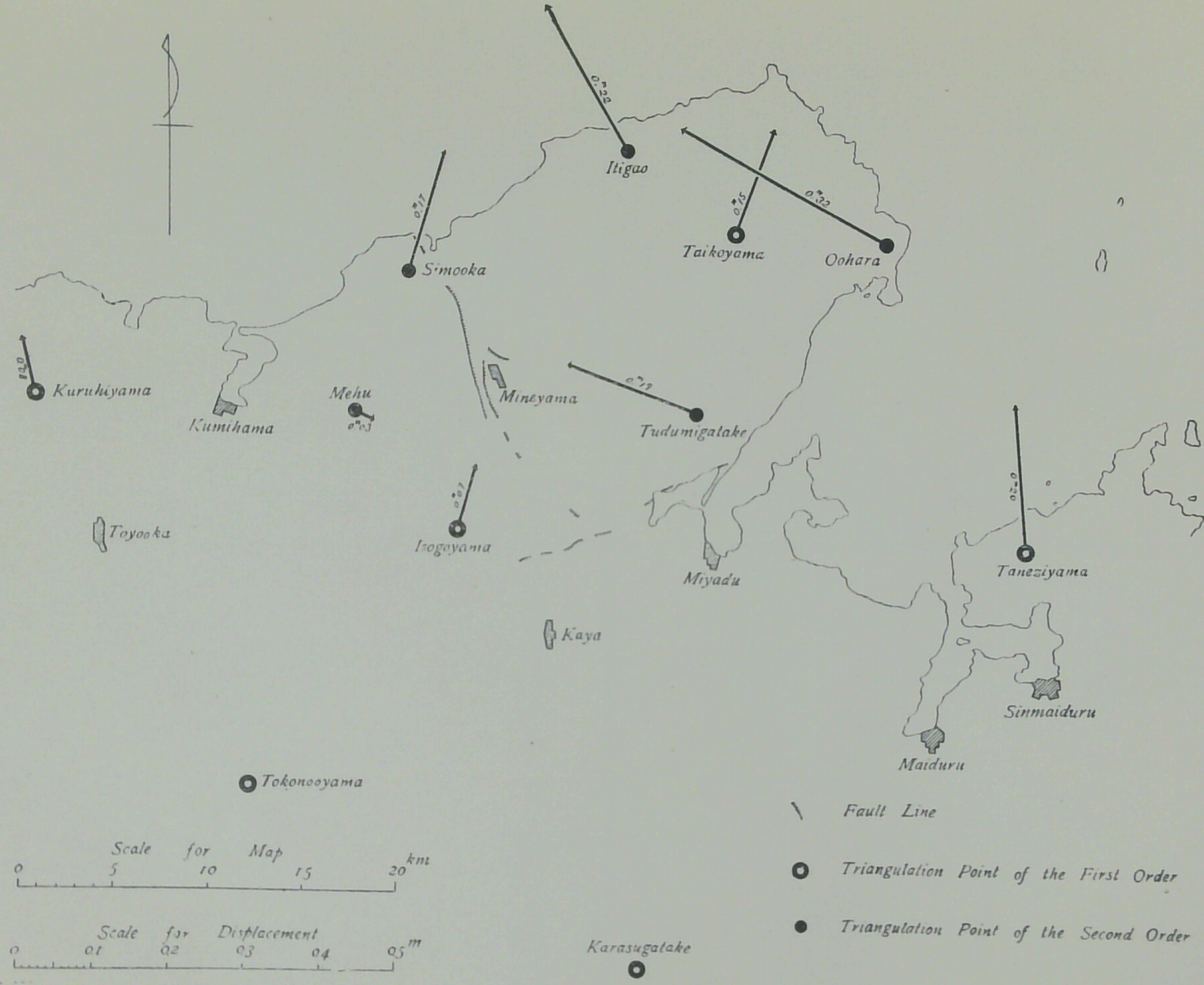

Fig. 51. Displacements of the triangulation points during the period between May and September, 1927.

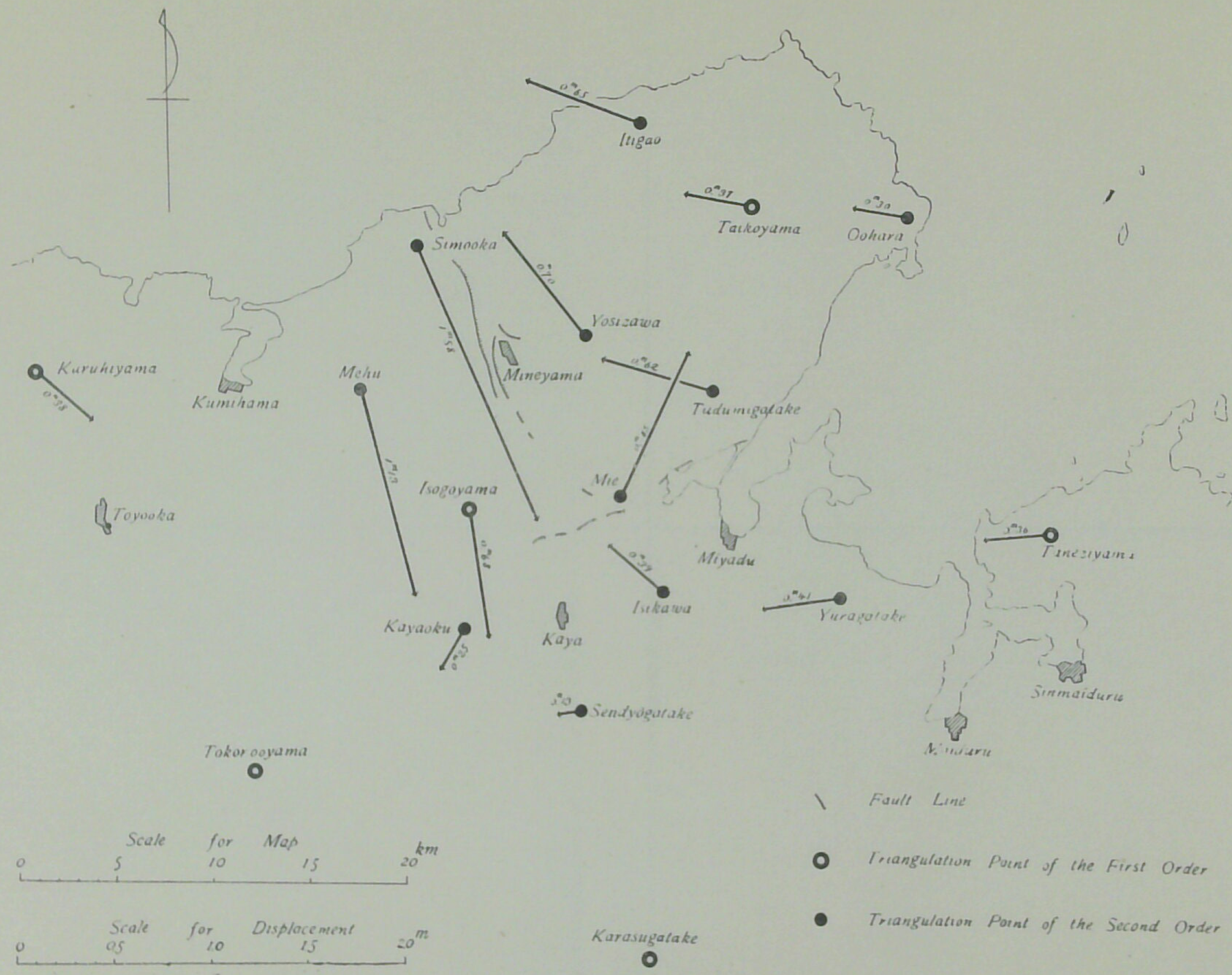

Fig. 52. Displacements of the triangulation points during the period between 1884 and September, 1927.

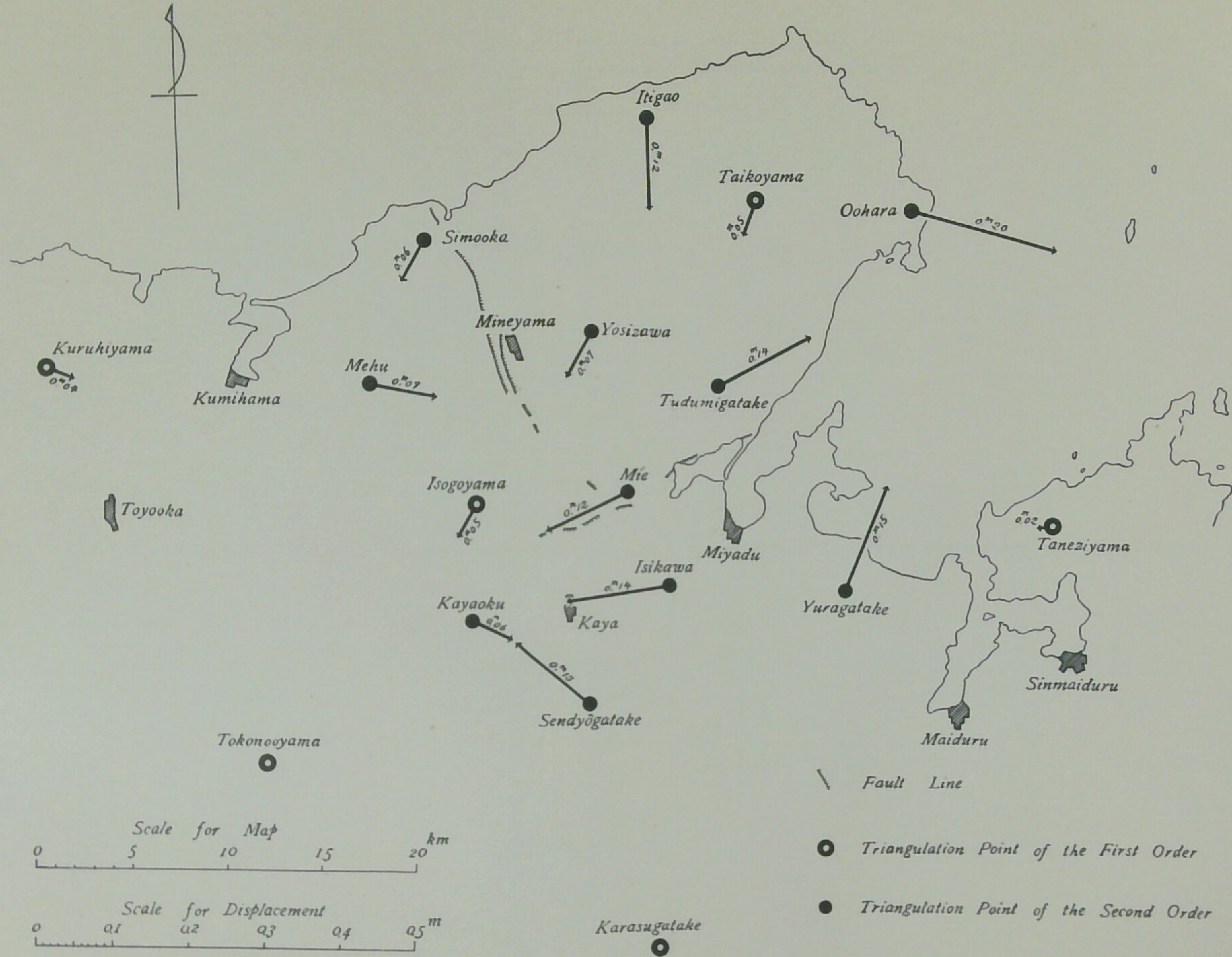

Fig. 53. Displacements of the triangulation points during the period between August and November, 1927.

