

Earthquake Measurement at Miyako.

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With Plates XVII—XXIII.

1. The Meteorological Observatory of Miyako (lat. $39^{\circ}38'$, long. $141^{\circ}59'$) is situated on a small promontary of palæozoic rocks, 30 m. in height, which separates the two towns of Miyako and Kuwagasaki. As, besides, the prevailing formation in this part of the Pacific coast of the Main Island is the granite, the following seismographical observations at Miyako are to be regarded as good illustrations of earthquake measurements in a rocky district.

The seismograph used was one of the Gray-Milne type, which records, by means of a pair of horizontal pendulums and compensated vertical springs, the earthquake motion in three rectangular components on a smoked paper wapped round a revolving drum, started, as usual, on the occurrence of an earthquake by a sensitive electric contact-maker.

2. There were 27 earthquakes, which gave diagrams sufficiently large and distinct to be measured. Their dates and time¹ of occurrence are given in the following table:

1. The time is given in the First Normal Japan Time, namely, that of longitude 135° E.

List of earthquakes observed at Miyako.

No.	Date.			Time of occurrence at Miyako.		
				h.	m.	s.
1	15th	June,	1896.	7.	32.	30 p. m.
2	17th	"	"	0.	46.	25 p. m.
3	31st	August,	"	4.	42.	15 p. m.
4	"	"	"	5.	09.	55 p. m.
5	"	"	"	7.	20.	52 p. m.
6	1st	September,	"	2.	55.	15 p. m.
7	5th	"	"	11.	09.	25 p. m.
8	7th	February,	1897.	4.	35.	30 p. m.
9	20th	"	"	5.	49.	00 a. m.
10	27th	March,	"	7.	46.	43 p. m.
11	30th	April,	"	5.	51.	15 a. m.
12	18th	June,	"	1.	18.	05 p. m.
13	5th	August,	"	9.	10.	47 a. m.
14	7th	"	"	9.	09.	07 p. m.
15	16th	"	"	4.	53.	03 p. m.
16	23rd*	"	"	9.	32.	56
17	27th	"	"	1.	06.	31 a. m.
18	2nd	October,	"	9.	42.	03 p. m.
19	4th	December,	"	9.	19.	21 a. m.
20	8th	"	"	5.	20.	48 p. m.
21	23rd	"	"	0.	29.	16 p. m.
22	26th*	"	"	3.		p. m.
23	31st	"	"	11.	50.	28 p. m.
24	23rd	April,	1898.	8.	34.	13 a. m.
25	19th	May,	"	9.	50.	40 a. m.
26	31st	"	"	1.	03.	22 a. m.
27	3rd	June,	"	3.	22.	10 p. m.

Besides these 27 earthquakes, four very small shocks, whose exact dates are missing, have also been measured, thus making up a total of 31 earthquakes.

*The dates of eqkes. Nos. 16 and 22 are not quite certain, there being no report in the Central Meteorological Observatory relating to these two shocks.

As typical specimens, are given in figs. 1, 2, and 3, Pl. XVII, the seismographic diagrams of three earthquakes, Nos. 2, 3, and 11. Further, in figs. 4, 5, 6, 7 and 8 are given, for the sake of reference, maps illustrating the areas of disturbance of seven earthquakes, Nos. 3 and 20, 8, 11, 10, and 1 and 2.

3. In the following description of the seismographic diagrams, the terms *preliminary tremor*, *principal portion* and *end portion* have been employed to designate three successive stages of an earthquake motion, defined as follows:

The *preliminary tremor* of an earthquake denotes the introductory movements of very small amplitude, their period being generally short.

The *principal portion* denotes the most active part of an earthquake, which follows the preliminary tremor and which consists of movements of larger amplitude.

The *end-portion* denotes the feeble finishing part of an earthquake, which follows the principal portion.

It is here to be noted that the limits of the principal portion are sometimes very well marked, but in other cases more or less indefinite.

Again the terms, *ripples* and *slow undulations*, have been used to denote respectively those quick earthquake vibrations, whose periods are mere fractions of a second, and those comparatively gentle movements, whose periods are much longer than those of the former.

The abbreviations used in this paper are as follows:—

H.M. denotes Horizontal Motion.

V.M. " Vertical "

2a " Range of "

T	denotes	Period of Vibration. ¹
(EW)	„	East-West Component.
(NS)	„	North-South „
(V)	„	Vertical „

4. Eqke. No. 1. The 15th June, 1896 ; 7.32.30 p. m. Intensity,² *weak*.

The seismographic record evidently indicates a distant shock, the motion consisting entirely of slow undulations, free from superposed ripples. According to Mr. T. Iki, who investigated the fearful sea-waves caused by this earthquake, the origin of disturbance was situated at a point, long. 144°30' E, lat. 39° N, that is to say, at about 240 km. ESE of Miyako. Judging, however, from the isoseismal lines,³ the origin of the earthquake seems to be situated at about 170 km. ESE of Miyako. (See fig. 8).

The H.M. was four to six times greater in the EW than in the NS component, the V.M. being very small. The motion was, therefore, practically horizontal and in the EW direction, there being occasional fluctuations in the range of motion. The maximum $2a$ was 4.0 mm. As the rotation of the record-receiving drum was unfortunately irregular, we can not measure exactly the period of vibration. The duration was probably not less than 5 minutes.

5. Eqke. No. 2. The 17th June, 1896 ; 0.46.25 p. m. Intensity, *slight*. (See fig. 1). The origin of the earthquake was probably close to that of Eqke. No. 1. (See fig. 8).

1. In this paper, the *period* signifies always the *complete period*.

2. The *intensity* of an earthquake is, in this paper, indicated as *strong*, *weak* or *slight*. A *slight* shock is one which is very feeble and just strong enough to be felt; a *weak* shock is one whose motion is well-pronounced but not so severe as to cause general alarm; and finally a *strong* shock is one which is sufficiently strong to knock down some furnitures, to cause people to run out of doors, etc.

3. All the distances between the origins of disturbance and Miyako, given in §§ 4-34, have been estimated from the isoseismal lines of the respective earthquakes.

The motion, which, as in No. 1, consisted of slow undulations almost perfectly free from superposed ripples, was about $2\frac{1}{2}$ times greater in the EW than in the NS component, the V.M. being also present. The duration of the H.M., as well as that of the V.M. was 56 seconds.

The *preliminary tremor*, whose duration was 13 seconds, consisted of very small slow undulations of an average period of 0.86 second.

The maximum vibration, whose period was 1.7 seconds, and which occurred at the beginning of the *principal portion*, consisted of the following two displacements :

(First motion): 2.8 mm. towards E, 0.9 mm. towards N and slightly upwards. Resultant $2a=2.9$ mm., direction E 25° N.

(Second motion): 3.8 mm. towards W, 1.4 mm. towards S, and 0.3 mm. downwards. Resultant $2a=4.1$ mm., direction W 25° S, the angle of emergence = 4° .

The average period of the seven small vibrations, which followed the maximum motion, was in the (EW) 0.82 second, and in the (NS) 0.77 second. At about 21 seconds from the commencement there was a second maximum epoch, which consisted of three nearly equal undulations of an average period of 1.4 seconds, the two displacements of the first vibration being as follows:—

(First motion): 0.7 mm. towards E, 0.2 mm. upwards. Resultant $2a=0.7$ mm., direction E, the angle of emergence = 16° .

(Second motion): 1.1 mm. towards W, 0.3 mm. downwards. Resultant $2a=1.1$ mm., direction W, the angle of emergence = 13° .

The third maximum epoch occurred at about 27 seconds from the beginning, the average period of vibration being 1.2 seconds in the (EW) and 1.0 second in the (NS).

The mean of the above three angles of emergence is 11° , and it will be observed that the direction of motion dipped towards W instead of towards E, where was situated the origin of the disturbance. Of course it is out of question to inquire into the relation between the direction of motion and the position of the origin in cases like the present, where the intensity of earthquake motion at the observing station is already very feeble.

6. Eqke. No. 3. The 31st August, 1896; 4.42.15 p. m. Intensity, *strong*. This earthquake was strongly felt in the central and western portions of the Province of Ugo and Rikuchū, and was one of the fore-shocks of the destructive earthquake, which took place on the same day at 5.9.55 p. m. Judging from the isoseismal lines (fig. 4), the epicentre was situated at about 100 km. S 80° W of Miyako.

The seismographic diagram (fig. 2) shows a considerable amount of horizontal and vertical motion, which consisted of ripples superposed on slow undulations. The H.M. was more than four times greater in the (EW) than in the (NS). The duration of the H.M. was 73 seconds, and that of the V.M. was 89 seconds.

The *preliminary tremor*, whose duration was 10 seconds, consisted of ripples of the following elements:—

	(EW)	(NS)	(V)
Maximum $2a$	1.0 mm.	1.2 mm.	0.2 mm.
Average period	0.07 second	(not clear)	0.06 second.

These ripples were superposed on slow undulations, whose maximum $2a$ was 1.4 mm. (period 1.4 seconds) in the (EW), very small in the (NS), and 0.2 mm. in the (V).

The *principal portion*, whose duration was 4 seconds, consisted essentially of three large well-defined vibrations of an average period of 1.0 second, the maximum horizontal motion (period 0.94 second), being composed of the following two displacements :

(First motion): $2a=9.0$ mm., direction S 79° W.

(Second motion): $2a=9.0$ mm., direction N 79° E.

The succeeding vibrations were executed also in nearly the same direction, that is, ENE—WSW, the direction of motion, however, gradually changing as we pass into later and smaller vibrations. Thus the second vibration after the maximum consisted of the following two displacements :

(First motion): $2a=5.0$ mm., direction S 66° W.

(Second motion): $2a=3.1$ mm., direction N 46° E.

The principal vibration of the V.M., whose average period was 0.9 second, occurred simultaneously, but did not synchronize, with those of the H.M. The maximum $2a$ of the V.M. was 1.3 mm., its period being 0.9 second.

In the *end portion*, the average period of ripples was 0.09 second in the (EW), and 0.06 second in the (V).

It may here be noted that the direction of the maximum vibration, namely S 79° W—N 79° E, pointed exactly towards the epicentre of the earthquake.

7. Eqke. No. 4. The 31st August, 1896; 5.9.55 p.m. Intensity, *very strong*. This was the great earthquake, which caused much destruction in the eastern part of the Province of Ugo and the western part of the Province of Rikuchu, the origin being at about 100 km. S 80° W of Miyako.

The duration of the H.M., as well as that of the V.M. was 100 second.

In the *preliminary tremor*, whose duration was 5.2 seconds, the amplitude of motion was much greater in the (EW) and the (V) than in the (NS), the maximum ranges being 5.4 mm. in the (EW), 1.4 mm. in the (NS), and 3.5 mm. in the (V).

