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Summary of Results.

Note on the Diagram of the Earthquake of June 7, 1904.

BY

F. OMORI, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates I and II.

1. The earthquake of June 7, 1904, whose time of occurrence in Tokyo was 5h 19m 29s p.m., had a wide area of disturbance, having been felt nearly along the whole Pacific coast of Japan, that is to say, from Nemuro on the north-east to the Shikoku Island on the south-west. Judging from the duration of the preliminary tremor at Tokyo and from the isoseismal lines (Pl. I), the origin of the earthquake was at a distance of about 460 km to the N 55° E of Tokyo, namely, at *lat.* 38° N and *long.* 144°¼ E. The ordinary seismograph observation at the Central Meteorological Observatory was as follows :—

Total duration. 5 minutes.

Maximum horizontal motion. Double amplitude = 1.6 mm ; complete period = 1.0 sec.

Direction of max. hor. motion. SWS-NEN.

Intensity. "Weak."

Character. Gentle.

Remark. The earthquake began with gentle shakings and the preliminary tremor lasted 56 sec. The above mentioned maximum motion occurred 6 sec. after the commencement of the principal portion. The vibrations were more or less active for about 1 m.

2. *Horizontal Pendulum Observation at the Seismological Institute.*

Pl. II shows the earlier portion of the EW component diagram of the

earthquake obtained at the Seismological Institute (Hongo, Tokyo) by means of a horizontal pendulum, whose multiplication was 15 and whose free period of oscillation was 62 sec. In the following description of the seismogram, $2a$ denotes the range, or the double amplitude, of a vibration.

The preliminary tremor, whose duration was 58 sec., began with a vibration, whose period was 6.2 sec.,* and whose two displacements were as follows:—

1st motion.....0.37 mm, toward W;

2nd motion.....0.57 mm, toward E.

Then there followed 7 nearly equal vibrations, which together lasted 45 sec. and had an average period of 6.4 sec.; the maximum $2a$ being 0.63 mm. These were superposed by quick vibrations of macro-seismic character, whose maximum $2a$ was 0.43 mm.

The principal portion began with a displacement of 1.2 mm toward W, followed by a counter motion of 3.2 mm toward E. The next vibration, which occurred 1m 0s from the commencement of the earthquake, was a maximum motion and had the greatest $2a$ of 3.7 mm. The next 5 vibrations, whose average period was 6.7 sec., gradually diminished in amplitude; the max. $2a$ of the superposed quick vibrations being 0.93 mm. At 1m 47s after the commencement of the earthquake, there occurred another maximum, which had the absolutely greatest $2a$ of 4.2 mm, the period being 6.8 sec. The 3rd and 4th maximum vibrations, whose $2a$'s were 3.7 and 2.7 mm, occurred respectively 2m 5s and 2m 46s after the commencement of the earthquake; the period in the later part of the principal portion being 6.4 sec.

The average periods deduced from two successive series each of 50 vibrations, between 6s and 11m 6s after the commencement of the earthquake, were respectively 6.4 and 6.8 sec.; the period thus remaining practically constant throughout the earthquake.