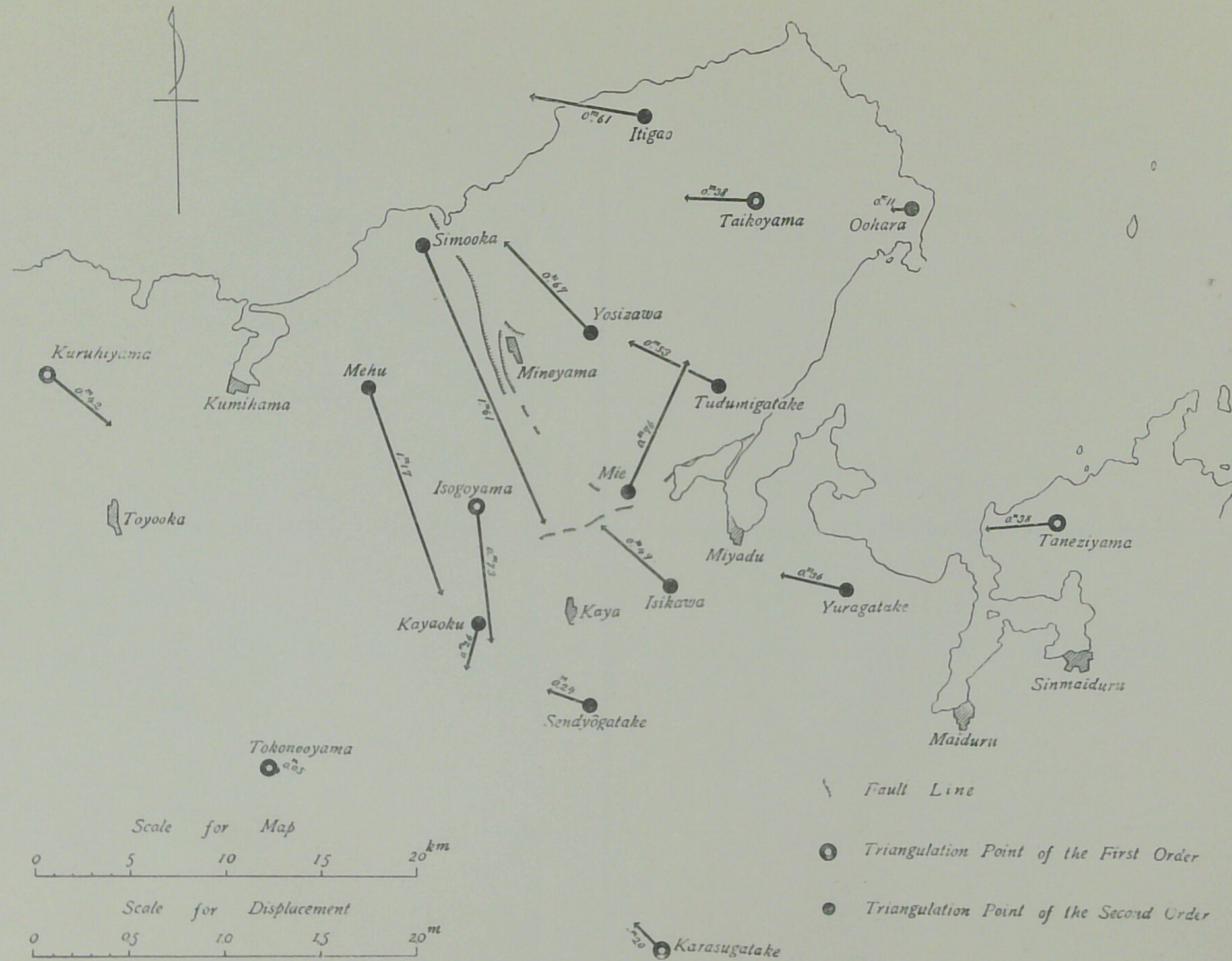

Fig. 54. Displacements of the triangulation points during the period between 1884 and November, 1927.

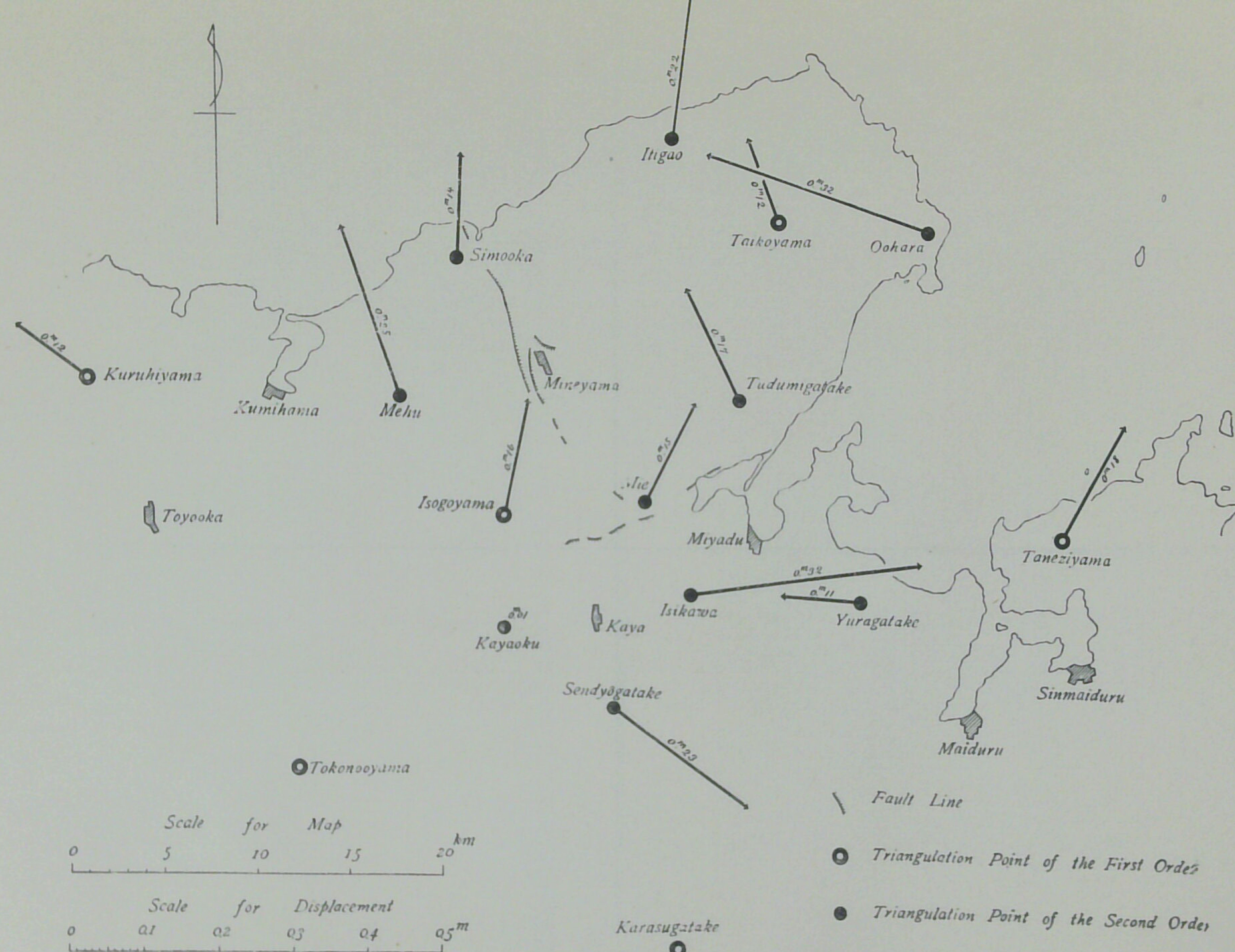

Fig. 55. Displacements of the triangulation points during the period between October, 1927, and September, 1928.

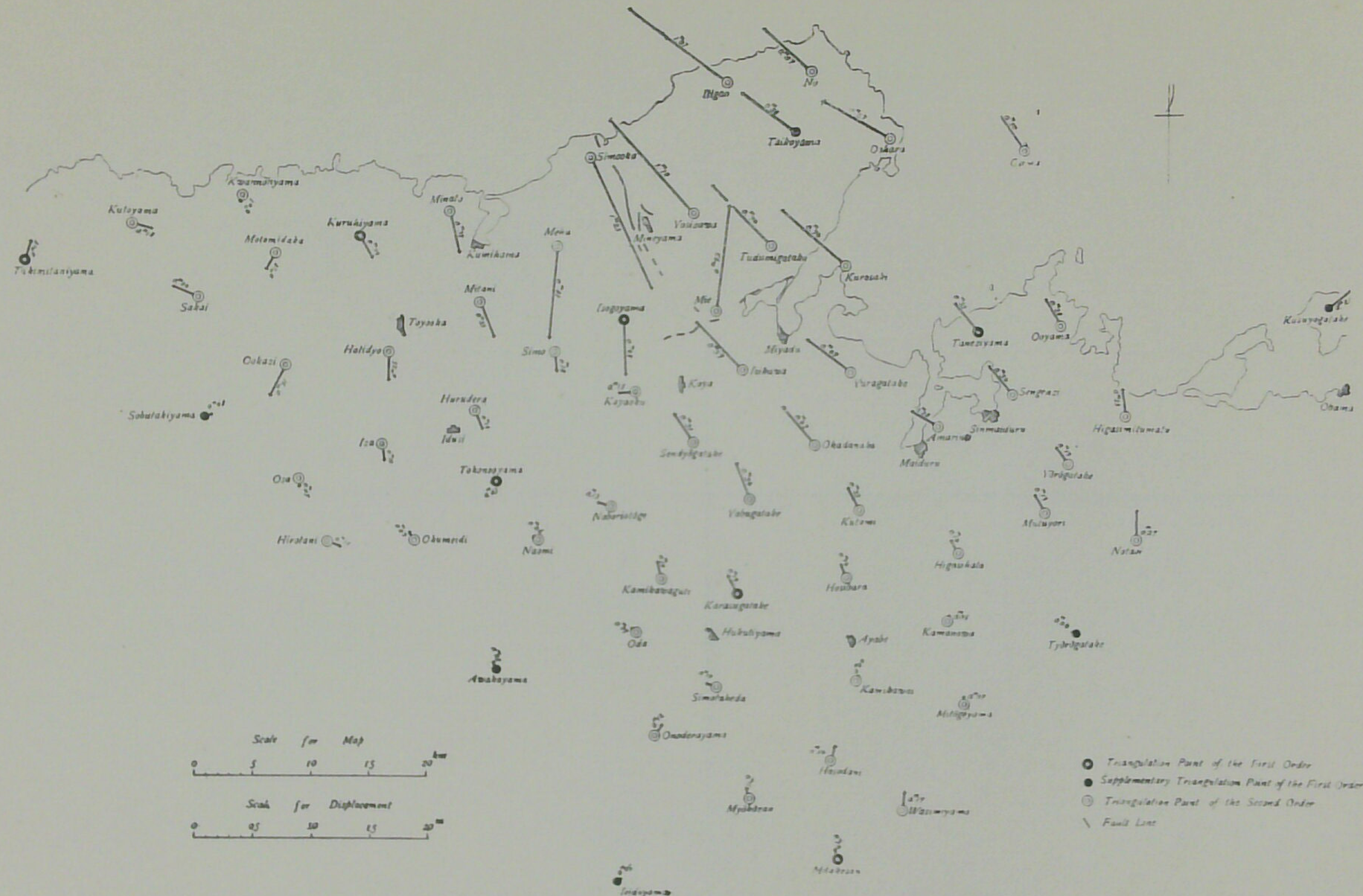

Fig. 56. Displacements of the triangulation points during the period between 1884 and 1928.

(3) The third revision of the above-mentioned points during October to November, 1927.

(4) The fourth revision of the above-mentioned points, with the addition of points situated in a much wider area, during April to September, 1928.

Figs. 50-56 show distribution of the horizontal displacements suffered by the triangulation points at the time of the earthquake and during the course of successive revisions of the triangulations. As might be expected, the displacements which the earthquake accompanied accord well with the horizontal shifts as ascertained by direct measurement along the Gomura and the Yamada faults. Roughly speaking, an equal extent of shearing took place along both sides of the faults, and the nearer a triangulation point was to a particular fault, the greater was the amount of displacement. The writer, accordingly, devised means for estimating the amount of horizontal displacement by utilizing data relating to the distance of each geodetic point from the fault, together with the horizontal displacement suffered by the triangulation point, and in this way arrived at 2.7 m. for the Gomura fault which is exactly the figure that was obtained by direct measurement.[1)]

On comparing Fig. 50 with Fig. 56 (see also Table XI), it will be noticed that although there is an irregularity in the former in the distribution of displacements suffered especially by points rather removed from the fault, it is considerably smoothed out in Fig. 56. This would suggest that after the earthquake the complete adjustment of the seismic area to a state of equilibrium required a year. It is more than likely that with the Yamada fault such adjustments were much at work. Another striking

1) A. Imamura & Kishinouye: Proc. Imp. Acad., Vol. IV (1928), No. 3 and Bull. Earthq. Res. Inst., Vol. V.

Table XI. Displacements of geographic positions observed in 1927–1928 compared with those observed in 1885–1891, Hyônosen and Kasagata-yama assumed as unaltered.