At about 4 seconds from the beginning, there were two vibrations of the period of 0.8 second each, which consisted of the following four displacements :

{(First motion): 2.6 mm. towards W, 2.1 mm. downwards.
{Resultant $2a=3.3$ mm., the angle of emergence = 39° .

{(Second motion): 1.7 mm. towards E, 3.5 mm. upwards.
{Resultant $2a=3.9$ mm., the angle of emergence = 64° .

{(Third motion): 2.8 mm. towards W, 3.4 mm. downwards.
{Resultant $2a=4.4$ mm., the angle of emergence = 50° .

{(Fourth motion): 4.2 mm. towards E, 2.8 mm. upwards.
{Resultant $2a=5.1$ mm., the angle of emergence = 34° .

It is to be remarked that the above four angles of emergence relate to the vibrations in the preliminary tremor, and are probably very different from those in the principal portion of the shock, the mean angle of emergence of 47° giving obviously a too great depth of the earthquake focus.

The *principal portion*, whose duration was 26 seconds, was unfortunately vitiated by the large oscillations of the seismograph pendulums. The elements of the ripples have, however, been measured and found to be as follows:—

	(EW)	(NS)	(V)
maximum $2a$	>3.4 mm.	3.4 mm.	(obscure)
average period	0.088 second	0.085 second	0.064 second,

8. Eqke, No. 5. The 31st August, 1896; 7.20.52 p. m. Intensity, *weak*. The origin of the earthquake was evidently in the vicinity of the observing station, the V.M. existing to a proportionally large amount. Owing, however, to the irregular distribution of the intensity of motion, it is difficult to determine exactly the position of the epicentre.

The duration of the H.M., as well as that of the V.M. was 50 seconds.

The *preliminary tremor*, whose duration was 5.7 seconds, consisted of very fine ripples of an average period of 0.054 second in the (EW), and 0.043 second in the (NS); these being superposed on slow undulations of an average period of 0.86 second in the (EW), and 0.87 second in the (NS).

The preliminary tremor was abruptly followed by the *principal portion*, whose H.M. was much greater in the (NS) than in the (EW). The maximum vibration, whose period was 0.56 second, consisted of the following two displacements:

{(First motion). 1.2 mm. towards S, 0.6 mm. towards E.
 {Resultant $2a=1.3$ mm., direction S 30° E.

{(Second motion). 2.1 mm. towards N, 0.6 mm. towards W.
 {Resultant $2a=2.2$ mm., direction N 20° W.

The mean direction of motion was thus S 25° E—N 25° W.

The maximum V.M., which did not perfectly synchronise with the H.M., was 0.3 mm., its period being 0.53 second.

The average period of the ripples in the *principal portion* was 0.054 second in the (EW), 0.056 second in the (NS), and 0.055 in the (V); these being superposed on the slow undulations of an average period of 0.68 second in the (EW), 0.58 second in the (NS), and 0.32 second in the (V).

9. Eqke. No. 6. The 1st September, 1896; 2.55.15 p. m. Intensity, *slight*. This was one of the after-shocks of the eqke. No. 4, the origin being probably situated in the same position as that of the latter.

The duration of the H.M., as well as that of the V.M., was 48 seconds.

The motion was much greater in the (EW) than in the (NS), and consisted of very small ripples superposed on slow undulations, whose maximum motion was 0.4 mm. in the (EW), 0.1 mm. in the (NS), and 0.14 mm. in the (V). As the rotation of the record-receiving drum was unfortunately not perfectly good, the period can not be determined accurately.

10. Eqke. No. 7. The 5th September, 1896; 11.9.25 p. m. Intensity *strong*. The origin of the earthquake was in the Pacific, probably at about 130 km. ENE. of Miyako.

The duration of the H.M. as well as that of the V.M. was 35 seconds. The motion, in which V.M. was present to a proportionally large amount, was active for the first 5 seconds and then became abruptly small. The maximum motion of the ripples, which were superposed on slow undulations, was 3.6 mm. in the (EW), 3.0 mm. in the (NS), and 0.4 mm. in the (V).

As the rotation of the record-receiving drum was unfortunately not perfectly regular, it is impossible to estimate accurately the periods of vibration.

11. Eqke. No. 8. The 7th February, 1897; 4.35.30 p. m. The earthquake consisted of two shocks with a time interval between them of about 1 minute, the intensity of the first shock being *weak*, and that of the second being *strong*. In these two shocks, the maximum motions in the (EW) were respectively 4 and $2\frac{3}{4}$ times greater than those in the (NS), the V.M. being

also present to a proportionately large amount. The character of motion in each earthquake was very simple, the *preliminary tremor* being followed abruptly by a large vibration.

The area of strong earthquake motion was an oblong ellipse, whose major axis, about 320 kilometres in length, was in the direction of NEN—SWS, and the shocks were probably caused by the formation of a long fissure or dislocation at a great depth under the mountain chains forming the back-bone of the northern part of the Main Island. The epicentre, or the central point of the meizoseismal area, was situated at about 130 km. S 60° W of Miyako. (See fig. 5).

The maximum range of motion of the first shock was 5.4 mm. in the (EW), 2.0 mm. in the (NS), and 0.5 mm. in the (V).

The maximum motion of the second shock was as follows: 26.0 mm. towards W, 9.6 mm. towards S, 3.5 mm. downwards. Resultant $2a=28.0$ mm., direction S 65° W, the angle of emergence=7.°2.

This maximum displacement was preceded by the following next-maximum movements:—

(First motion). 4.2 mm. towards W, 3.5 mm. towards S, 0.5 mm. downwards. Resultant $2a=5.5$ mm., direction SW, the angle of emergence=5.°2.

(Second Motion). 14.4 mm. towards E, 8.4 mm. towards N, 2.3 mm. upwards. Resultant $2a=17.0$ mm., direction N 55° E, the angle of emergence=7.°8.

As the rotation of the record-receiving drum was unfortunately irregular, the periods of particular waves can not be accurately determined. But, judging from the number of the superposed ripples, the period of the principal vibration was

probably about 1.2 seconds. The movements, which followed the principal motion, were very small.

The direction of motion, averaged from the three chief displacements of the second shock given above was S 55° W—N 55° E, pointing very nearly towards the centre of the meizo-seismal area. The greatest motion was in this case directed towards the origin.

Adopting the mean angle of emergence of 6.7°, which, as it relates to well-defined maximum vibrations, can not but be regarded as real, the depth of the earthquake focus comes out to be 16 km.¹

12. Eqke. No. 8'. This was a very small shock, whose date is not given, but which was recorded on the same smoked paper as eqke. No. 8. Intensity, *very slight*. The motion, which consisted entirely of ripples, was chiefly in the (EW) and (V), and was practically zero in the (NS), the maximum range of motion being 0.4 mm. in the (EW), 0.0 mm. in the (NS), and 0.1 mm. in the (V).

13. Eqke. No. 9. The 20th February, 1897; 5.49.0 a. m. Intensity, *very strong*. This earthquake was very extensive in area and caused some damage in the provinces of Rikuzen and Rikuchu, the origin being situated probably at about 220 km. SE of Miyako.

The motion was much greater in the (EW) than in the (NS), a considerable amount of the V.M. being also present. The record was, however, imperfect, all the three writing pointers having been thrown out of the record-receiving smoked paper at 18.6 seconds from the beginning.

1) The depths of earthquake foci have in this paper been calculated by the usual method of the angle of emergence.

14. Eqke. No. 10. The 27th March, 1897; 7.46.43 p. m. Intensity, *slight*. The origin was situated probably at about 70 km. NE of Miyako. (See fig. 7).

The motion, which consisted of regular ripples, was larger in the (EW) than in the (NS). The duration of the H.M. was 80 seconds, and that of the V.M. was 47 seconds.

The *preliminary tremor*, whose duration was 4.2 seconds, consisted in each component of vibrations of an average period of 0.078 second.

The transition from the *preliminary tremor* to the *principal portion* of the shock was marked by the appearance of slow undulations with minute ripples superposed, which formed the apparent continuation of those in the preliminary tremor, but whose period became slightly longer than before. The average period of the ripples in the *principal portion*, whose duration was about 24 seconds, was 0.100 second in the (EW), 0.093 second in the (NS), and 0.091 second in the (V); the maximum range of these vibrations being 0.39 mm. in the horizontal, and 0.08 mm. in the vertical component.

From about 29 seconds after the beginning, the period of ripples became again shorter, being practically the same as that in the preliminary tremor, namely, 0.076 second in the (EW).

The elements of the slow undulations were as follows:—

	(EW)	(NS)	(V)
Maximum $2a$:	0.4 mm.	0.3 mm.	0.2 mm.
Average period:	1.1 seconds	(obscure)	1.5 seconds.

15. Eqke. No. 11. The 30th April, 1897; 5.51.15, a. m. Intensity, *weak*. This was a small local shock, whose origin was situated probably at about 60 km. NE of Miyako. (See fig. 6).

The duration of the H.M. was 42 seconds, and that of the V.M. was 33 seconds.

The *preliminary tremor*, whose duration was 2.6 seconds, consisted of ripples of an average period of 0.080 second in the (EW), 0.073 second in the (NS), and 0.065 second in the (V). (For the diagram, See fig. 3).

The *principal portion*, which lasted for about 0.7 second, consisted of vibrations of an average period of 0.12 second in the (EW), 0.12 second in the (NS), and 0.13 second in the (V). The first prominent displacement and the two succeeding ones were as follows :—

(First motion). 0.8 mm. towards W, 0.62 mm. towards S, 0.2 mm. upwards. Resultant $2a=1.0$ mm., direction $W\ 43^\circ\ S$, the angle of emergence = 12° .

(Second motion). 1.2 mm. towards E, 1.0 mm. towards N, 0.2 mm. downwards. Resultant $2a=1.6$ mm., direction NE, the angle of emergence = $7.^\circ 2$.

(Third motion). 1.2 mm. towards W, 1.0 mm. towards S, 0.2 mm. upwards. Resultant $2a=1.6$ mm., direction SW, the angle of emergence = $7.^\circ 2$.

The mean direction of motion deduced from the above three displacements is NE—SW, while the corresponding angle of emergence = 9° . The depth of the earthquake focus comes out to be 10 km.

The *end portion* of the earthquake consisted of ripples, whose average period was a little shorter than that in the principal portion. Thus, measuring from about 3.3 seconds after the beginning, when the principal portion ceased, the average period was 0.078 second in the (EW), 0.078 second in the (NS), and 0.067 second in the (V). Again, measuring from 7.8 seconds

after the beginning, the average period was 0.094 second in the (EW), and 0.081 second in the (NS). There were also some slight traces of slow undulations.