3. What is here to be particularly noted is that the seismogram

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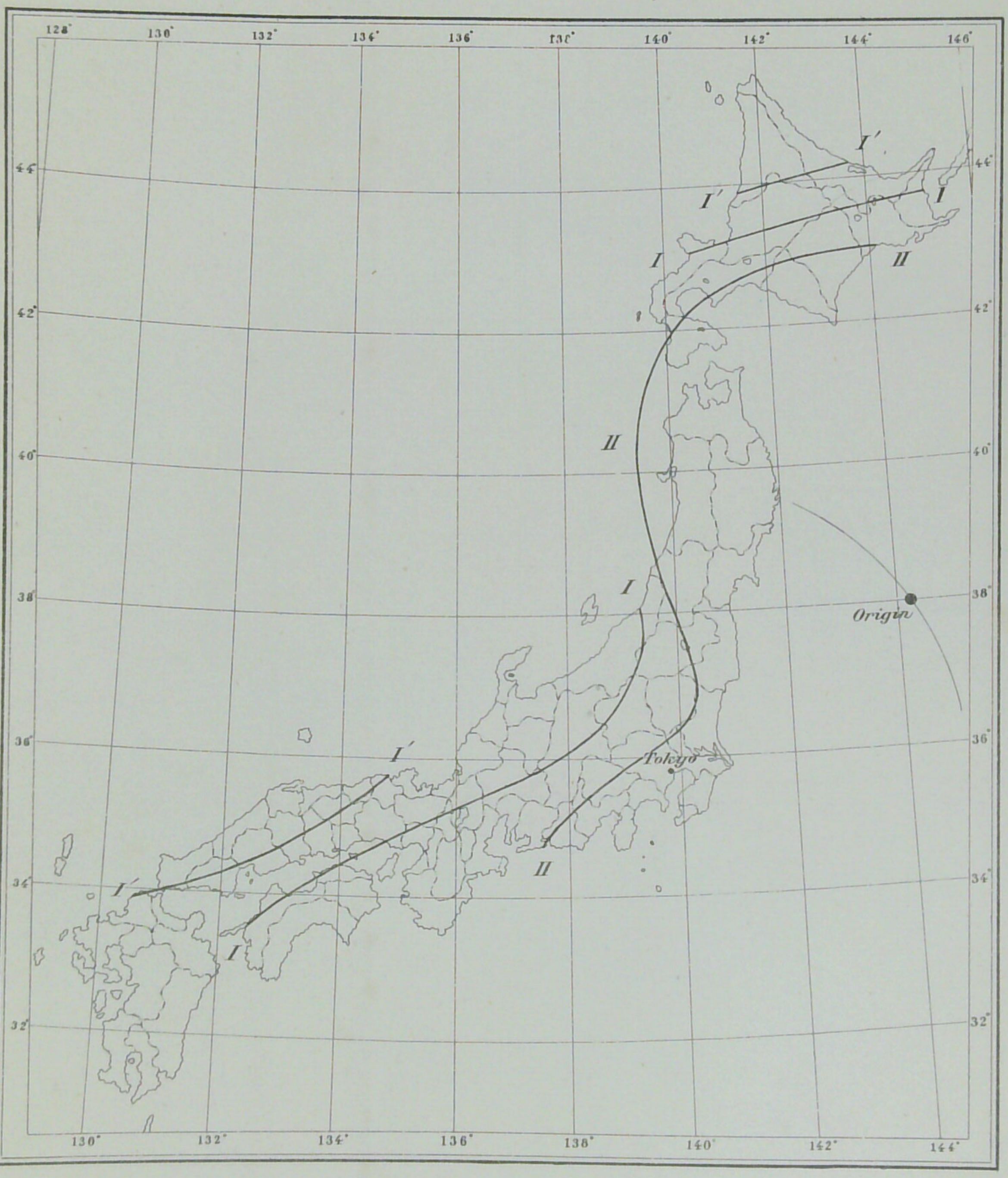
* The term "period" is always used in the sense of the "complete period."

clearly indicates the occurrence of a slow vibration at the very beginning of the earthquake; quick movements of macro-seismic nature appearing a few seconds later on. Similar characteristic is to be seen more or less distinctly in earthquakes, which are not quite local. This fact may be taken as indicating that the smallest and quick-period vibrations do not necessarily possess the highest velocity of propagation. On the contrary, the very first vibration of the earthquake motion must probably be of a nature similar to the pulsatory oscillation; the latter being the predominating component in the preliminary tremor of the distant earthquake motion.

Tokyo. Jan., 1905.

Earthquake of June 7, 1904; 5h 19m 29s p m.

I′ I′ .....Boundary of area of slight *unfelt* motion.
I I ..... „ „ "slight" motion.
II II ..... „ „ "weak" „



Boundary of provinces.

Horizontal Pendulum Diagram obtained during a Storm.

BY

F. OMORI, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates III-V.

1. Pl. III is a half size reproduction of the diagram given by an EW component horizontal pendulum during about $24\frac{2}{3}$ hours from the 10th, 10h 5m a.m., to the 11th, 10h $44\frac{1}{2}$m a.m., Oct. 1904. The instrument, which is set up in the brick "Earthquake-proof House" in the University Compound (Hongo, Tokyo), has the following specifications :—

Length of the strut, or the horizontal distance between the pendulum axis and the centre of the heavy bob $=L=75$ cm;

Period of the pendulum when suspended vertically $=T_0=1.74$ sec.;

Period of the horizontal pendulum as actually set up $=T=33$ sec.;

Multiplication ratio of the recording pointer $=n=20$;