Triangulation point	Displacement		Triangulation point	Displacement	
	Azi-muth	Mag-nitude		Azi-muth	Mag-nitude
	°	m		°	m
Hyônosen	—	—	Isikawa-mura	316	0.59
Kasagata-yama	—	—	Yuraga-take	307	0.49
Kurui-yama	152	0.22	Kayaoku	267	0.15
Isanago-yama	178	0.48	Sengenzi	320	0.34
Tanezi-yama	322	0.33	Hurudera	159	0.18
Tokonoo-yama	260	0.03	Higasimitumatu-m.	352	0.25
Karasuga-take	333	0.19	Amauti-mura	299	0.28
Mitake-san	344	0.10	Sendyôga-take	324	0.31
Taiko-yama	306	0.58	Iza-mura	172	0.15
Sobutaki-yama	68	0.08	Okadanaka-mura	320	0.42
Tyôrôga-take	294	0.04	Yôrôga-take	323	0.19
Awaka-yama	335	0.08	Osa	180	0.07
No-mura	311	0.57	Hatibuga-take	339	0.34
Itigao	306	1.07	Noborio-tôgo	289	0.13
Oohara	299	0.67	Kutami	334	0.23
Osima	325	0.50	Mutuyori	324	0.19
Simooka	155	1.25	Notaoi-mura	0	0.27
Kwannon-yama	199	0.07	Naomi	309	0.06
Minato	168	0.37	Okumeidi	328	0.09
Yosizawa	317	1.10	Hirotani	109	0.11
Kuto-yama	105	0.18	Higasiyata-mura	341	0.14
Tudumiga-take	315	0.74	Kamikawaguti-m.	292	0.17
Mehu (Nyoo)	185	0.81	Hosibara	332	0.14
Motomiduka	209	0.17	Kamanowa	17	0.05
Kurosaki	311	0.74	Oda	303	0.07
Sakai	293	0.24	Kamikawai	18	0.04
Mitani	158	0.33	Simotakeda	288	0.10
Mie-mura	7	0.93	Mitôge-yama	353	0.07
Oo-yama	330	0.28	Onodera-yama	30	0.12
Simo-mura	175	0.18	Hosotani	13	0.14
Hatidyô	179	0.25	Myôkôzan	341	0.11
Ookazi	206	0.31	Wasiohuka-yama	7	0.17

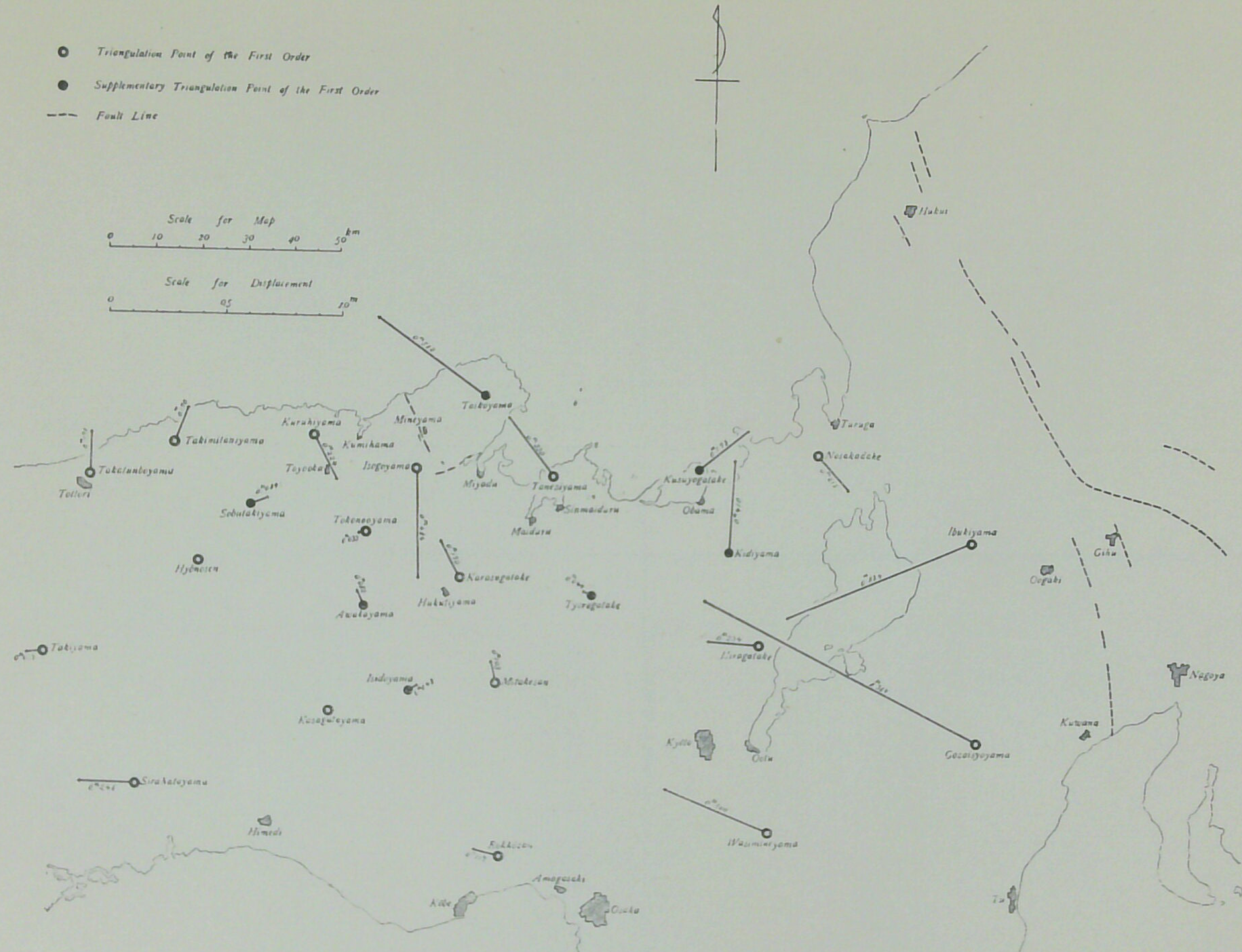

Fig. 57. Displacements of the triangulation points over a much wide area during the period between 1884 and 1928.

feature in connexion with the Yamada fault is the presence of the belt of contraction (see Fig. 56) which would suggest that the same fault had its further westward extension up to that place. The gradual progress of adjustment is also recognisable in the figures corresponding to the intermediate periods. These characteristics have already been illustrated in connexion with the post-seismic earth-tiltings revealed by precise levellings carried out in parallel with the geodetic triangulation, though to be exact the former was run slightly in advance of the latter.

Fig. 57 shows the result of triangulation carried out in a much wider area than in the foregoing cases. It not only gives the changes connected with the Tango earthquake of 1927, but possibly those also connected with the great Mino-Owari earthquake of 1891 and the Anegawa earthquake of 1909. Thus the displacement suffered by Gozaisyo-yama, which measures 1.4 m. in the azimuth N 63° W, may be attributed to the former earthquake, in which case, according to the writer's view, Ise Bay must have widened itself out causing the land on the west of the bay to be displaced westwards. It is equally probable that the movement shown by the point Ibuki-yama (displacement=0.88 m., azimuth=S 67° W) has some connexion with the Anegawa earthquake and also with the Mino-Owari earthquake.

Immediately after the earthquake, the writer jointly with Mr. N. Nasu set up in the disturbed area a seismic triangulation consisting of a network of four seismograph stations suitably located in the disturbed district for the purpose of making exhaustive studies of aftershocks, particularly of the stereometrical distribution of their hypo-centres; some of the results of which have already been published. Owing to enforced absence abroad on the part of the writer, the work has devolved solely on Mr.

Nasu, who has obtained many important results from these studies. Among the results since then obtained, the one especially concerned with our present problem is the movement of a particular crust block, which, according to him, has the form of a triangular prism with the Gomura- and the γ-fault planes as its bases, and the Yamada- and the b-fault planes, together with the rectangular area partly bounded by the Gomura and Yamada faults as its sides.[1] Since he felt no aftershocks originating within this block, though

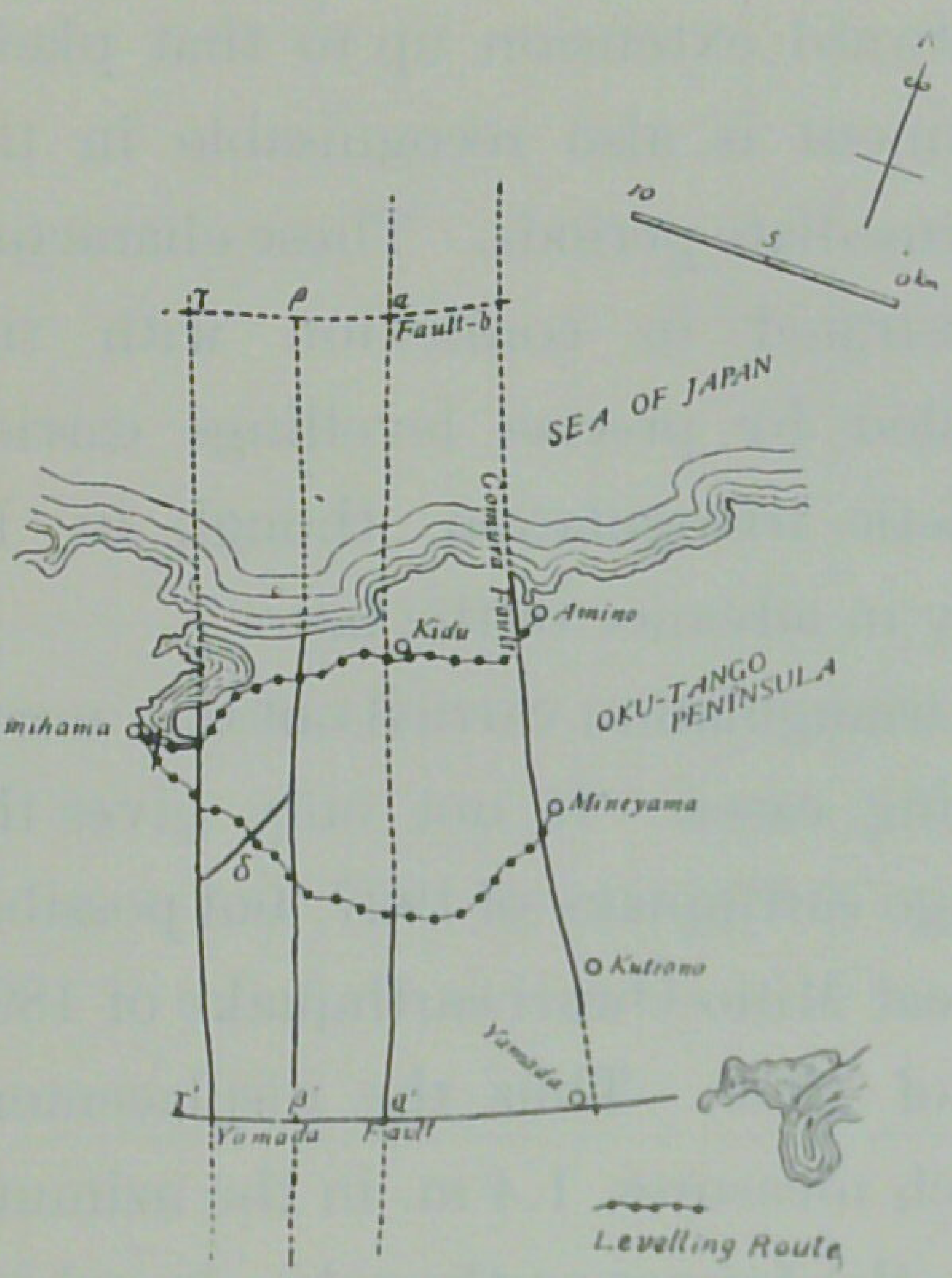

Fig. 58.

many of them developed on a series of planes parallel to its subterranean boundaries, he visualised the mechanism through which the present earthquake occurred in somewhat the following manner:—

"First, the equilibrium which had obtained in the Tango block was disturbed along the old fault plane, thus resulting in the new Gomura fault, causing the block lying on the western side of this