16. Eqke. No. 12. The 18th June, 1897; 1.18.5 p. m. Intensity, *strong*. The origin was evidently in the vicinity of the observing station, probably near to the sea-coast, at about 90 km. SE of Miyako.

The duration of the H.M. was 50 seconds. The V.M. was evidently very considerable, but was unfortunately not recorded; the pointer of the vertical motion seismograph having been thrown off the record-receiver immediately after the termination of the preliminary tremor.

The *preliminary tremor*, whose duration was 8.5 seconds, consisted of ripples of the following elements.

	(EW)	(NS)	(V)
Maximum $2a$:	0.12 mm.	0.3 mm.	very small.
Average period:	0.083 second	0.078 second	0.064 second.

It is to be remarked that during the preliminary tremor, the motion was much greater in the horizontal than in the vertical component, and again about twice as great in the (NS) as in the (EW). Further, the motion remained nearly constant throughout this epoch, the amplitude being not smaller in the beginning than in the ^vlater portion.

In the *principal portion*, whose duration was 9 seconds, the motion was about twice as great in the (EW) as in the (NS), the average period being longer than that in the preliminary tremor, namely, 0.11 second in the (EW), and 0.10 second in the (NS). The most active movement was limited to the first 2.3 seconds of the principal portion, and the mean direction

of motion, whose maximum $2a$ was 7.4 mm., was N 60° E—S 60° W.

In the *end portion*, the period became again a little shorter.

17. Eqke. No. 13. The 5th August, 1897; 7.10.47 a. m. Intensity, *weak*. This extensive earthquake originated under the ocean, probably at 220 km. SE of Miyako, the epifocus being evidently linear and running nearly parallel to the coast.

The duration of the H.M. was 200 seconds, and that of the V.M. was 150 seconds. In the preliminary tremor, the motion was equally pronounced in the two horizontal components; but in the principal and the end portions, it was much larger in the (EW) than in the (NS), and consisted of small ripples superposed on slow undulations indicative of a distant origin.

The *preliminary tremor*, whose duration was 22 seconds, consisted of ripples of an average period of 0.07 second in the (EW) and 0.06 second in the (NS); these ripples being superposed on slow undulations of an average period of 0.8 second in the (NS).

The *principal portion*, consisted of ripples whose maximum $2a$ was 0.4 mm. in each component, and whose average period was 0.087 second in the (EW), 0.080 second in the (NS), and 0.075 second in the (V). The period of the ripples remained nearly constant throughout the duration of the shock, these being superposed on slow undulations of an average period of 0.82 second in the (NS), (uncertain in the (EW)), and 0.7 second in the (V). One of the largest of these slow undulations in the (NS) had the maximum $2a$ of 1.8 mm., its period being 0.74 second. The corresponding movement in the (EW) was

probably still greater, but was unfortunately obscured by the proper oscillations of the pendulum. The corresponding maximum vertical motion was 0.57 mm., its period being 0.6 second.

There existed in the (EW) still slower undulations of an average period of 1.7 seconds, the maximum motion of this kind being $2a=1.6$ mm., period=1.8 seconds.

18. Eqke. No. 14. The 7th August, 1897; 9.9.7 p.m. Intensity, *slight*. The earthquake had its origin probably at nearly the same locality as earthquake No. 13; the disturbed area being, however, smaller in this case.

The duration of the H.M. was 150 seconds, and that of the V.M. was 60 seconds, the character of the motion being gentle and indicative of a distant origin.

The *preliminary tremor*, whose duration was 23 seconds, consisted of fine ripples of an average period of 0.08 second in the (EW), which were prominent only for the first 5.8 seconds, becoming thereafter very small.

The *principal portion*, in which the motion was greater in the (EW) than in the (NS), consisted of slow undulations of an average period of 1.6 seconds in the (EW), 1.0 second in the (NS), and 0.8 second in the (V), these being in the earlier portion of the epoch superposed upon by traces of ripples. The maximum horizontal range of motion of slow undulations was $2a=0.9$ mm. toward NE, $T=1.0$ second; and the corresponding maximum vertical motion was $2a=0.12$ mm., $T=0.78$ second.

19. Eqke. No. 15. The 16th August, 1897; 4.53.3 p. m. Intensity, *weak*. The origin of this earthquake was probably a little nearer to the coast than that of the two preceding ones.

The duration of the H.M. was about 140 seconds, and that of the V.M. was 70 seconds, the character of motion being mild

and indicative of a rather distant origin. In the *principal portion*, the amplitude was much greater in the (EW) than in the (NS).

The *preliminary tremor*, whose duration was 16 seconds, consisted of ripples of an average period of 0.085 second in the (EW), and 0.08 second in the (NS). These movements, whose maximum $2a$ was 0.12 mm. in each horizontal component, were superposed on slow undulations of an average period of 1.0 second in the (NS). The transition from the preliminary tremor to the *principal portion* was marked in the (NS) by the slow undulations becoming more prominent. The (EW) was unfortunately confused by the proper oscillations of the pendulum.

The *principal portion*. The maximum motion of the ripples, which, including the preliminary tremor, lasted for 70 seconds, was

$$\begin{aligned} \text{(H.M.) } 2a &= 0.64 \text{ mm., } T = 0.12 \text{ second,} \\ \text{(V.M.) } &\text{very small;} \end{aligned}$$

their average period, which remained nearly constant throughout the earthquake, being 0.081 second in the (EW), and 0.083 second in the (NS). The maximum slow undulations were the following :

$$\begin{aligned} \text{(H.M.) } 2a &= 2.8 \text{ mm., } T = 1.6 \text{ seconds.} \\ \text{(V.M.) } 2a &= 0.4 \text{ mm., } T = 0.7 \text{ second.} \end{aligned}$$

20. Eqke. No. 15'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 15. Intensity, *very slight*. The earthquake was evidently a small local one, and the motion, whose duration was 23 seconds consisted entirely of minute ripples, the V.M. being practically zero.

The *preliminary tremor*, whose [duration was 7.8 seconds, was composed of vibrations of an average period of 0.078 second in the (EW), and 0.074 second in the (NS).

The initial movements ceased almost completely a short time before the appearance of the *principal portion*, whose maximum $2a$ was 0.2 mm., and whose average period was 0.084 second in each component. It is here to be remarked that in cases of small shocks like the present, there often exists no prominent maximum motion, a great number of vibrations having nearly the same amplitude.

21. Eqke. No. 16. The 23rd August, 1897; 9.32.55. Intensity, *weak*. The date is possibly erroneous, there being in the Central Meteorological Observatory no report relating to this earthquake. The duration of the H.M. was 100 seconds, and that of the V.M., 70 seconds.

The *preliminary tremor*, whose duration was 11 seconds, consisted of fine ripples of an average period of 0.090 second in the (EW), 0.083 second in the (NS), and 0.086 second in the (V). It is to be remarked that these ripples were greatest in the (NS) and smallest in the (V), the maximum $2a$ being 0.24 mm. in the (EW), 0.4 mm. in the (NS), and 0.05 mm. in the (V).

The *principal portion*, which was well marked off by greater amplitude and larger period, lasted for 9.3 seconds, the motion being especially active during 4 seconds at the middle of this epoch. The average period of these principal vibrations, whose general direction was WSW—ENE, was 0.11 second in each horizontal component; the maximum motion being

(H.M.) $2a=2.1$ mm. $T=0.14$ second,

(V.M.) $2a=0.3$ mm.

The average period of the ripples occurring immediately after the most active portion of the shock was 0.10 second in the (EW), 0.09 second in the (NS), and 0.10 second in the (V).

In the *end portion*, the average period of ripples was 0.10 second in each horizontal component.

The ripples were superposed on slow undulations of an average period of 1.7 seconds in the (EW), 1.0 second in the (NS), and 0.8 second in the (V).

22. Eqke. No. 16'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 16. Intensity, *very slight*. The duration was 23 seconds, there being no V.M. The shock consisted of very fine ripples, which were greater in the (EW) than in the (NS). There was no preliminary tremor, and the motion was greatest at the commencement, thence gradually diminishing. The average period was 0.082 second in the (EW), and 0.084 second in the (NS).

23. Eqke. No. 16''. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 16. Intensity, *very slight*. The duration was 8.5 seconds, there being no V.M. The average period was 0.09 second in the (EW).

24. Eqke. No. 17. The 27th August, 1897; 1.6.31 a. m. Intensity, *slight*. The origin was situated probably at 160 km. SE of Miyako, and the motion consisted of slow undulations, which were perfectly free from superposed ripples, evidently indicating a very distant origin.

The duration of the H.M. was 70 seconds, and that of the V.M., 39 seconds.

The *preliminary tremor*, whose duration was 21 seconds, was succeeded by the maximum motion of the following elements :

(H.M.) $2a=1.0$ mm., $T=1.2$ second, direction $N 60^\circ W$.

(V.M.) $2a=0.1$ mm.

The average period was 1.6 seconds in the (EW), and 0.8 second in the (NS).

25. Eqke. No. 17'. The date is not given, but the record was taken on the same smoked paper as Eqke. No. 17. Intensity, *very slight*. The duration was 26 seconds, there being no V.M. The average period of vibrations, whose maximum $2a$ was 0.1 mm. in each horizontal component, was 0.09 second in the (EW) and also 0.09 second in the (NS).

26. Eqke. No. 18. The 2nd October, 1897; 9.42.3 p. m. Intensity, *strong*. This was an extensive earthquake, whose origin was probably situated at about 150 km. ESE of Miyako. The duration of H.M. was 110 seconds.

The *preliminary tremor*, whose duration was 12.5 seconds, consisted of small ripples of an average period of 0.07 second in each horizontal component. These movements, whose maximum $2a$ was 0.2 mm. in each horizontal component, were superposed on slow undulations of an average period of 0.9 second in each horizontal component.

The *principal portion* lasted for 13.6 seconds, and consisted of ripples, whose average period was 0.09 second in the (EW), and 0.08 second in the (NS). The V.M. was confused by the proper pendulum oscillations. The maximum horizontal ripple was $2a=1.5$ mm., $T=0.12$ second, direction S 75° W. The ripples were superposed on slow undulations of an average period of 1.3 second in the (EW). 1.0 second in the (NS), and 1.0 second in the (V); the maximum motion of this kind being

(H.M.) $2a=2.3$ mm., $T=1.0$ second, direction S 55° W.

(V.M.) $2a=1.4$ mm.

The *end portion* consisted of ripples of an average period of 0.06 second in each horizontal component; these being

superposed on well-defined slow undulations of an average period of 0.65 second in the (EW), and 0.64 second in the (NS). One of the largest vibrations of the latter kind was $2a=1.0$ mm., $T=0.74$ second, direction N 30° E. In the (EW), there were also present vibrations whose average period was 1.3 seconds.