1 mm displacement of the writing index, or r,

$$=L\times n\times \sin 1''\times \frac{T^2}{T_0^2}=0.''0385.$$

2. ***The weather on the 10th and 11th at Tokyo.*** The barometric pressure* was 770 mm at 10 p.m., on the 9th, thence gradually decreasing to 758.2 mm at 4 p.m., on the 10th. The pressure, which reached the minimum of 757.5 mm at 6 o'clock on the

* With temperature, gravity, and sea-level corrections.

latter day, remained low and less than 758 mm till the midnight. Thereafter the pressure began to increase, reaching the maximum value of 776.8 mm at the midnight of the following day. The wind velocity, which was on the morning of the 10th between about 8 and 10 metres per second, increased at 3 p.m. to 12.6 metres per sec. and reached the maximum value of 14.8 metres per second, at 7 p.m. on the same day. The velocity remained greater than 13.7 metres per sec. till 10 p.m., thence gradually decreasing to 1.6 metres per sec. at 7 a.m. on the following morning. The hourly values of the pressure and wind velocity during Oct. 10th and 11th, were as follows.

BAROMETRIC PRESSURE AND WIND VELOCITY AT TOKYO.
OCT. 10 AND 11, 1904.

Hour.	Barometric Pressure.		Wind Velocity.		Hour	Barometric Pressure.		Wind Velocity.	
	10th	11th	10th	11th		10th	11th	10th	11th
	mm.	mm.	m/sec.	m/sec.		mm.	mm.	m/sec.	m/sec.
1 a.m.	767.3	757.3	6.5	6.5	1 p.m.	761.1	761.2	8.8	9.7
2 „	66.6	57.8	6.3	4.8	2 „	59.4	61.3	9.4	9.4
3 „	66.6	58.1	7.4	5.9	3 „	58.4	61.7	12.6	9.0
4 „	65.1	58.5	8.5	3.9	4 „	56.9	62.3	11.9	6.1
5 „	65.5	59.1	8.1	3.5	5 „	56.5	63.2	13.9	4.6
6 „	65.0	59.6	8.1	2.4	6 „	56.2	63.9	13.0	2.4
7 „	65.4	60.7	9.0	1.6	7 „	56.6	64.5	14.8	2.8
8 „	64.4	61.1	9.9	1.8	8 „	56.6	64.9	14.6	1.5
9 „	64.0	61.5	9.4	2.8	9 „	56.7	65.4	14.3	0.9
10 „	62.4	61.5	9.4	6.1	10 „	56.7	65.4	13.7	0.9
11 „	62.1	61.4	9.2	8.5	11 „	56.7	65.4	10.3	1.1
Noon	61.7	61.3	10.1	8.5	Midnight	56.7	65.5	9.9	1.1
					Mean.	761.02	761.77	10.38	4.41

It will be observed that the fall of the barometric pressure during the 10th and 11th was 12.5 mm, while the maximum wind velocity was 14.8 metres per sec., so that the storm on these two days was

not one of exceptional violence. The precipitation on the 10th was, however, very great, amounting to 126.1 mm. On the 11th there was practically no precipitation.

As shown in Pls. IV and V, the positions of the low pressure centre at 7 p.m. and at 11 p.m. on the 10th were respectively at distances of 250 km to the SE, and 350 km to the ESE, from Tokyo; the cyclone having thus travelled, within the two above-mentioned hours, in an north-easterly direction and to the east of the place of observation.