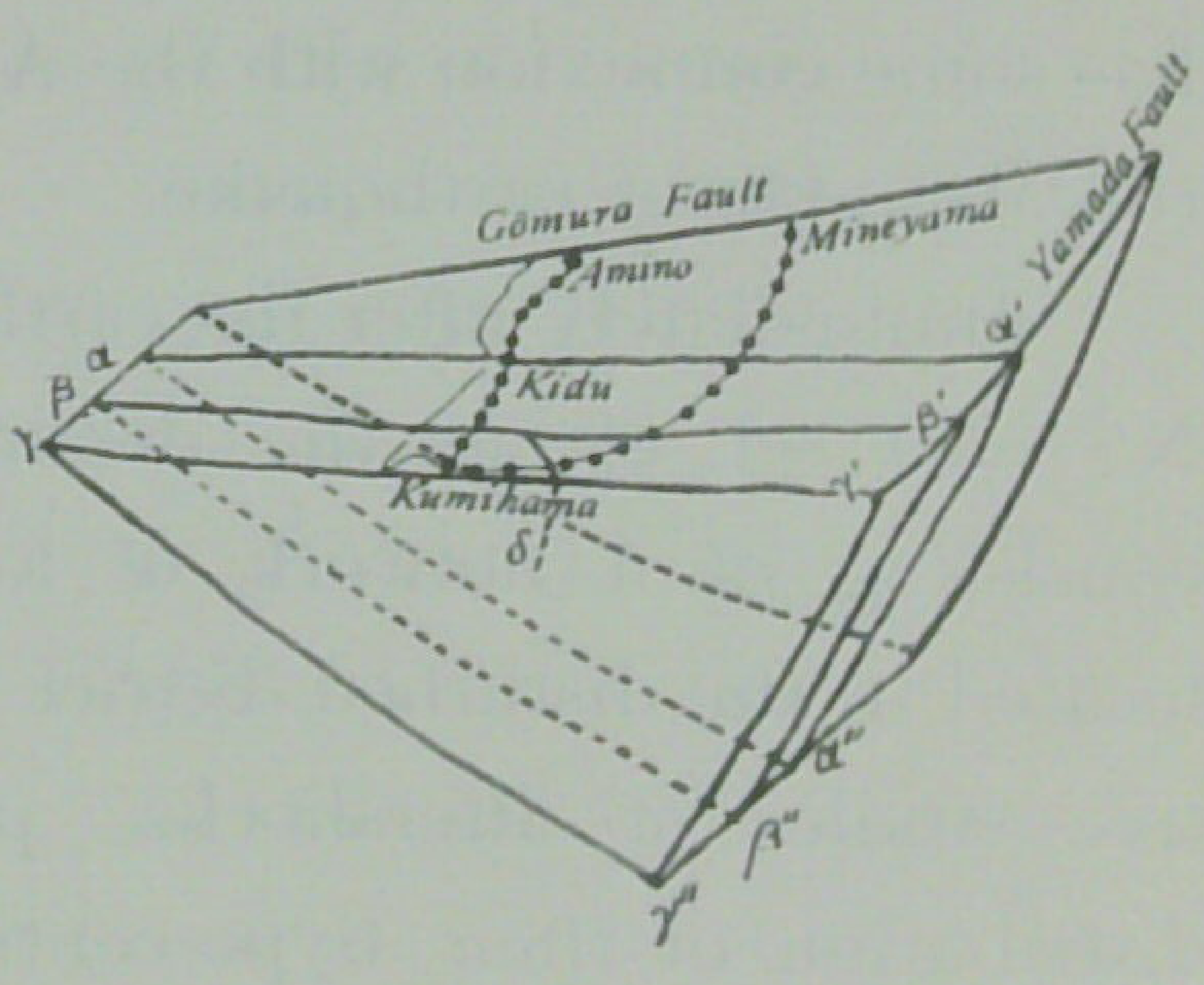

Fig. 59.

1) N. Nasu: Proc. Imp. Acad., Vol. V (1929), No. 4.

fault to be detached from the surrounding body along the weak zones represented by the Yamada- and the *b*-fault planes. The wedge shaped block thus formed being then elevated and shifted towards the south."

If the above interpretation is accepted, the up-bulge of land which was observed at Mitu and Sunakata two and half hours before the earthquake may be regarded as having been caused by the stress thus directed to detach the said block from the surrounding body, the up-bulged land having made a rebound upon release of stress when the block was elevated and shifted.

No. 26. The Sekihara earthquake of 1927.

In response to the joint request of Prof. N. Yamasaki and the writer, the Military Land Survey Department carried out during the summer of 1927 precise levellings over a distance of some 274 km. in the littoral of the province of Etigo and the northern part of the province of Sinano (see Figs. 2 and 60), a route that was first laid down in 1894. Fortuitously, a severe earthquake, remarkable for the small extent of the area disturbed (only 23 houses partially destroyed and 2 persons wounded), visited the place where the survey was held three months previously, or to be

Fig. 60. Map showing the seismic area of the Sekihara earthquake of 1927.

Table XII.

B.M.	H. in 1927 – H. in 1894	B.M.	H. in 1927 – H. in 1894
	mm		mm
2928	– 94	3730	– 28
3703*	—	3731	– 32
3704	– 94	3732	– 27
3705	–112	3733	– 19
3706	– 88	3734	– 11
3707	– 75	3735	– 13
3708	– 79	3736	– 7
3709	– 84	3737	0
3710	– 76	3738*	—
3711	– 72	3739	+ 8
3712	– 53	3740	– 3
3713*	—	3741	+ 6
3714*	—	3742	+ 7
3715	– 56	3743	+ 2
3716*	—	3744	– 32
3717	– 47	3745	– 42
3718	– 44	3746	– 26
3719	– 37	3747	– 66
3720	– 43	3748	– 37
3721*	—	3749	+ 3
3722	– 48	3750	+ 26
3723	–113	3751	+ 7
3724	– 85	3752	– 8
3725	–101	3753	+ 2
3726	– 98	3754	+ 7
3727	– 53	3755	– 5
3728	– 48	3756	– 5
3729	– 39	3757	+ 6

Table XII. (*continued.*)

B.M.	H. in 1927 − H. in 1894
	mm
3758	+ 9
3759	− 3
3760	−27
3761	−21
B.M.	**H. in Nov.-Dec. − H. in July, 1927**
	mm
3752	0
3753	+ 0.5
3754	− 0.9
3755	− 2.2
3756	+ 0.3
3757	+ 17.1
3758	+ 20.9
3759	+ 2.4
3760	+ 0.4
3761	+ 2.6
B.M.	**H. in 1927 − H. in 1894**
	mm
3762	−18
3763	− 3
3764	− 6
3765	−21
3766	+ 1
3767	+ 8
3768	+18
3595	+27

B.M.	H. in 1927 − H. in 1894
	mm
3596	+27
3597	+44
3598	+52
3599*	—
3600	+44
3601	+34
3602	+43
3603	+44
3604	+27
3605	+33
3606	+31
3607	+26
3608	+ 4
3609	+ 18
3610	0
3611	+30
3612	+32
3613	+30
3614	+33
3615	+28
3616	+33
3617	+23
3618	+29
3619	+25
3620	+18
3621	+24
3622	+28
3623	+23

Table XII. (*continued.*)

B.M.	H. in 1927 – H. in 1894	B.M.	H. in 1927 – H. in 1894
3624	mm +14	3645	mm +46
3625	+13	3646	+53
3626	+ 6	3647	+47
3627*	—	3648	+16
3628	–26	3649	0
3629	– 2	3650	+56
3630	–15	3651*	—
3631	– 2	3652	+12
3632	–30	3653	–23
3633	–28	3654	–23
3634	–35	3655	–26
3635	–56	3656	–10
3636	–44	3657	–12
3637	–50	3658	–10
3638	–97	3659	– 4
3639	–22	3660	– 2
3640	–31	3661	+ 8
3641	–12	3662*	—
3642	– 2	3663	+27
3643	– 2	3664	+32
3644	–30	3665	+31

*......Original identity uncertain.

more precise, on Oct. 27th at 10 h 53 m 35 s. No time was lost in taking advantage of this unique opportunity, and at our request, the same department re-examined that part of the route affected by the earthquake, the results attained thus far being shown in Table XII.

As just stated, a prominent feature of the earthquake was the sharp decline in intensity from the focus towards the surrounding districts. Although in Sekihara some houses were badly damaged, yet in the City of Nagaoka, about 10 km. east of the epicentre, the shock was felt only as a moderate one. Possibly it originated at a depth not exceeding a few km. This phenomenon is consistent with that striking feature manifested in the topography of the epicentral area as shown in the results of levellings (Fig. 61).

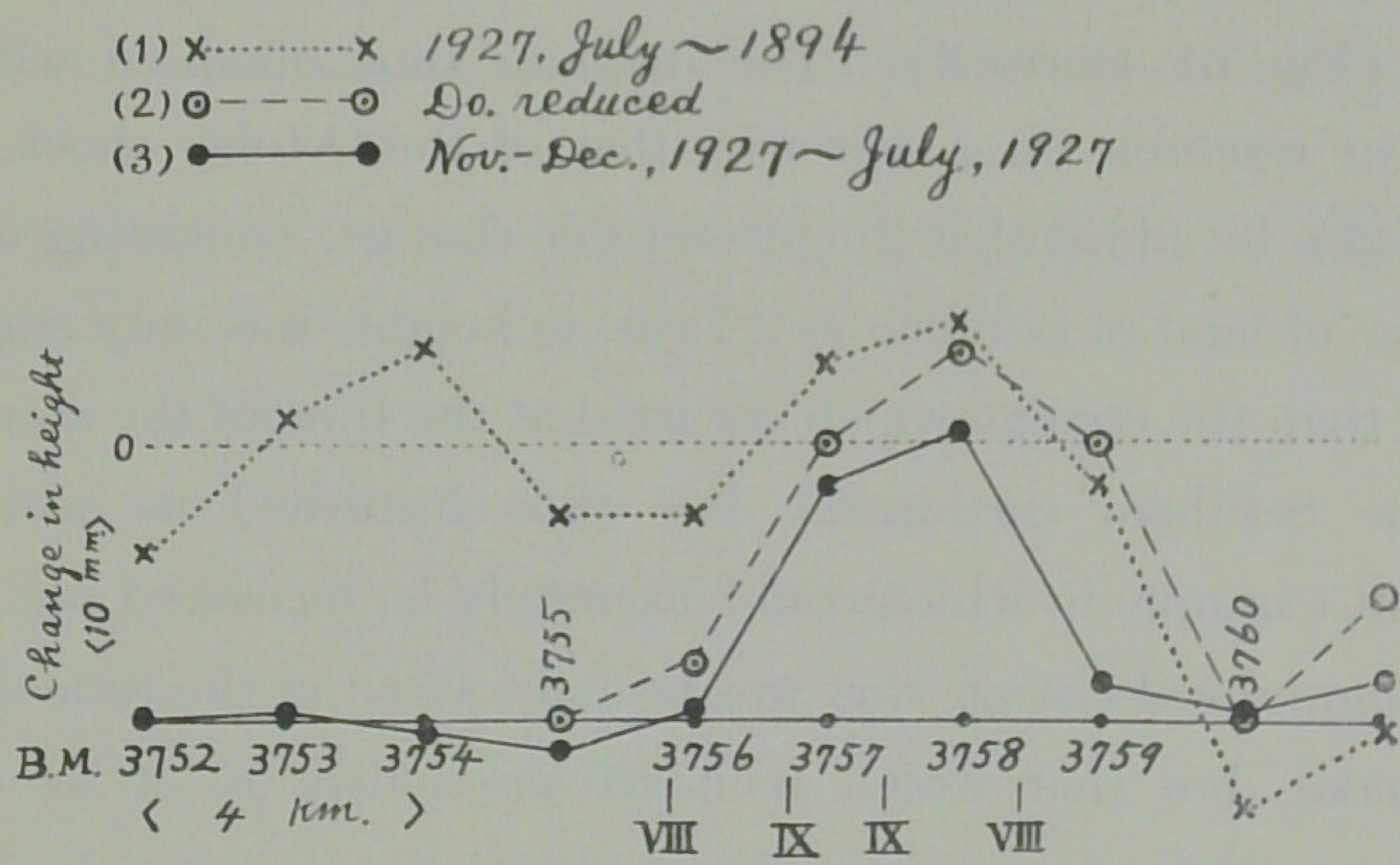

Fig. 61. Diagram illustrating the change of land-level associated with the Sekihara earthquake.

The latter consists of an upheaval of as much as 2.1 cm. but for an extent of only about 4 km. This may be accounted for entirely by the October earthquake—the first result which we have ever attained that was quite independent of the so-called secular variation of land-level. Furthermore, if the stress that was responsible for the recent earthquake had been accumulating there for many years, then the variation of land-level which had been going on would have manifested itself before the final catastrophe.

Fig. 61 gives a comparative view of the topographical changes which took place before, and also at the time of, the earthquake. Roughly speaking, for a distance of 10 km. (from B.M. 3755 to 3761) the curves resemble each other. On close examination, however, the variation which took place prior to the earthquake is seen to be superposed on another curve much more extensive, and showing a downward tilt towards the right. To eliminate the latter, the writer selected B.M. No. 3755 and No. 3760 as standards, and by means of the straight line joining the two marks just mentioned, estimated the changes undergone by the other marks (Fig. 61, Curve 3). The diagram thus obtained will be found to resemble in a fair way that of the October shock. It should also be added that the pre-seismic change, consisting of an up-bulge of land of as much as 2.7 cm. in height, was only slightly greater than the change which occurred at the time of the shock.

The Sekihara earthquake has thus furnished us with an excellent example in which could accurately be measured not only the topographical change that was brought about at the time of the earthquake, but that which occurred previously to it as well. Although nothing is accurately known as to the time in which the pre-seismic change took place, except that it was some time during the period between 1894 and August of 1927, yet the greater part of the change might have taken place towards the latter part of the 33 years that intervened. No hesitation is felt in calling it the pre-seismic change of the second stage.

Chapter IV. Topographical Changes that Have Accompanied Volcanic Eruptions.

The two phenomena of earthquakes and volcanic eruptions differ so much from each other that it would be superfluous for one to emphasize the dissimilarity. In one point, however, they resemble each other, and that is the earth-tilting which takes place either antecedent to, simultaneously with, or after, the earthquake or eruption, whichever it may be.