27. Eqke. No. 19. The 4th December, 1897; 9.19.21 a. m. Intensity, *weak*. The maximum H.M. was about 1.6 mm., the V.M. being also present. As the rotation of the record receiving drum was unfortunately not good, further measurement could not be made.

28. Eqke. No. 20. The 8th December, 1897; 5.20.48 p. m. Intensity, *weak*. Two shocks, (a) and (b), of nearly the same range of motion happened one after the other, the time interval between their occurrences being 43 seconds. The origin of disturbance was, like that of Eqke. No. 4 and its after-shocks, situated inland at about 100 km. W of Miyako. (See fig. 4). The total duration of the two shocks was 100 seconds.

(a) First shock. The *preliminary tremor*, whose duration was 11 seconds, and whose amplitude was greater in the (EW) than in the (NS), consisted of ripples of an average period of 0.089 second in the (EW), 0.088 second in the (NS), and 0.08 second in the (V); these movements being superposed on slow undulations of an average period of 1.7 seconds in the (EW), and 1.0 second in the (NS).

The *principal portion*, whose duration was about 12 seconds, consisted of ripples of the following elements :

	(EW)	(NS)	(V)
Maximum $2a$	0.74 mm.	0.9 mm.	0.1 mm.
Average period	0.10 second	0.10 second	0.10 second.

The average period of slow undulations was 1.6 seconds in the (EW), 1.8 seconds in the (NS), and 0.8 second in the (V), one of the maximum movements of this kind, whose period was 1.4 seconds, being :

0.8 mm. towards E, 0.6 mm. towards N, 0.7 mm. upwards.

Resultant $2a=1.2$ mm., direction $E 40^\circ N$, the angle of emergence $=36^\circ$.

In the *end portion*, the average period of the ripples was 0.085 second in the (EW), 0.08 second in the (NS), and 0.09 second in the (V); these being superposed on slow undulations of an average period of 1.7 seconds in the (EW), 0.9 second in the (NS), and 0.4 second in the (V).

(b) Second shock. The *principal portion*, whose duration was 7 seconds, consisted of ripples of the following elements :—

	(EW)	(NS)	(V)
Maximum $2a$:	0.5 mm.	0.6 mm.	0.1 mm.
Average period:	0.088 second	0.082 second	(obscure).

The ripples were superposed on slow undulations, whose average period was 1.6 seconds in the (EW), and whose maximum H.M. = 1 mm., V.M. = 0.2 mm.

In the *end portion*, the average periods were as follows :—

	(EW)	(NS)	(V)
Ripples:	0.074 second	0.077 second	0.079 second.
Slow undulations:	1.5 ,,	0.9 ,,	0.9 ,,

29. Eqke. No. 21. The 23rd December, 1897; 0.29.16 p. m. Intensity, *weak*. The origin was situated at about 70 km. NE of Miyako. The duration was about 35 seconds.

The *preliminary tremor*, whose duration was 3.6 seconds, consisted of very fine ripples of an average period of 0.05 second.

The *principal portion*, whose duration was 3.6 seconds, consisted of movements of the maximum $2a$ of 1.0 mm. in the (EW), and 1.2 mm. in the (NS), the amplitude of motion being nearly equal in the two horizontal components.

In the *end portion*, the motion consisted of ripples superposed on slight slow undulations.

30. Eqke. No. 22. The 26th December, 1897; 3 p. m. Intensity, *slight*. The date is possibly erroneous, there being in the Central Meteorological Observatory no report relating to this earthquake, which was evidently a rather great shock at a distance.

The duration was about 150 seconds.

The *preliminary tremor*, whose duration was 26 seconds, began very gradually and consisted of small slow undulations perfectly free from superposed ripples.

The *principal portion* consisted of slow undulations of an average period of 2.2 seconds, the motion being almost entirely in the (EW). The maximum motion was $2a=0.6$ mm., $T=2.3$ seconds.

The average period of the ripples superposed on the slow undulations in the principal portion was 0.11 second, the maximum $2a$ being 0.2 mm.

31. Eqke. No. 23. The 31st December, 1897; 11.50.28 p. m. Intensity, *slight*. The origin was situated to the ESE of Miyako. The duration was 70 seconds.

The motion, which consisted entirely of slow undulations free from superposed ripples, was about twice as great in the (EW) as in the (NS), V.M. being almost zero.

The *preliminary tremor* was not recorded, having probably been lost on account of its feeble intensity. The maximum motion, which occurred at the commencement, was $2a=1.1$ mm., direction N 60° E.

32. Eqke. No. 24. The 23rd April, 1898; 8.34.13 a. m. Intensity, *strong*. The origin of this extensive earthquake was situated probably at about 200 km. ESE of Miyako.

The duration of the H.M. was about 120 seconds. The V.M. was recorded till 20 seconds from the commencement, when the motion became very large and the pointer went off the record-receiver.

The *preliminary tremor*, whose duration was about 13 seconds, and whose range of motion was greatest in the (NS), consisted of ripples of the following elements:—

	(EW)	(NS)	(V)
Maximum $2a$:	1.2 mm.	1.5 mm.	0.3 mm.
Average period:	0.084 second	0.080 second	0.087 second.

The ripples were, as is usually the case with strong shocks, superposed on slow undulations.

The *principal portion*, whose duration was 19 seconds, was unfortunately vitiated by the proper oscillations of the seismograph pendulums. The average period of the ripples has, however, been measured and found to be 0.11 second in each horizontal component, the elements of the largest ripples being

(First vibration): $2a=6.4$ mm., $T=0.15$ second, direction NE.

(Second vibration): $2a=5.4$ mm., $T=0.18$ second, direction N 30° E.

In the *end portion*, the average period of the ripples was 0.06 second in the (EW); these being superposed on slow

undulations, whose average period was 0.93 second in the (EW), and 0.87° second in the (NS), and whose maximum motion was $2a=3.0$ mm., $T=1.2$ seconds.

33. Eqke. No. 25. The 19th May, 1898; 9.50.40 a. m. Intensity, *very slight*. This was a small local shock, whose origin was at about 43 km. S of Miyako.

The duration was only 10 seconds, the motion consisting entirely of small ripples of an average period of 0.069 second.

34. Eqke. No. 26. The 31st May 1898; 1.3.22 a. m. Intensity, *slight*. The origin was at about 80 km. ESE of Miyako.

The duration of the H.M. was 77 seconds, and that of the V.M. 43 seconds. The motion consisted of small ripples superposed on slight slow undulations, there being no prominent maximum movements.

The *preliminary tremor*, whose duration was 7.7 seconds, consisted of very fine ripples.

The *principal portion* consisted of ripples, whose maximum $2a$ was 0.1 mm. in each component, and whose average period was 0.085 seconds in the (EW), 0.085 second in the (NS), and 0.07 second in the (V); the period of the slow undulations, whose amplitude was very small, being 1.5 seconds in the (EW).

35. Eqke. No. 27. The 3rd June, 1898; 3.22.10 p. m. Intensity, *slight*. This was a small shock, whose origin was at about 52 km. SE of Miyako. The duration was 25 seconds.

The motion was rather greater in the (EW) than in the (NS), traces of the V.M. being also present.

The duration of the *preliminary tremor* was very short, and the maximum motion of 0.4 mm. occurred immediately after

the commencement, the average period being 0.089 second in the (EW), 0.081 second in the (NS), and 0.076 second in the (V).

Summary of Results.

The results are collected in the Table at the end of this paper, to which the following remarks may be prefixed.

36. *The area of earthquake disturbance.*

Of the earthquakes whose exact dates are known, No. 4 and its fore-and after-shocks, namely, Nos. 3, 5, 6, 8, and 19, originated in the mountain regions forming the boundary between the provinces of Rikuchu and Ugo, while the remaining 19 earthquakes all originated under the Pacific Ocean at variable distances from the coast. The isoseismal lines and the areas of disturbance of these earthquakes, the typical ones of which are illustrated in figs. 4, 5, 6, 7 and 8, were generally not circular, but more or less elliptical, with the longer axes parallel to the coast, that is to say, in a direction of N slightly E to S slightly W. In the last column of the Table, therefore, both the greatest and the least radii of propagation are given for each earthquake, the exceptions being Nos. 22, 26, 4, 5, 6 and 10, whose areas of disturbance were nearly circular. The smallest and the greatest among the 25 earthquakes here considered, were respectively No. 24 and No. 9, the radii of propagation of the former being 50 and 65 km. and those of the latter 430 and 700 km.

In those cases in which the earthquakes originated under the Pacific Ocean, the shocks were generally propagated only to an insignificant amount to the western coast of Japan. This is probably due to the seismic waves having been stopped by the heavy mountain masses running through the Main Island.

Propagation along the coast is, however, evidently much favoured by the geological formations, which generally run parallel to the coast. On the other hand, it is also very probable that the epifoci of most of the earthquakes under consideration were not points, but were linear and parallel to the axis of the Island. Thus, the forms of the isoseismal lines in figs. 4 and 5, suggest very naturally that the earthquakes, Nos. 20 and 8 were probably caused by long fissures or faults in the direction of nearly NEN—SWS.

37. *The position of the earthquake origin.*

Of the 25 earthquakes above considered, six originated at distances of 100 to 130 km. to the W or WSW of Miyako, while the remaining nineteen originated under the sea at distances between 40 and 210 km. to the ENE, E, or ESE of the same station. The positions of the nineteen suboceanic origins are included within a circle of about 2° radius, the centre being in long. 143° E, lat. 39° N. This point, which is at about 1° or 110 km. to the E of Miyako, is thus to be regarded as the most active centre of earthquakes disturbing the eastern part of Northern Japan.

As the majority of earthquakes disturbing Miyako, or more generally the eastern coast of Northern Japan, originate under the Pacific, it is to be expected that the shocks will sometimes, like No. 1 and No. 12, be accompanied by sea-waves. It may be that the disturbance of the sea occurs more or less whenever a sufficiently strong shock takes place, either at the sea-bottom itself or at a very small depth below it, so as to give commotion to the water. Of course, the same phenomena may be produced, when a comparatively sudden elevation or depression of the sea-bottom takes place.

38. *The duration of an earthquake.*

It is impossible to measure exactly the total duration of an earthquake, which is of course much longer when instrumentally recorded than when simply felt without such an aid. Again, the duration recorded by an instrument depends on its sensibility. Thus, for instance, the duration of motion in Eqke. No. 23 was, as given in the Table, only 120 seconds; but the duration of the same earthquake in Tokyo, recorded by Omori's Horizontal Pendulum, was 2 hours. The fact is that the ordinary seismographs of the Ewing and Milne and Gray types so widely used in Japan, are capable of registering only the quicker vibrations of an earthquake but insensitive to waves of long period, the latter being very easily obscured by the friction of the instruments.