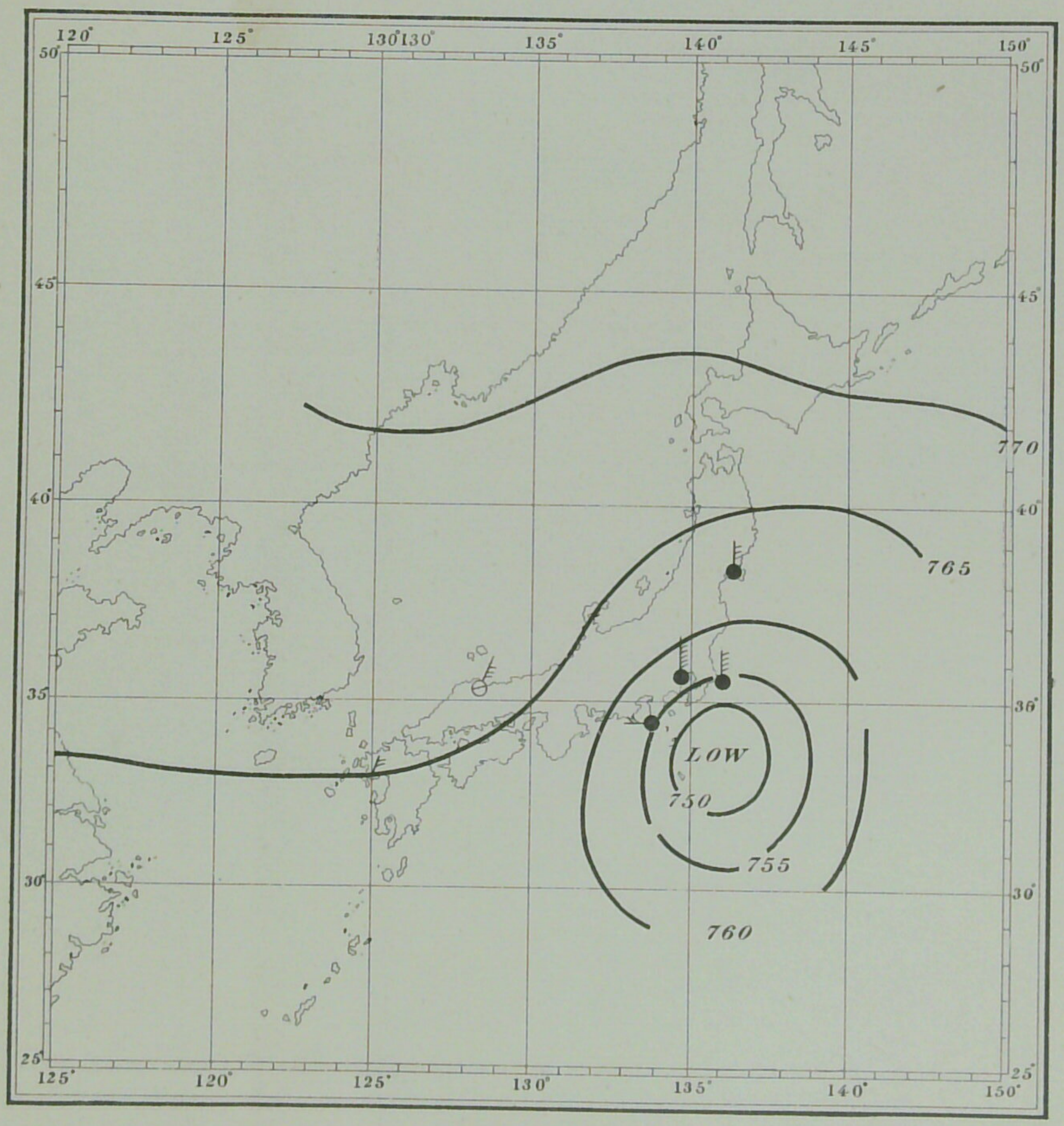
3. ***Tilting of the ground.***—According to Pl. III, the inclination of the ground toward the east, which began on the morning of the 10th, greatly increased at 7 p.m. and reached the limit at about 10h 15m p.m. on the same day. Thence began the inclination in the opposite sense, which continued till about 4h 40m a.m. on the 11th. The extreme amount of the inclination during these 10 hours amounted on the original diagram to 93 mm, which corresponds to an angular motion of about $3''\frac{1}{2}$. On the 11th, there was practically no tilting motion between 4h 40m a.m. and 7h 25m a.m. After the latter epoch, there began a slight inclination toward the west, till at 10 a.m., when the index of the tiltometer returned nearly to the same position as at the same hour on the preceding day.

It will thus be seen that the marked inclination of the ground toward the east occurred during those hours when the barometric pressure was low and the wind was strongest, the ground having regained its original position with the rise of the barometre. A fact to be noted in this connection is that the low pressure centre which caused the eastward inclination, pased to the east of Tokyo. Now it might be supposed that the ground, when subject to a fall of the pressure, will be elevated by a certain amount so as to adjust itself to equilibrium. If such be true, the inclination of the ground during the passage of the cyclone under consideration ought to have been directed toward the west, which was not the case. The explanation of this apparently anomalous phenomenon is probably to be found in the accumulation of

sea waters under the low pressure centre to a degree greater than the amount of the diminution of the atmospheric pressure, thereby creating an increase in the resultant pressure at the sea bottom.