As will be made clear from the following paragraphs, eruptions of volcanoes subject to paroxysmal explosions are generally ushered in by earth-tiltings (pre-eruptive tiltings) which occur in the same sense as tiltings that take place simultaneously with the explosive outbursts, so that in this respect the tiltings are similar in character to such topographical alterations as are brought about by local destructive earthquakes. The topographical changes around a volcano may de called an up-bulge of the land, but essentially they are discontinuous tiltings of mosaic blocks, such as we find commonly associated with big earthquakes.

There is a decided difference between a topographical change that has been accompanied by an earthquake and one that takes place simultaneously with a volcanic outburst. In the case of an earthquake, the acute tilting may be said to occur instantaneously when compared with the much slower tiltings associated with a volcanic eruption; the eruption itself being a long-drawn-out process spread over many days, weeks, and even months. In these respects an earthquake phenomenon is a condensed volcanic phenomenon. This may indeed explain why volcanoes frequently serves as safety valves for earthquake.

We have seen that in the case of earthquakes, the line of demarcation between the acute and the post-seismic topographical changes, especially in the matter of their magnitudes, is very clearly defined, but when we attempt to distinguish the simultaneous from the posterior phenomena in the case of a volcanic eruption, we are immediately confronted with difficulties. The one, in fact, merges insensibly into the other.

What we have just described are general characteristics that were exhibited by some of the volcanoes which came under observation in this country; accurate determinations having first been made in connexion with the fairly recent eruption of Usu-san in Hokkaido and that of Sakura-zima in Kyûsyû. They will be amplified in the following paragraphs.

No. 1. The Usu-san eruption of 1910.[1]

The eruption of Usu-san, which began on the 25th of July, 1910, at about 22h, and which resulted in the formation of 45 craterlets, was both preceded and accompanied by numerous earthquakes. The epoch of maximum explosive activity, which was brought to an end in the beginning of August, was followed by a remarkable example of mountain elevation; this being probably a unique instance of a rapid upheaval of ground quite distinct from the formation of a lava spine or lava dome.

Previous eruptions of this volcano were as follows:—

1) On Aug. 16, 1663. Fore-shocks and subterranean rumblings felt since Aug. 13.

2) On July 23, 1769.

1) For details see F. Omori: Bull. Imp. Earthq. Inv. Comm., Vol. V, Nos. 1 & 3, and Vol. IX, No. 2.

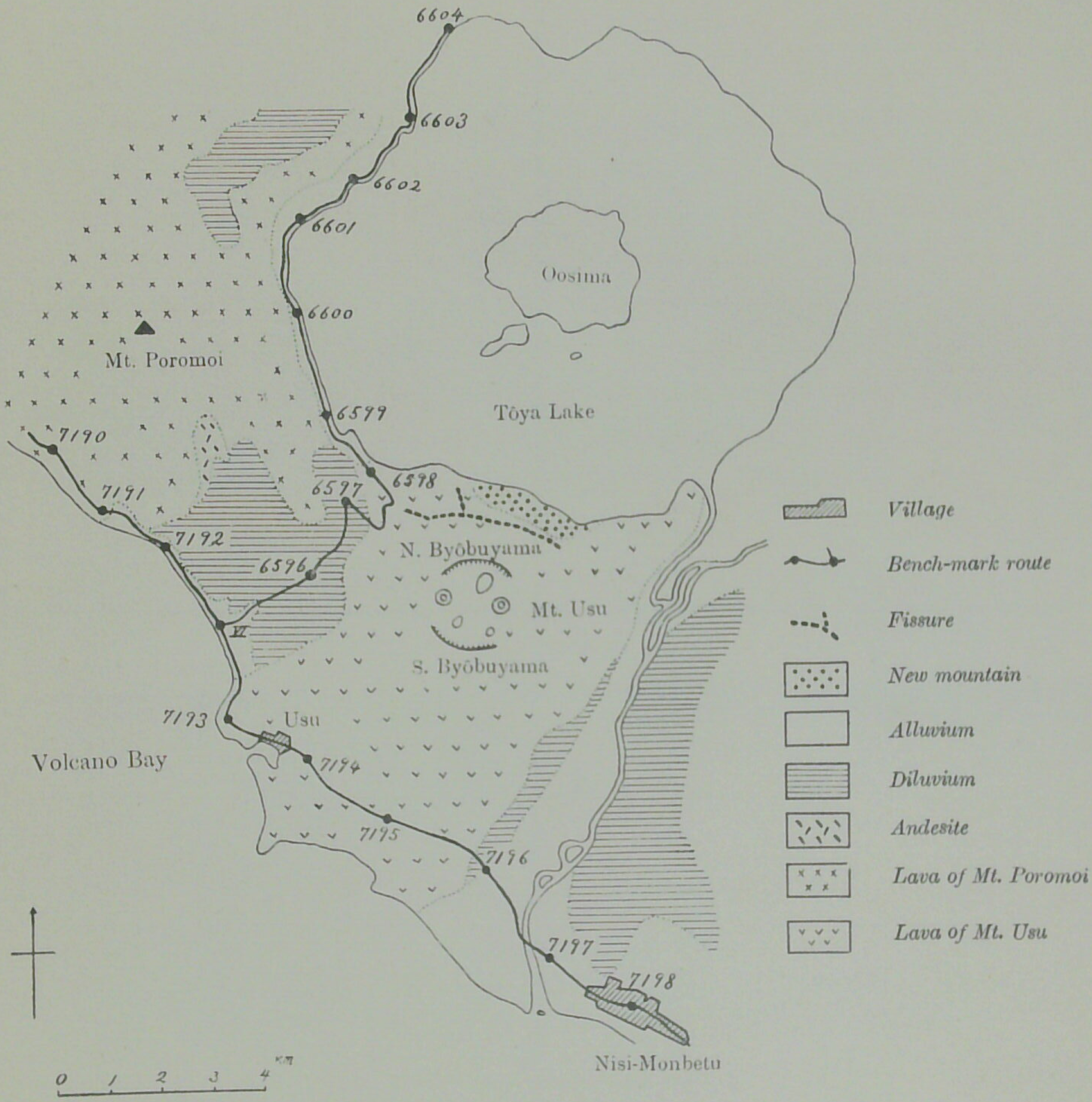

Fig. 62. Geological map of the Mt. Usu district with bench-mark route.

3) On March 12, 1822. Number of fore-shocks and rumblings 3 on the 9th, 44 on the 10th, 75 on the 11th and more than 100 on the 12th before the outburst at 14h.

4) On April 22, 1853. Eight fore-shocks on the day before the outburst, which took place at noon.

In the very recent case, a number of fore-shocks and subterranean rumblings were felt on the 21st; the number gradually increased as it neared the outburst, at least 25 having been felt on the 22nd, 110 on the 23rd and 351 on the 24th. Usu-san is thus subject to paroxysmal explosions with a period of quiescence ranging from 31 to 106 years, the explosive outburst being preceded by many shocks and subterranean rumblings.

As will be seen from the accompanying map, Usu-san is situated between Volcano Bay and the Lake of Toya. It is essentially a flat, plateau-like elevation with a central crater, the major and minor diameters of which are respectively about 2.1 km. and 1.7 km. The northern and southern halves of the crater wall, the height of which is 540 m., are known respectively as the North-Byobu-yama and the South-Byobu-yama. Within the crater walls are two crater domes and three lakes.

It was in the northern flank of the N.-Byobu-yama that the eruption of 1910 took place. Explosions occurred from craterlets produced on a new fissure which had been formed practically along the 200 m. contour line for a length of nearly 4 km., with a minor branch trending N-S. It is worth noting that these craterlets displayed their activities in turns, in quite irregular order; none of them remaining active for more than two to three days at the most, the whole having ceased towards the end of October.

The astounding feature in connexion with this eruption was the elevation of a new mountain. A tract of land between the new fissure and the lake measuring some 2700 m. long by 600 m. wide, and with an original altitude of 55 m. above the lake-level, began (very possibly together with the lake-bottom extending further northwards) to rise up gradually at a rate in proportion to the increase of the eruptive activity, until in early November it reached the height of 210 m. above the lake-level, making the net rise in height 150 m. After that it began to sink, having gone down some 36 m. during the course of the next five months.

According to Prof. Omori, the fundamental telluric disturbance in the present activity was due to this mountain elevation; the shocks and eruptions being nothing else than secondary or attendant phenomena. The whole activity, in short, was caused by intrusion of magma into the subterranean cavity under the elevated tract.

As the resultant change in topography affected an extensive area, a re-levelling of the route around the base of the mountain was felt to be desirable, so that the route which had previously been laid down in 1905 was surveyed in the summer of 1911. They were repeated during the summers of 1912 and 1913, and lastly in 1919; the results thus far obtained being shown in Figs. 63–65.

Fig. 63 shows the height difference suffered by each bench-mark during the 6 years interval between 1905 and 1911. A glance will show that a general upheaval of ~~1.4~~ 2.4 to ~~11.6~~ 1.16 m. took place around the base of the mountain, while outside of this area is a zone of steep depression. Our data being based on observations of 1905 and 1911, the latter of which was made after the extent in height the mountain had recovered was ascertained, they ought to

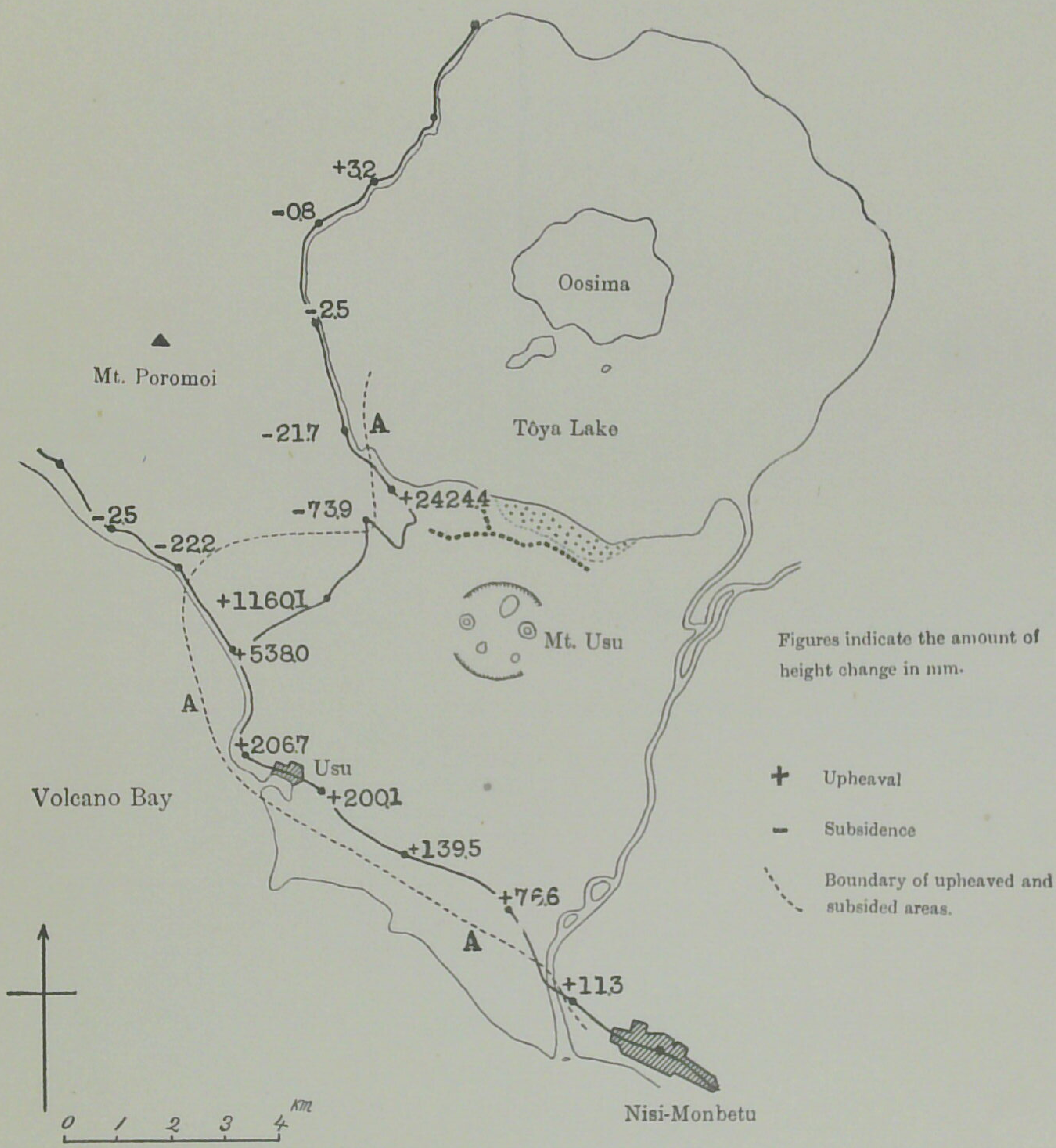

Fig. 63. Map showing the height difference in the Mt. Usu district before and after the eruption of 1910.