The total earthquake durations given in this paper, which varied between 8.5 and 200 seconds (see the 3rd column of the Table), are to be regarded as the durations of the sharper vibrations in different earthquakes, namely of those waves causing the greatest effects on our senses.

Speaking generally, the duration of an earthquake will depend both on its magnitude and on the distance of the observing station from the origin. As a rough approximation, let us assume

$$D = \frac{A}{k \pi d},$$

in which $\pi=3.1416$; k is a constant; D , the duration in seconds of an earthquake (less the duration of the preliminary tremor) at a given station; d the distance in kilometres between the origin and the observing station; and A the area of disturbance, in which the intensity of motion is sufficiently strong

to be generally felt without any instrumental aid. The values of the constant k , given in the 6th column of the Table vary within rather wide limits, namely, 4 and 28, but it would be impossible to expect any very perfect agreement between several cases, as, besides the difficulty of accurately measuring the duration, D , the value of the area of disturbance, A , is very apt to be subjected to accidental modifications, the origins being, in the present cases, mostly submarine. The average value of k is 13.6, so that the above equation becomes, for Miyako,

$$D=0.024 \times \frac{A}{d}.$$

Further discussions of this question shall be made in the report on the Tokyo seismometrical observations to be soon published.

39. *The duration of the vertical motion.*

The relation of the duration of the vertical motion, measured in 14 cases, to that of the horizontal, was as follows.

In 5 cases, the durations of the two components were equal to each other; in 1 case, the V.M. lasted longer than the H.M. in the ratio of 1.2:1; and in the remaining 8 cases, the duration of the V.M. was shorter than that of the H.M., the ratios being respectively 0.6:1, 0.8:1, 0.8:1, 0.4:1, 0.5:1, 0.7:1, 0.6:1 and 0.6:1. Taking the average of these 14 cases, the durations of the vertical and the horizontal components were in the ratio of 0.8:1.

40. The duration of the *principal portion* of an earthquake, which is much shorter than that of the whole of it, varied in the present cases, as given in the 5th column of the Table, between 0.7 and 26.0 seconds. The principal portion is generally

well-defined for comparatively near shocks, but often very indefinite for distant ones.

41. The duration of the preliminary tremor, which has been measured in 24 cases, varied between 0 and 26 seconds. As already discussed by one of the present authors,¹ the duration of the preliminary tremor of an earthquake, y (expressed in seconds), at a given station seems to be related to the distance of the latter from the origin, x (expressed in kilometres), by the following linear equation—

$$7.51 y = x - 24.9 \text{ km.} \quad (2)$$

x being assumed to be sufficiently great, say, greater than 100 kilometres, or y greater than 10 seconds. The approximate distances of the epicentres from Miyako have been calculated by means of equation (2) in 11 cases, in which the duration of the preliminary tremor was greater than 10 seconds. These results are given in the 17th column of the Table, while the distances judged from the earthquake maps are given in the 16th column.

It will be observed that the two sets of values given in columns 16 and 17 agree on the whole pretty well with each other. Thus, the mean value of the distances under consideration deduced from eight cases, namely, Nos. 2, 3, 12, 13, 14, 17, 19 and 23, is according to equation (2), 160 km., and according to the method of seismic maps, 180 km.

42. *The period of vibration.* In the Table are given for different earthquakes the complete periods of maximum movements, as well as the average complete periods of vibrations in

1. *F. Omori.* Note on the preliminary tremor of earthquake motion.

the *preliminary tremor*, the *principal portion*, and the *end portion*, with respect to both the ripples and the slow undulations.

The period of the maximum H.M. varied, for slow undulations, between 0.53 and 1.7 seconds; and, for ripples, between 0.12 and 0.15 second. The corresponding period in the vertical motion varied, for slow undulations, between 0.53 and 1.7 seconds, the vertical and the horizontal components having, in most cases, the same period.

With regard to ripples, the period, which was identical in all the three components of an earthquake, became generally a little longer in the principal portion than in the preliminary tremor. Thus, for the latter epoch, the mean value of the average periods which varied between 0.04 and 0.087 second, was 0.08 second; while that of the average periods for the former epoch, which varied between 0.055 and 0.12 second, was 0.10 second. For the end portion, the mean value of the average periods of ripples, which varied between 0.06 and 0.10 second, was 0.08 second, namely the same as in the case of the preliminary tremor. The average period of ripples in the principal portion, which are characterized by their having larger amplitude, is thus seen to be longer than that in the two other portions of the earthquake motion, the difference amounting to 0.02 second.

For the *principal portion*, the mean value of the average periods of horizontal slow undulations, which varied between 0.56 and 1.7 seconds, was 1.3 seconds in the (EW) and 1.0 second in the (NS); while the mean of the corresponding quantities for the end portion, which varied between 0.9 and 1.7 seconds, was 1.3 seconds in (EW), and 0.94 second in the (NS). Thus, for the horizontal slow undulations, the average

period seems to remain approximately constant in the principal and the end portions. These undulations existed more or less also in the *preliminary tremor*, the mean of the average period being 1.1 seconds in the (EW) and 1.0 second in the (NS).

For the V.M., the mean of the average periods of slow undulations was about 0.8 second.

It is remarkable that the average period of ripples remained roughly constant in the different earthquakes here considered, never varying much from 0.1 second. It is possible that these ripples were preceded by, or superposed upon, very minute vibrations of still shorter periods.

43. *The range of motion.* The maximum ranges of motion in different earthquakes are given in the 9th column of the Table. The greatest ripple of 7.4 mm. occurred in Eqke. No. 11, the next greatest of about 5 and 6.4 mm. occurring respectively in Eqke. No. 4 and Eqke. No. 23. The greatest slow undulations, which probably occurred in these two earthquakes, were unfortunately confused by the proper oscillations of the pendulums serving as the "steady masses" of the seismograph. As an example, in which this element of motion was satisfactorily measured, Eqke. No. 3 may be mentioned, the maximum range of motion in question being 9.1 mm.

The range of V.M. was invariably smaller than that of the corresponding H.M., the maximum motions of the two components being, for ripples, in the average ratio of 0.20:1; and for slow undulations, in the average ratio of 0.21:1.

44. *The direction of motion.* The motion in the principal portion was, with the exception of one case or two, always greater in the (EW) than in the (NS). For the preliminary tremor, however, no such peculiarity was found, the ratio of the ranges

of motion in the two horizontal components during this epoch having generally no relation to the corresponding ratio for the principal portion.

The directions of the maximum movements in different earthquakes are given in the 10th column of the Table, from which it will be observed that these were, with the exceptions of Eqkes. No. 5 and No. 16, nearly EW, ESE—WNW or ENE—WSW. (See fig. 9). It will also be seen that the majority of the suboceanic earthquake origins were situated towards the E, ESE and ENE of Miyako, so that we may, in a general way, say that the directions of the maximum earthquake movements were nearly coincident with the directions of the lines joining the observing station with the epicentres. The fact that the origins under consideration were chiefly in the directions of SE or ESE from Miyako, while the majority of the directions of the maximum movements were included between the directions EW and NE—SW, seems to indicate some peculiarity inherent in the region about the observing place, causing the direction of motion in different earthquakes to approach to a certain prevailing direction.

In the cases of nine earthquakes, Nos. 1, 2, 3, 8, 10, 14, 16, 19 and 22, the directions of the maximum movements did exactly, or roughly, coincide with the respective directions of the origins from Miyako; and especially, in three earthquakes, Nos. 8, 11 and 20, the angles of emergence have been measured respectively to be $7^{\circ}.2$, 9° and 36° . Of these three last earthquakes, two, namely, Nos. 8 and 20, were the after-shocks of the Eqke. No. 4; while the remaining one, No. 11, had its origin under the Ocean, towards NE of Miyako. The value of 36° for Eqke. No. 20 was evidently too great, the error being probably

due to its having been obtained, not from the principal portion, but from the preliminary tremor of the earthquake. Omitting this case, we obtain for the focal-depths of the two earthquakes Nos. 8 and 11, respectively the values of 15 and 9 km.

December, 1898.

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Table showing the results of seismographical observations at Miyako.

No.	Date of occurrence.	Total duration, in seconds.	Duration of the preliminary tremor, in seconds.	Duration of the principal portion, in seconds.	Value of k. (See § 38).	Preliminary tremor.		Principal portion.					End portion.		Distance of eqke. origin from Miyako, estimated from seismic maps, in km.	Distance of eqke. origin from Miyako, according to eq. (2), § 41, in km.	Direction of eqke. origin from Miyako.	Greatest and least radii of the area of disturbance, in km.
						Average period of ripples, in seconds.	Average period of slow undulations, in seconds.	Maximum motion, in mm.	Direction of the maximum motion.	Complete period of the max. motion, in seconds.	Average period of ripples, in seconds.	Average period of slow undulations, in seconds.	Average period of ripples, in seconds.	Average period of slow undulations, in seconds.				
1	15th June 1896 7.32.30 p. m.							4.0	E-W						170.		ESE	600×300
2	17th June 1896 0.46.25 p. m.	(H) 56. (V) 56.	13.		20.		(EW) 0.9 (V) 0.6	4.1	W 25° S Angle of emerg. = 4°	1.7		(H) 0.8; 1.4 (V) 1.4		(EW) 1.2 (NS) 1.0	170.	123.	ENE	520×310
3	31st Aug. 1896 4.42.15 p. m.	73.	10.	4.	14.	0.07	(H) 1.4	(H) 9.0 (V) 1.3	S 79° W-N 79° E	(H) 0.94 (V) 0.9		(H) 1.0 (V) 0.9	(EW) 0.09 (V) 0.06	100.	100.	S 80° W	330×70	
4	" 5.09.55 p. m.	100.	5.2	26.	26.		0.8	(Motion not well recorded) ripple: (EW) 3.4 (NS) 3.4			(H) 0.087 (V) 0.064			100.		S 80° W	500×500	
5	" 7.20.52 p. m.	50.	5.7		13.	(EW) 0.05 (NS) 0.04	(H) 0.87	(H) 2.2 (V) 0.3	N 20° W	(H) 0.56 (V) 0.56	0.055	(EW) 0.68 (NS) 0.58 (V) 0.32		110.		W slightly S	250×250	
6	1st Sept. 1896 2.55.15 p. m.	(H) 58. (V) 50.			18.			(EW) 0.4 (NS) 0.1 (V) 0.14						100.		"	280×280	
7	5th Sept. 1896 11.09.25 p. m.	35.			20.			(EW) 3.6 (NS) 3.0 (V) 0.4						130.		ENE	300×300	
8	7th Feb. 1897 4.35.30 p. m.							28.	W 25° S, Angle of emerg. = 7.2°	About 1.2				130.		S 60° W	200×360	
8'								(EW) 0.4 (NS) 0.0 (V) 0.1										
9	20th Feb. 1897 5.49.00 a. m.													220.		SE	430×700	
10	27th March 1897 7.46.43 p. m.	(H) 80. (V) 47.	4.2	24.	16.	0.078		(H) 0.39 (V) 0.08			(H) 0.097 (V) 0.091		(EW) 0.076 (EW) 1.1 (V) 1.5	70.		ENE	240×350	
11	30th April 1897 5.51.15 a. m.	(H) 42. (V) 33.	2.6	0.7	8.	(H) 0.075 (V) 0.07		1.6	NE-SW, Angle of emerg. = 9°	0.12	0.12		(H) 0.081 (V) 0.080	60.		NE	140×140	
12	18th June 1897 1.18.05 p. m.	(H) 50. (V) —	8.5	9.	12.	(H) 0.08 (V) 0.064		7.4	E 30° N-W 30° S		(H) 0.11			90.		SE	170×260	
13	5th Aug. 1897 9.10.47 a. m.	(H) 200. (V) 150.	22.		7.	(EW) 0.07 (NS) 0.06	(NS) 0.8	(EW) — (NS) 1.8 (V) 0.57		(EW) — (NS) 0.74 (V) 0.6	(EW) 0.087 (NS) 0.080 (V) 0.075	(EW) — (NS) 0.82 (V) 0.7		220.	190.	SE	380×650	
14	7th Aug. 1897 9.09.07 p. m.	(H) 150. (V) 60.	23.		4.	(EW) 0.08		(H) 0.9 (V) 0.12	NE	(H) 1.0 (V) 0.8				170.	198.	SE	260×350	
15	16th Aug. 1897 4.53.03 p. m.	(H) 140. (V) 70.	16		9.	(H) 0.083 (NS) 1.0		(Ripple) 0.64 (Slow undulation) (H) 2.8 (V) 0.4		0.12				170.	145.	ESE	350×520	
15'		23.	7.8			0.076		0.2			0.084							
16	23rd Aug. 1897 9.32.56	(H) 100. (V) 70.	11.	9.3		(H) 0.087 (V) 0.086		(H) 2.1 (V) 0.3		(H) 0.14 (V) —	(H) 0.11 (V) —		(H) 0.10 (V) —	(EW) 1.7 (NS) 1.0 (V) 0.8	110.			
16'		23.	0								0.083							
16''		8.5									0.09							
17	27th Aug. 1897 1.06.31 a. m.	(H) 70. (V) 39.	21.		15.			(H) 1.0 (V) 0.1	W 30° N	(H) 1.2		(EW) 1.6 (NS) 0.8		160.	183.	SE	250×520	
17'		26.	0								0.09							
18	2nd Oct. 1897 9.42.03 p. m.	(H) 110	12.5	13.6	16.	(H) 0.07 (V) —	(H) 0.9 (V) —	(Ripple) (H) 1.5 (Slow undulation) (H) 2.3 (V) 1.4	W 15° S W 35° S	(H) 0.12 (H) 1.0	(H) 0.09 (V) —	(H) 1.2 (V) 1.0	(H) 0.06 (H) 0.65; 1.3 (V) —	150.	120.	ESE	380×540	
19	4th Dec. 1897 9.19.21 a. m.							(H) 1.6 (V) —						100.		SE	280×500	
20	8th Dec. 1897 5.20.48 p. m.	100. { 1st eqke. 2nd eqke.	11. 7	12. 7	24.			(Ripple) (EW) 0.74 (NS) 0.9 (V) 0.1 (Slow undul.) 1.2 (H) 1.0 (V) 0.2	E 40° N, Angle of emerg. = 36°	1.4	(H) 0.10 (V) 0.10	(H) 1.7 (V) 0.8	(H) 0.083 (V) 0.09	(EW) 1.7 (NS) 0.9 (V) 0.4 (EW) 1.5 (NS) 0.9 (V) 0.9	100.	100.	W	87×270
21	23rd Dec. 1897 0.29.16 p. m.	35.	3.6	3.6		(H) 0.05		(EW) 1.0 (NS) 1.2 (V) —						70.		NE	210×230	
22		150.	26.					0.6	E-W	2.3?	0.11	2.2?		220.				
23	31st Dec. 1897 11.50.28 p. m.	70.	0					1.1	E 30° N			(EW) — (NS) 1.5				ESE	100×100	
24	23rd April 1898 8.34.13 a. m.	(H) 120. (V) —	13.	1.9	14.	0.084		(One of ripples) (H) 6.5		0.15	(EW) 0.11 (V) —		(EW) 0.06 (H) 0.9	200.	120.	ESE	380×650	
25	19th May 1898 9.50.40 a. m.	10.	0		8.						(EW) 0.069			43.		S	50×65	
26	31st May 1898 1.03.22 a. m.	(H) 77. (V) 43.	7.7		7.						(H) 0.085 (V) 0.07	(EW) 1.5		95.		SE	250×170	
27	3rd June 1898 3.22.10 p. m.	25.	very short.		5.						(H) 0.085 (V) 0.076			52.		SE	80×80	

(H) denotes Horizontal Component
(V) denotes Vertical Component

(EW) denotes EW-component
(NS) denotes NS-component

Fig. 1. The Earthquake of June 17th, 1896; 0. 46. 25 p. m.
(Observed at Miyako).

Multiplication of horizontal motion 5 times, that of vertical motion 10 times.
The beginning of motion is marked *a*.

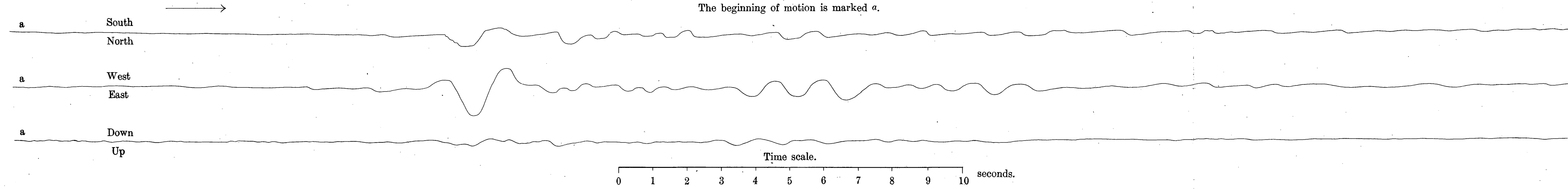


Fig. 2. The Earthquake of August 31st, 1896; 4. 42. p. m.
(Observed at Miyako).

Multiplication of horizontal motion 5 times, that of vertical motion 10 times.
The beginning of motion is marked *a*.

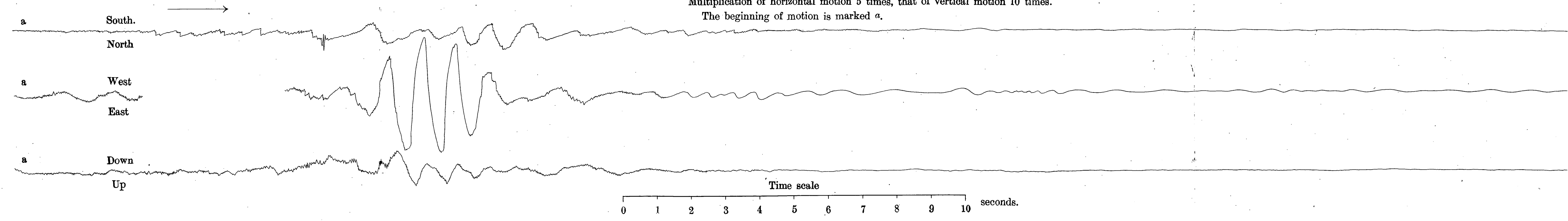


Fig. 3. The Earthquake of April 30th, 1897; 5. 51. 15 a. m.
(Observed at Miyako).

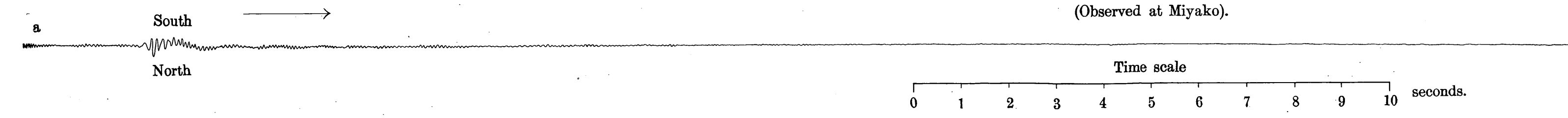
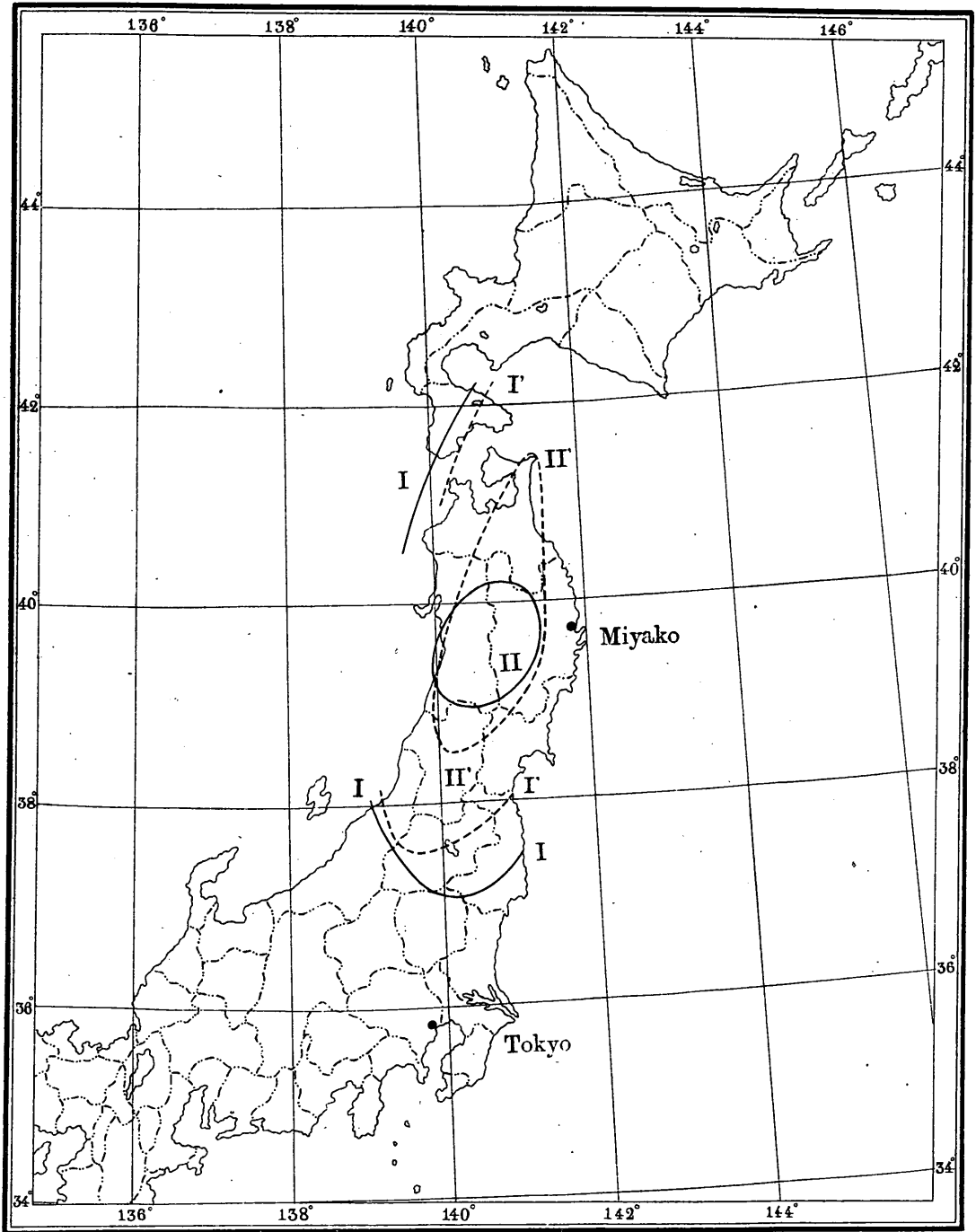