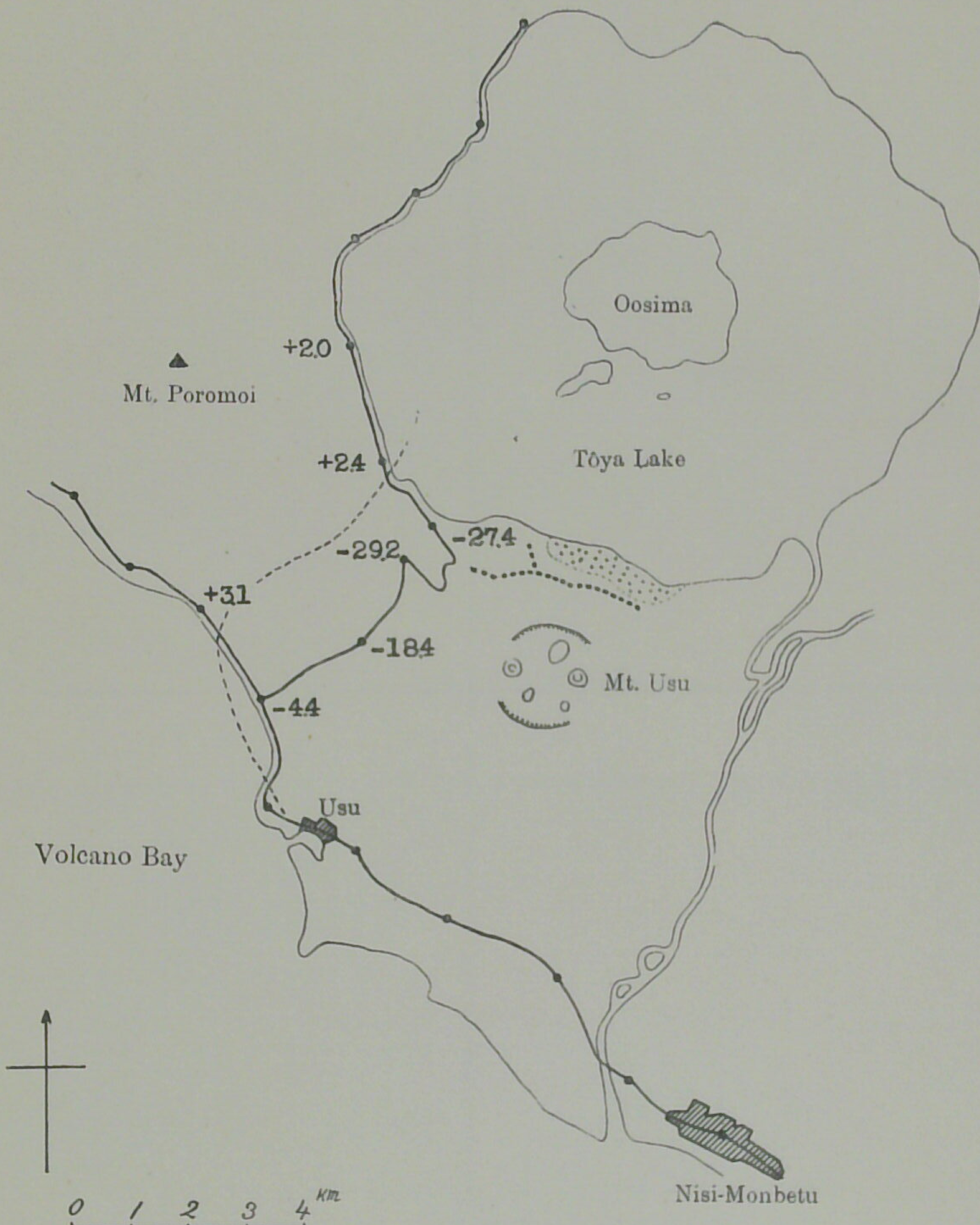

Fig. 64. Map showing the height difference in the Mt. Usu district between 1911 and 1912.

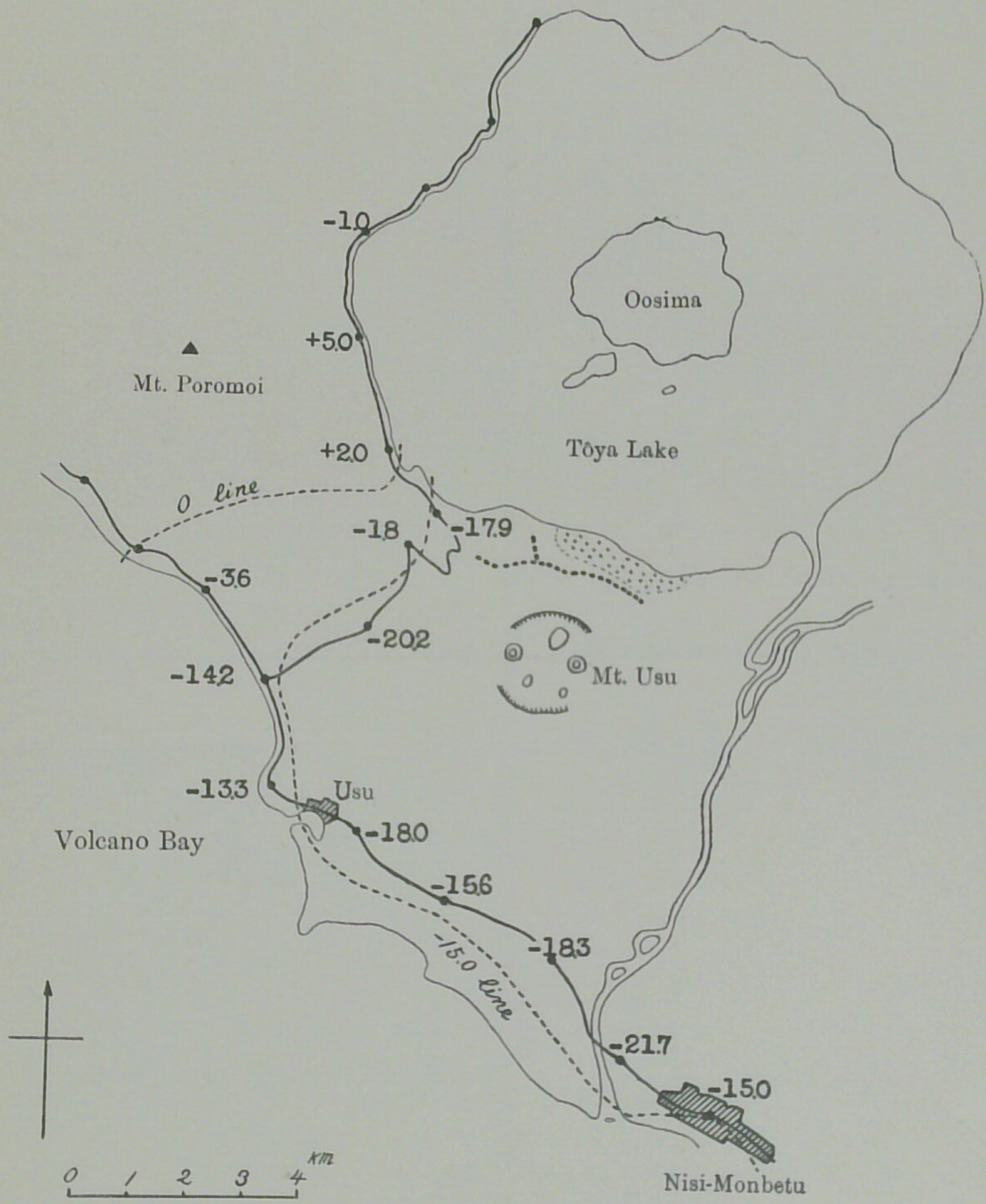

Fig. 65. Map showing the height difference in the Mt. Usu district between 1913 and 1919.

be regarded as an underestimate of the maximum change of topography. A feature of this restitution, that is the post-eruptive change is clearly shown in Figs. 64 and 65, the former of which indicates the amount of restitution during the subsequent year, while the latter gives the total amount of restitution undergone during the 6 years between 1913 and 1919.

No. 2. The Sakura-zima eruption of 1914.

Sakura-zima, now a peninsula of Osumi in Kyûsyû Island, was formerly, as the name indicates, an island situated in the central part of Kagosima Bay with an area of about 70 sq. km.

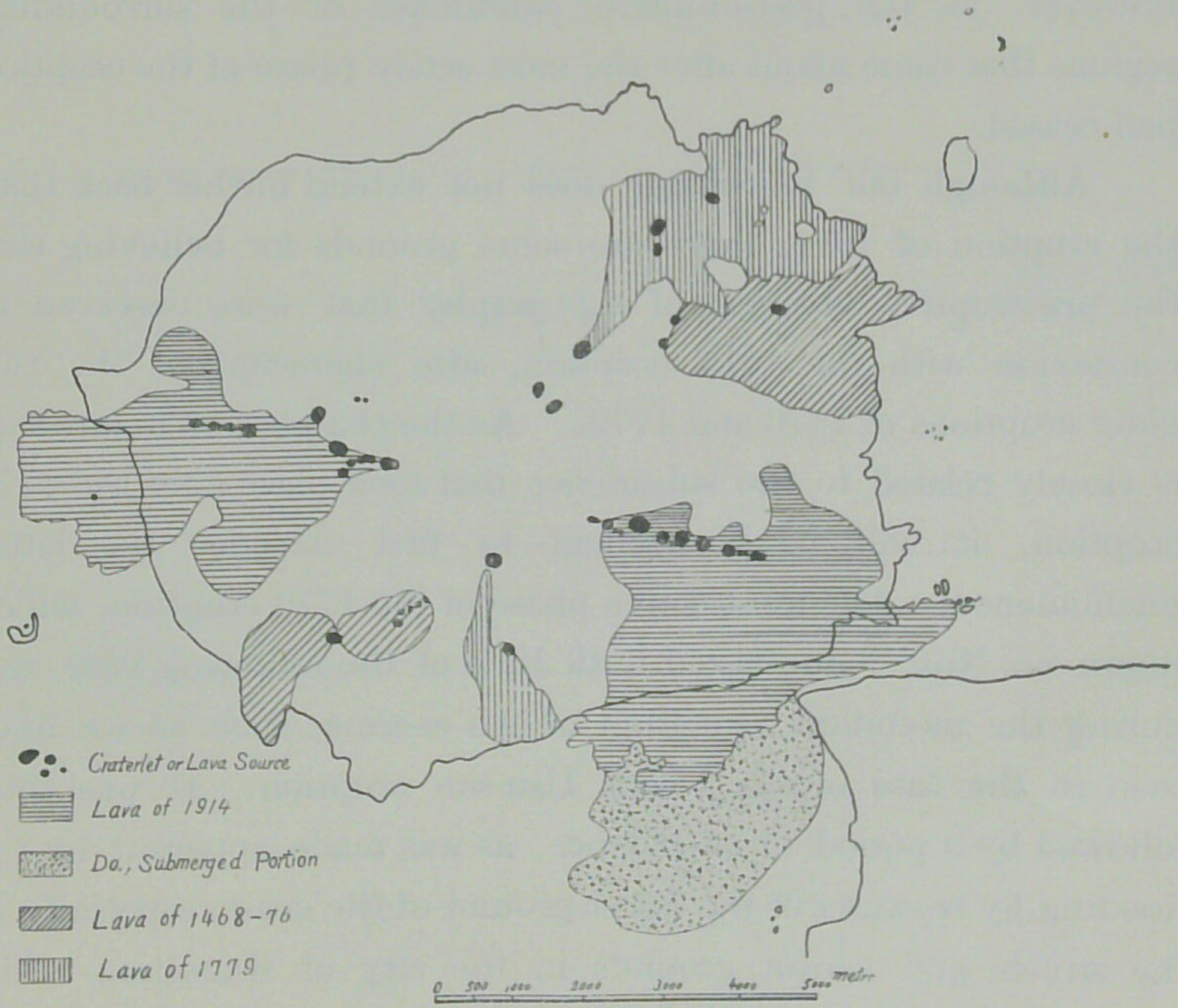

Fig. 66. Map showing the distribution of lava out-flows in the last three great eruptions of Sakura-zima.

During historical times, only the southernmost of the three peaks lying on a line trending N–S used to show any activity, although in the three activities of 1476, 1779 and 1914, the eruptive phenomena manifested themselves mainly from some 10 vents formed on a pair of fissures that were produced on both sides of the southern peak, emitting from each craterlet showers of ashes, lapilli, etc., and finally molten lava (Fig. 66). The above-mentioned peculiarities obtained also for the premonitory shocks and subterranean rumblings which began 5 days before the 1476 outburst, 17 hours before the 1779 outburst and 31 hours before that of 1914. The most remarkable phenomena of all must, however, be the post-eruptive subsidence of the surrounding regions that came about after the most active phase of the eruption had ceased.