Fig. 4. The Earthquakes of Aug. 31st, 1896, and of Dec. 8th, 1897.

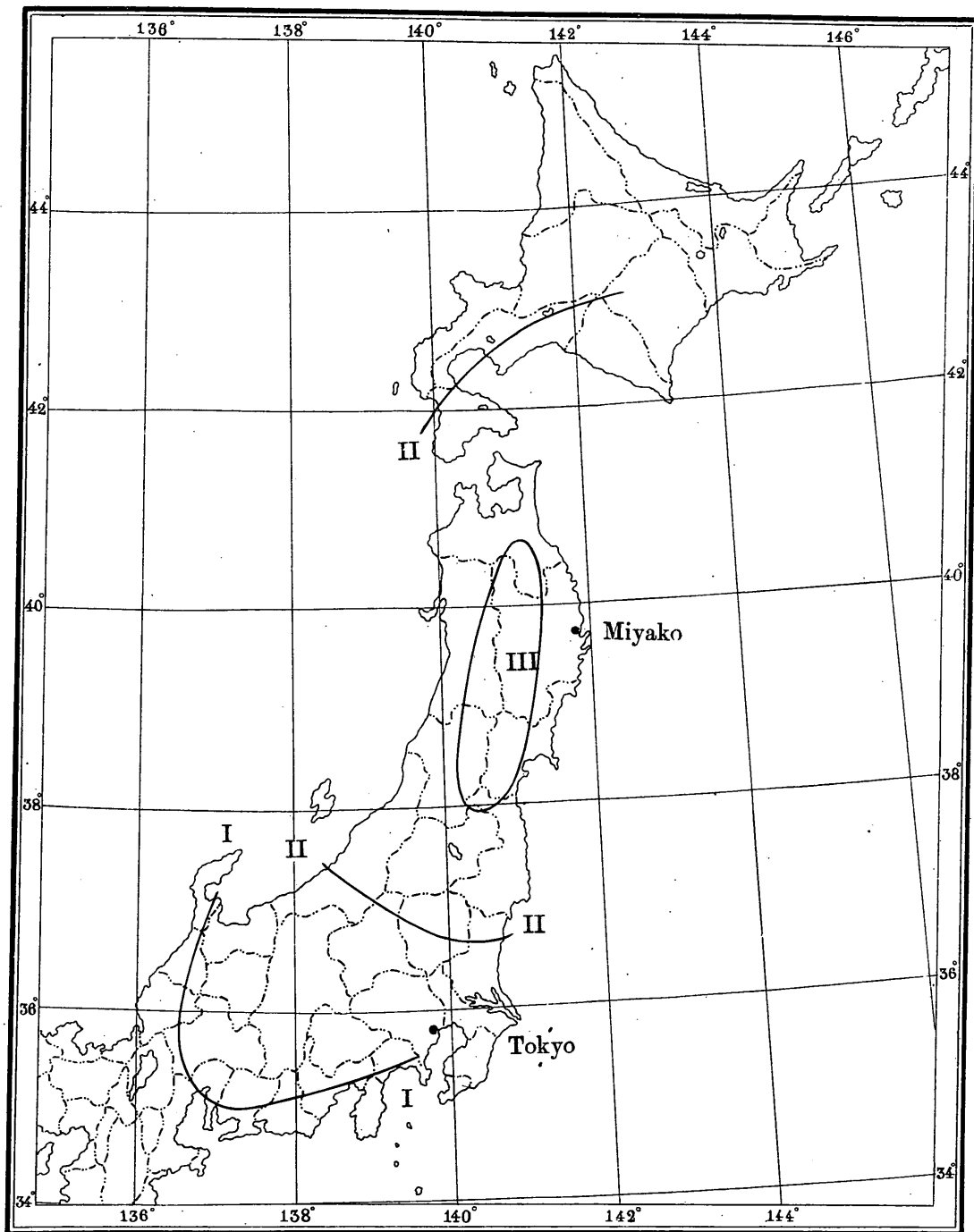


----- Boundary of provinces.

Full curves, I and II, refer to the eqke of Aug. 31st, 1896, and dotted curves, I' and II,' to that of Dec. 8th, 1897.

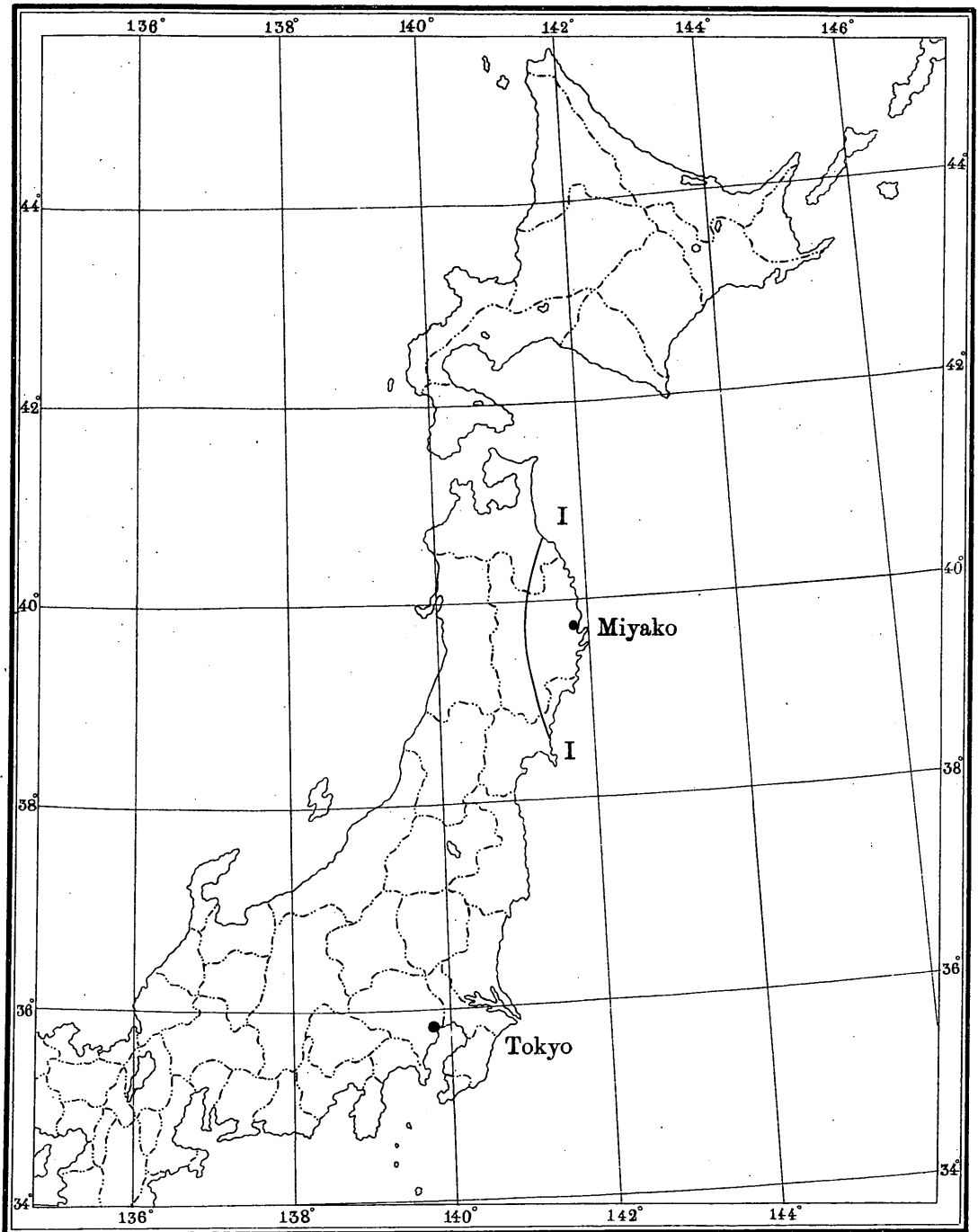
I, I', Boundary of the area of slight motion.
 II, II,' " " " " " strong "

Fig 5. The Earthquake of February 7th, 1897.