Although our knowledge does not extend further back than the eruption of 1914, there are some grounds for believing that the pre-eruptive changes of topography that were observed in connexion with the 1914 eruption, also characterized the two older eruptions of 1476 and 1779. As the change just mentioned is closely related to the subsidence that took place after the 1779 eruption, it will be convenient to first consider the latter phenomenon. The most active phase of the 1779 eruption, which began on Nov. 9 and lasted until June of the following year, was during the mountain formation of An'ei-zima, such as we have seen in the case of the recent Usu-san eruption. It was then followed by a period of subsidence, as was made apparent by the flooding by seawater of the lower ground of the coast, especially in the streets and vacant grounds in the city of Kagosima. The event was first reported officially in August 1780 as having happened during the period June to August, and for the second time in April, 1781. It would seem that the phenomenon, though on a lesser scale, continued for the ensuing 40 or 50 years until the new phase of the next eruption began to take definite shape.

We have reasons to warrant the belief that the phase of pre-eruptive upheaval connected with the eruption under discussion had begun already in the latter part of the last century. It was most conspicuous along the coast of Sakura-zima. At Yokoyama, in a village on the west coast of the island, a road skirting the seashore, and so close to it that one side was practically the shore-line some 70 to 80 years ago, had been receding until, at the time of the eruption, the distance between high water-mark and the side of the road nearest the water and which was the old shore-line, had widened to as much as 40 m. Besides this, at the lower courses of rivers which have their outlets in the NW part of Kagosima Bay, such as the Kôtuki-gawa, Byû-gawa, Amikake-gawa, etc., the lowering of high-water marks had been noticed for many years before the eruption. All these facts would seem to suggest that Sakura-zima and vicinity had been undergoing pre-eruptive upheaval for a few decades, resulting in the rise of land-level of as much 1.5 m. in Sakura-zima and of 1.0 m. on the coast bordering the northern half of Kagosima Bay.[1)]

As stated above, premonitory signs of the present eruption began to manifest themselves on the evening of the 10th although the actual outburst was on the morning of the 12th at about 10 h. At 18 h 29 m of the very same evening came the severest shock and which levelled 39 houses and killed 29 people. The next evening lava began to flow out from the craterlets on both sides of the mountain, the lava which flowed from the eastern side having

1) A. Imamura: Rep. Imp. Earthq. Inv. Comm., No. 92.

blocked up the Strait of Seto on the 29th of January. The eruption was at its height during the first three days, whence it declined rapidly.

As regards changes of land-level, nothing remarkable was noticed for the first three weeks, but at springtide on March 13th it was found that at Kagosima the high-water level had arisen one and half feet over that of the corresponding month in previous years. This would suggest that the post-eruptive subsidence, which probably started with the decline of eruptive energy, had in the meantime reached appreciable proportions. The later progress of the subsidence will be seen from the accompanying tables.

Table XIII. Rise (in ft.) of heighest sea-water levels in Kagosima Harbour in comparison with those in 1903–1905.

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
years 1914	—	0.3	1.8	1.5	1.6	1.1	1.3	2.7	1.5	1.9	1.9	1.5
1915	0.8	1.6	1.4	1.7	1.9	1.6	1.3	1.9	1.9	1.5	2.2	1.8

Table XIV. Rise (in ft.) of mean monthly heights of sea-level in Kagosima Harbour in comparison with those in 1903–1905.

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
years 1914	—	1.4	1.4	1.3	1.5	1.4	1.2	1.7	2.0	2.2	3.0	3.0
1915	2.8	2.3	2.0	1.8	1.8	1.8	1.5	1.7	1.6	1.6	2.0	1.7

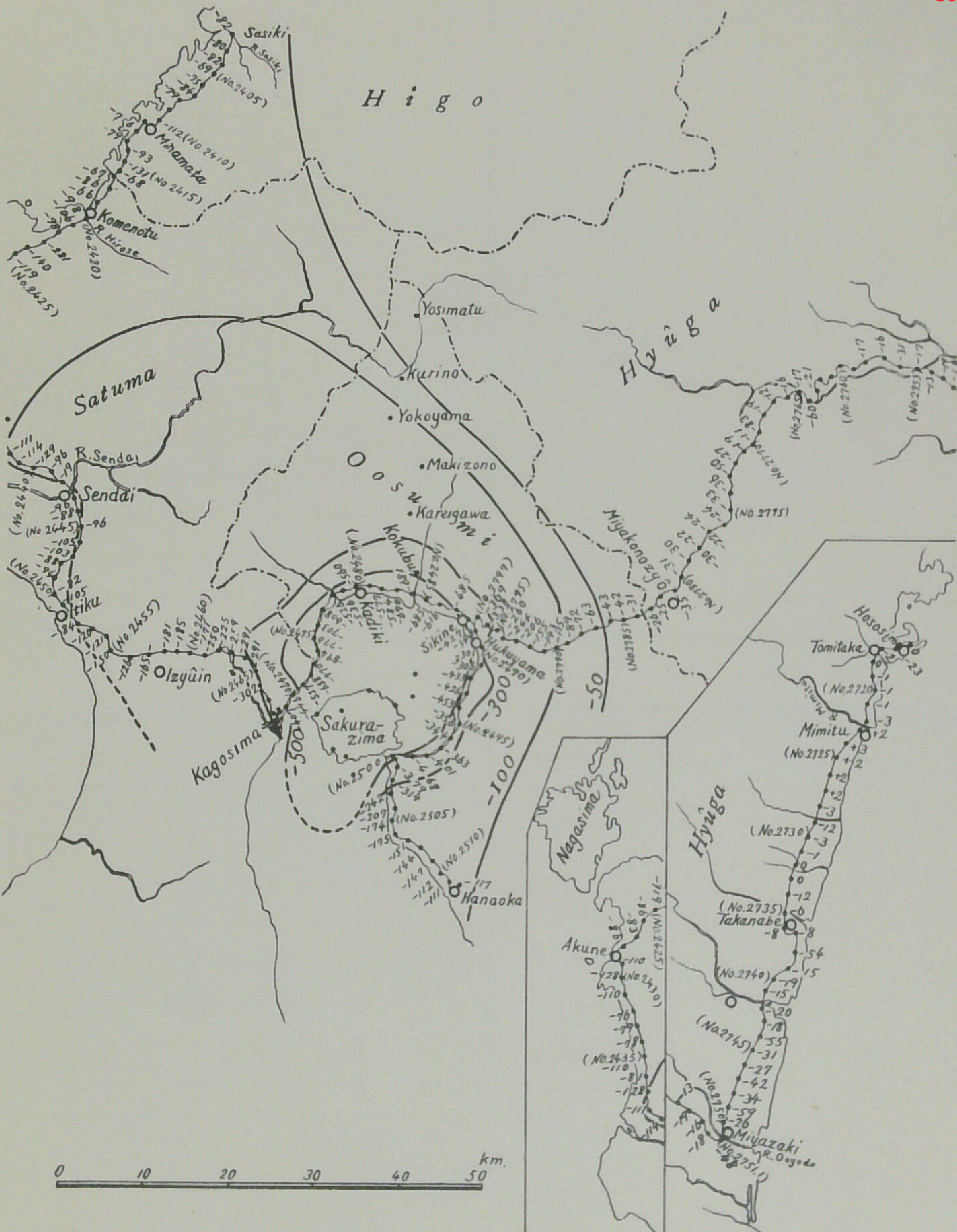

Fig. 67. Map of Sakura-zima and vicinity showing the depression of the ground in mm. after the eruption of 1914.

On examining these tables, it will be noticed that the maximum subsidence took place in November of the same year, that is to say 10 months after the decline of eruptive energy, the subsequent change being a slight recovery of the level.

The writer will now state the results of precise levellings that were carried out in this district in connexion with the recent Sakura-zima eruption. The route extends from Hososima in the eastern part of Kyûsyû to Sasiki in the western, passing on its course through the northern and north-western coast of Kagosima Bay, with a short branch laid down along the eastern coast of the same bay. The route was first laid down in Dec., 1891–Jan., 1895, the post-eruptive re-levellings of its different sections having been carried out as follows:—

(1) In June–Sept., 1914, over the stretch of 22 km. from Izyuin to Kagosima, and of 104 km. from Hukuyama to Hanaoka.

(2) In Dec., 1914–Jan., 1915, over the stretch of 157 km. from Hukuyama to Hososima.

(3) In Feb., 1915, over the stretch of 49 km. from Kagosima to Hukuyama.

(4) In Feb.-May, 1915, over the stretch of 83 km. from Izyuin to Sasiki.

(5) In Nov., 1918,–Feb., 1919, over the stretch of 130 km. from Izyuin to Hanaoka and from Sikine to Sueyosi.

Re-levellings Nos. 1–4 constitute a complete set of surveys over the whole route, though No. 3 is the second re-levelling of the section linking Kagosima with Hanaoka along the shore of the bay. A comparison of the two surveys of the last-mentioned section shows that the subsidence which had been going on continued in the NW coast of Kagosima Bay, the amount being 4 cm. on the average and 5.5 cm. at the maximum. Combining, therefore, the mean values for this section with those for the rest of the whole route, the following will be noticed:—

(i) A maximum depression of 89 cm. occurred near Oosakihana.

(ii) The curve of 50 cm. depression is somewhat of a circular shape with its centre in the north of Sakura-zima, i.e., at a point to the west of the centre of the inner part of Kagosima Bay. Here it must be remarked that the results of soundings carried out in this part of the bay by the Naval Hydrographers, first in 1906 and later in 1917, gave the same position for the maximum depression of the sea-bottom, the amount of depression ranging from 2.5 m. to 6.0 m.

(iii) The variation in the amount of subsidence in direction from the above-mentioned centre towards the outside is very sharp, especially in the eastward direction.

(iv) The change of topography consists of discontinuous tiltings of contiguous mosaic blocks, as pointed out by Prof. C. Tsuboi.[1)]

Fig. 68 shows the change of topography experienced during the period between 1915 and Nov., 1918,–Feb., 1919, the outstanding feature being that the area which had undergone that conspicuous depression, with its centre at a point to the west of the middle of Inner Kagosima Bay, underwent a little elevation. Since the B.M. which was previously depressed as much as 89 cm. underwent during the later period an elevation of as much as 18 cm., the recovery of topographical change may be said to have amounted to about one-fifth of the initial depression.

As for Sakura-zima itself, where there is no network of bench-marks, the alterations in height cannot be ascertained by

1) C. Tsuboi: Bull. Earthq. Res. Inst., Vol. VII.

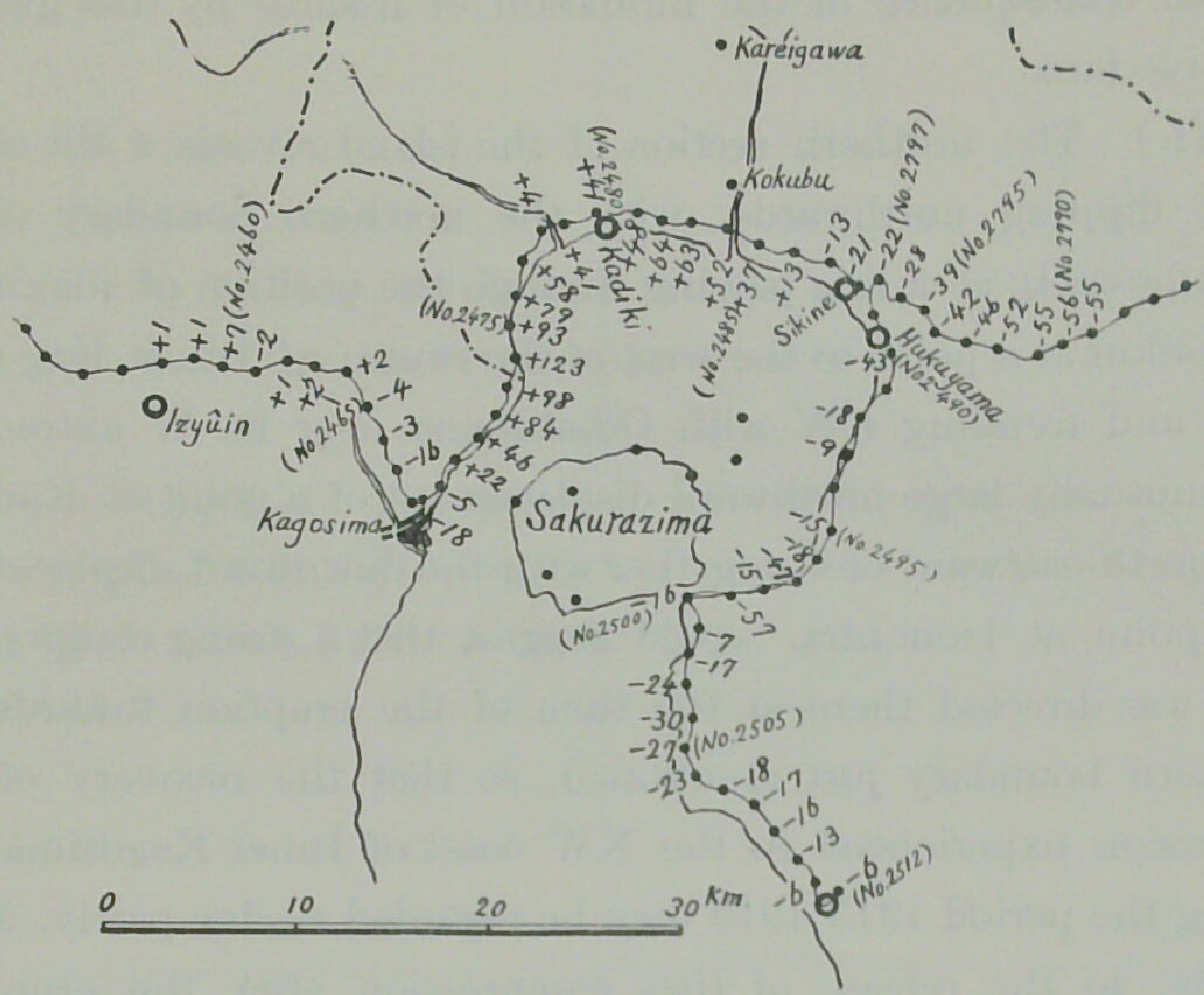

Fig. 68. Map showing the post-eruptive variation (in mm.) of land-level.

the method of precise levelling. Much light, however, has been thrown on the question of the vertical and the horizontal displacements in the principal area by means of geodetic triangulations of trigonometrical points of the first–fourth orders in Sakura-zima and neighbouring coast districts, carried out first in 1898 and after the eruption in 1914; the results worked out being shown in Fig. 69. The change of topography thus exhibited are as follows:—

(i) The change of topography in Sakura-zima and neighbouring islets consist in the main of displacements of two kinds, one in each half of the island (for convenience called N. and S. sections) and in an outward direction from the boundary, the said boundary being the fissure line with craterlets; this being the natural consequence of the formation of fissures by that gigantic eruptive force.

(ii) The northern section of the island reveals a tilt of the block dipping northwards, with the northern boundary of the block possibly at a line passing through the position of maximum depression at a point to the west of the centre of Inner Kagosima Bay, and trending EW with Oosakihana near its W extremity. An unusually large northward displacement of a point at Kamano and north-eastward of it, together with the downward displacement of a point at Isonohira, would suggest that a strong compressive force was directed there at the time of the eruption towards the northern boundary just mentioned, so that the recovery of the depression experienced in the NW coast of Inner Kagosima Bay during the period 1915–1919 may be regarded as due partly, if not wholly, to the release of that compression after the eruption, although the writer is not averse to take also into consideration the effect of the removal of subterranean magma.

(iii) The southern section of the island reveals a tilt dipping southwards.

(iv) The displacements undergone by points in the NW coast of the bay and in Hetakozima might be changes of an accessory nature to the action in the northern section of the island as mentioned in (ii).

(v) The displacements undergone by points in the E coast of the bay might have been caused by the rebound that came into play on release of tensile stress, which had been exerted there before the eruption in sense outward from the axis obtained by producing the fissure line slightly eastwards.

The changes of topography described thus far are from the results of accurate measurements made upon definite points,

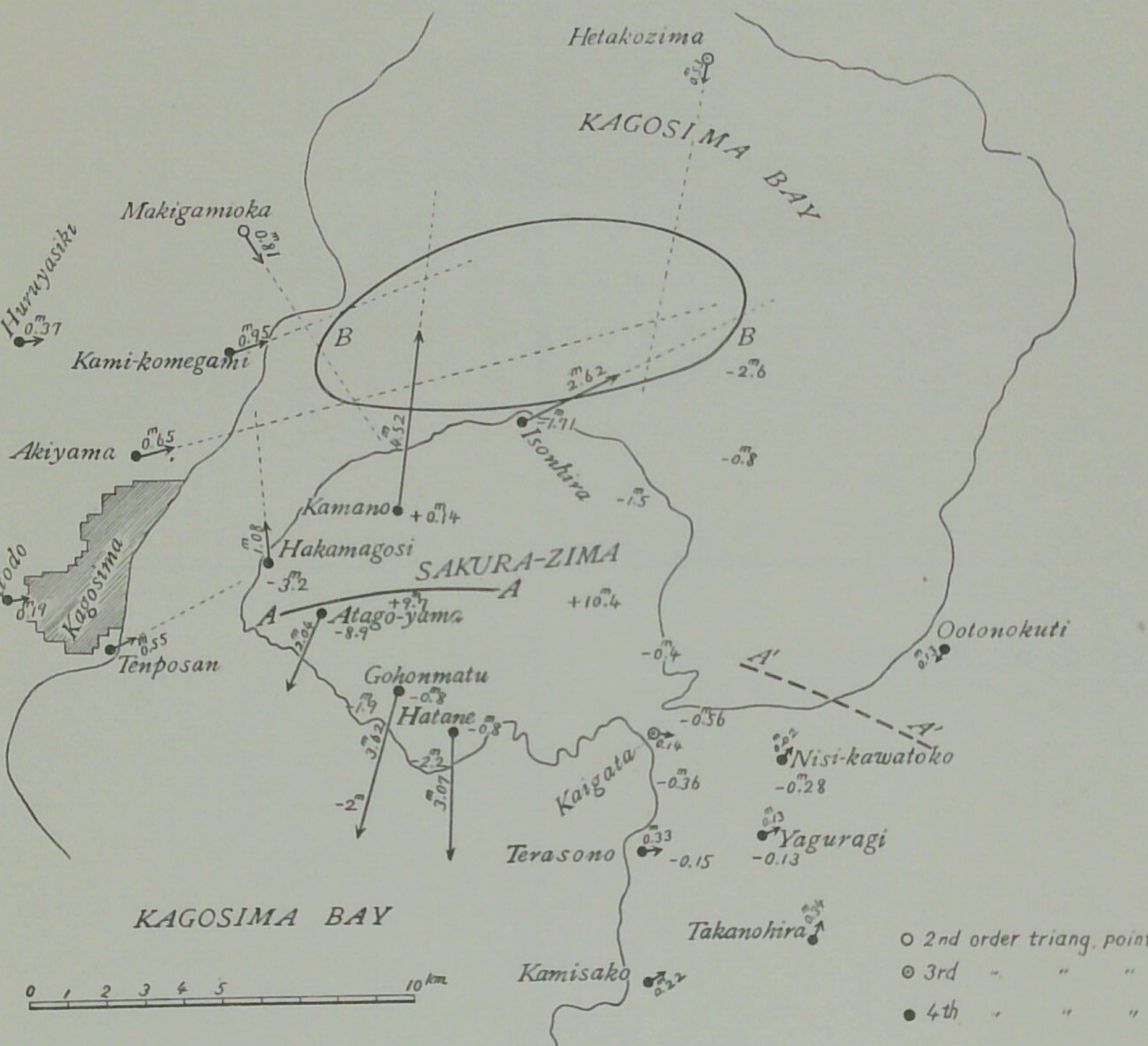

Fig. 69. Map showing the horizontal and vertical displacements suffered by triangulation points in Sakura-zima and vicinity.

whether bench-marks or trigonometrical points. If we were to accept the results of triangulations based on indefinite points represented by hill peaks, such as Hikinohira, Nabeyama, etc., with of course due allowance for changes in height owing to ejectamenta, it may be said that a narrow zone along the line of craterlets underwent, on account of the eruption, and probably during its most energetic phase, an elevation of a few metres.

It thus seems that the pre-eruptive topographical changes showed themselves in the form of an up-bulge of the principal area accompanied by tensile stress exerted there horizontally.

Although unnoticed, perhaps the distribution of strains were manifested in some such way as to render it possible to infer the position of fissure lines of later outbreaks. It is also quite possible that the movement continued for the most part in the same sense throughout the most energetic period of the eruption, the subsidence phase following it closely as the energy declined.

Chapter V. Concluding Remarks.

The conclusions arrived at in the foregoing chapters are now briefly summarized as follows:—

(i) Topographical changes whether accompanied by earthquakes or taking place with them, invariably occurred even when the earthquakes were not severe.

(ii) Geologically speaking, the elevations were in general peculiar to regions of Tertiary and post-Tertiary formation, while the depressions confined themselves to regions of pre-Tertiary formation.

(iii) Pre-seismic topographical changes appear to be the rule with most earthquakes.

(iv) Topographical changes connected with earthquakes, whether taking place before, simultaneously with, or after, the earthquake, consist, for the most part, of discontinuous tiltings of consecutive mosaic blocks, which in turn constitute the whole earthquake district. In some cases, rotational displacements about a horizontal axis or bodily displacements in vertical direction occurred as well.

(v) Discontinuous tiltings of contiguous blocks result in the formation of fault or flexure at the boundary of the blocks. Many cases have been met with where a differential tilting of the blocks caused the relative vertical displacements on one side of the fault plane to be arranged in veritable sea-saw fashion.

(vi) The fault-system is simple in local earthquakes, but complex in non-local earthquakes. Sometimes it consists of segments arranged *en échelon*, but in more complex cases it is distributed over the whole disturbed area in somewhat the same manner as the pre-existing tectonic lines are distributed there.

(vii) Changes of land-level, such as has been revealed by precise levellings run across a fault, give their diagrammatic figure an *N*-shape when the fault occurs on the compression side or in the area of upheaval, and a funnel-shape when it occurs on the tension side or in the area of subsidence.

(viii) Earth-tiltings related to a particular earthquake, whether taking place before, simultaneously with, or after, the earthquake, occur in types, which are either similar or are symmetrical to one another, or at least with gaps at the boundaries of the mosaic blocks; all of which may be regarded as the natural consequence of the characteristics mentioned in (iv).

(ix) In large, non-local, sub-oceanic earthquakes, pre-seismic earth-tiltings occurred in three stages, namely: (a) The first or earliest which has been going on from several years back and continuing up to the beginning of the next stage of the corresponding earthquake and in backward sense, i.e. in opposite sense to that assumed at the time of the earthquake, which latter is that of recent crustal movement. (b) The second or intermediate stage which follows the pre-seismic topographical change of the first stage and occurs in the onward sense. (c) The third or last stage which takes place shortly before the corresponding earthquake and occurs at a greater rate than the preceding two.

(x) With local earthquakes, pre-seismic tiltings corresponding in character to the second and third stages of large, non-local, sub-oceanic earthquakes have been observed. Whether or not pre-seismic tiltings of the backward sense do take place is uncertain, though the writer is inclined to consider that they do not.

(xi) The pre-seismic changes of topography of the last stage occurred as temporary changes in some cases, and as permanent changes in others.

(xii) The pre-seismic changes of topography occurred in only a limited portion of the meizo-seismal area.

(xiii) In large, non-local, suboceanic earthquakes, post-seismic topographical changes occurred sometimes in the backward sense and at others in the onward sense; whereas in large local earthquakes they generally occurred in the onward sense.

(xiv) Pre-eruptive topographical changes related to volcanic eruptions possess characteristics in common with pre-seismic changes related to large local earthquakes.

(xv) Topographical changes connected with volcanic eruptions, whether taking place before, simultaneously with, or after, the most energetic phase of the eruption, proceed leisurely in contrast with the quick and sudden changes that take place in the case of earthquakes.

The pleasant duty now remains of acknowledging most gratefully the invaluable help the writer has received from several quarters during the progress of the work. First, there is to be mentioned the staff of the Military Land Survey Department, without whose valuable and excellent surveys, to say nothing of the liberal manner in which the results of their arduous labours were placed at the writer's disposal, the present work could never have been accomplished These remarks apply equally to the Naval Hydrographers, whose labours as contributions to the promotion of this branch of Seismology, rank second to none in importance. There is also the staff of the Earthquake Research Institute of the Tokyo Imperial University, who, having received as legacy amongst other things from the now defunct Imperial Earthquake Investigation Committee the problems here discussed, completed investigations recently of the great Tango earthquake in a most able and thorough-going manner; the results of which having been promptly made available to the writer proved of great value in the writing of this paper. There is also the Imperial Academy and the few enthusiasts, whose generosities have rendered possible the prosecution of these studies. Lastly there remains to be mentioned Mr. T. Kodaira who gave invaluable help in collecting and arranging the materials for the purpose of these studies.

Finally, the writer, who, since the death of Prof. F. Omori in 1923 was secretary to the former Imperial Earthquake Investigation Committee, and who now retains a similar position with the Imperial Earthquake Invesitigation Council, seeing that

although No. 26 of these publications appeared as far back as 1908 No. 25 is only now on the eve of publication, desires to take this opportunity of soliciting the indulgence of his readers for the great delay which was largely owing to circumstances unavoidable.

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