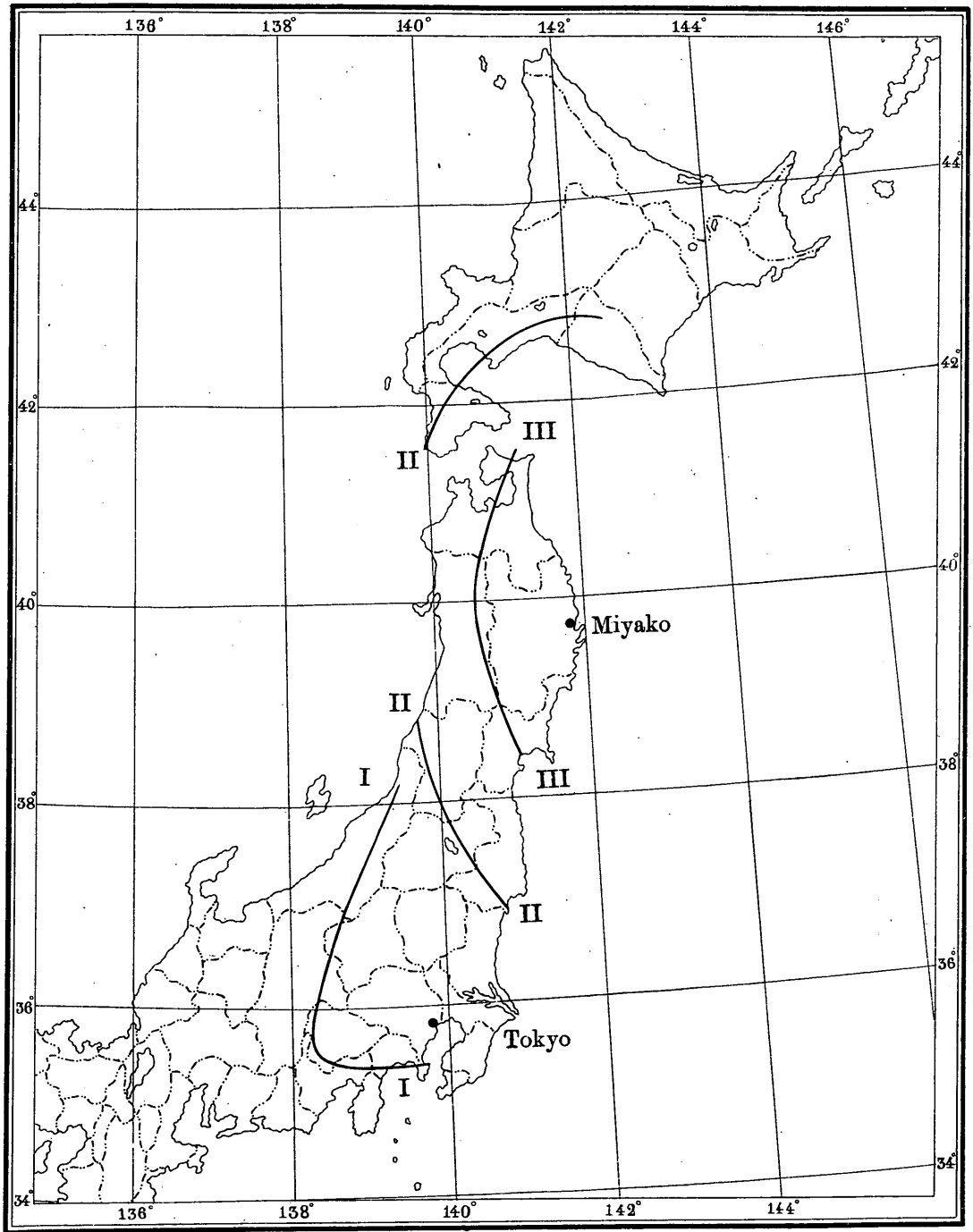
----- Boundary of provinces.
 I, Boundary of the area of slightest motion.
 II, " " " " slight " "
 III, " " " " strong "

Fig. 6. The Earthquake of April 30th, 1897.



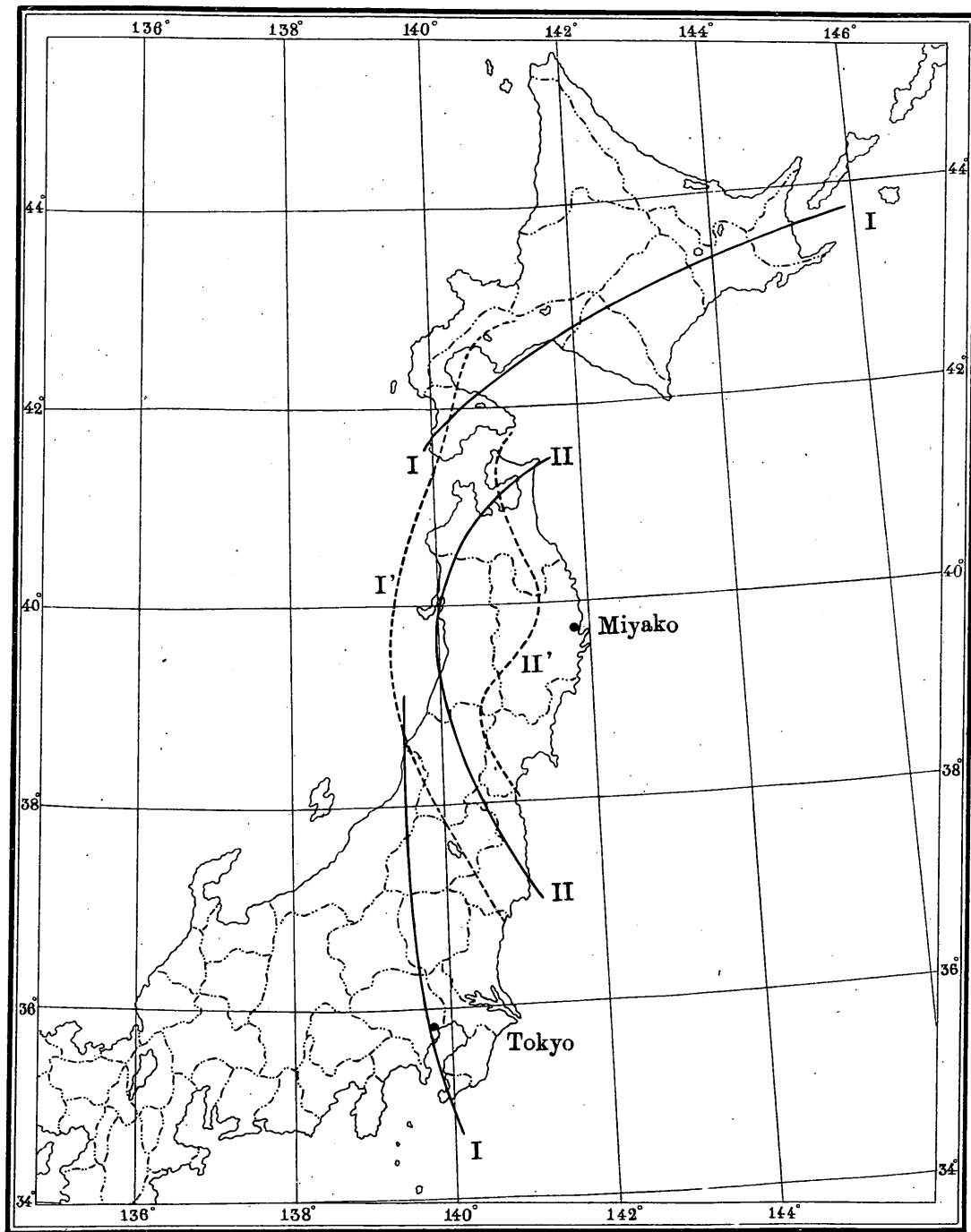
----- Boundary of provinces.
I, Boundary of the area of slight motion.

Fig. 7. The Earthquake of March 27th, 1897.



----- Boundary of provinces.
 I, Boundary of the area of slightest motion.
 II, " " " " " slight "
 III, " " " " " weak "

Fig. 8. The Earthquakes of June 15th and 17th, 1896.

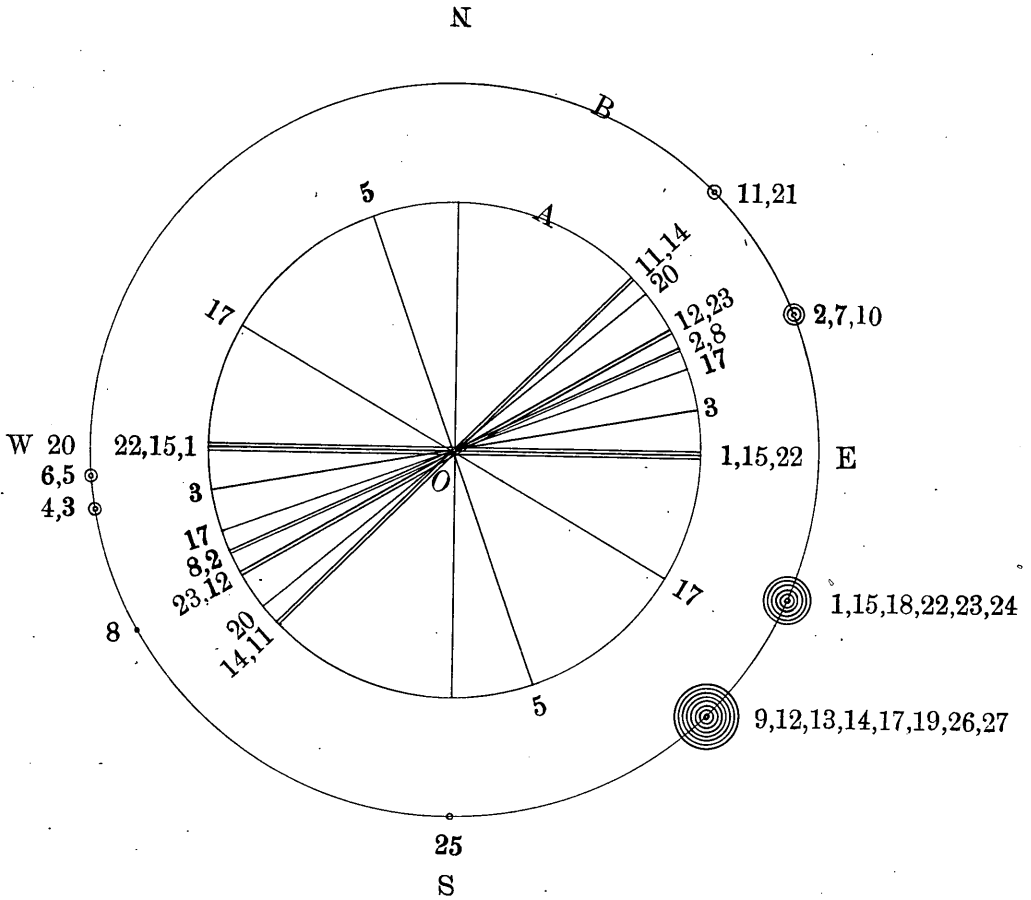


----- Boundary of provinces.

Full curves, I and II, refer to the eqke of June 15th, and dotted curves, I' and II', to that of June 17th.

I, I', Boundary of the area of slight motion.
 II, II', " " " " weak "

Fig. 9.—Diagram showing the directions of maximum movements in the different earthquakes at Miyako.



Note.—The diameters of the inner circle, A, indicate the directions at Miyako of maximum movements in the different earthquakes; and the points or small circles on the circumference of the outer circle, B, indicate the azimuthal positions of the earthquake origins, the central point, O, being supposed to represent Miyako. The numbers are the same with those of earthquakes as given in the List, § 2.