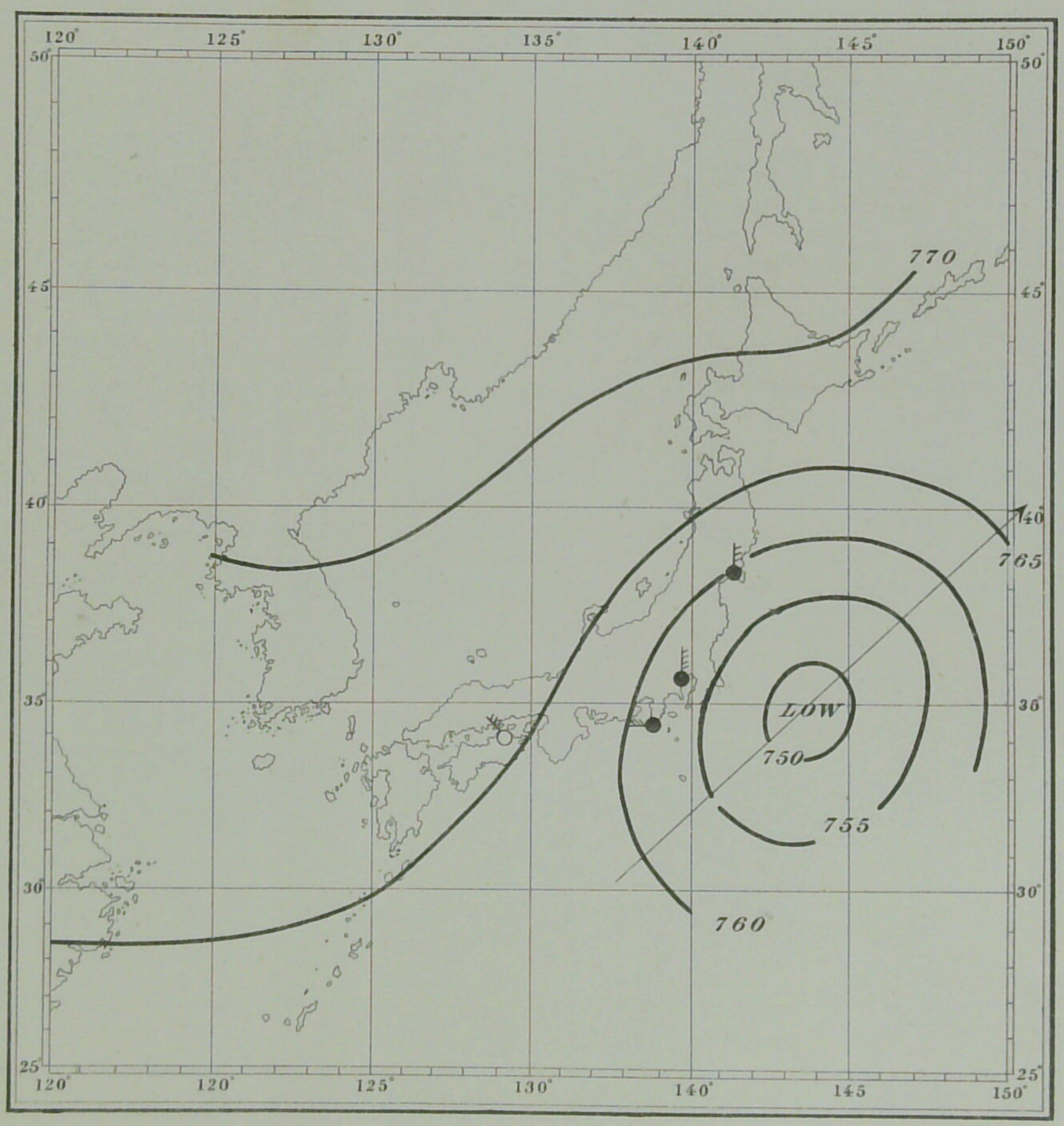
Tokyo. Jan., 1905.

Position of the Low Pressure Centre at 7 p.m., Oct. 10, 1904.



Position of the Low Pressure Centre at 11 p.m., Oct. 10, 1904.

The arrow indicates the path of the centre.



Horizontal Pendulum Observations of Earthquakes in Tokyo: Similarity of the Seismic Motion originating at neighbouring Centres.

BY

F. OMORI, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates VI—XXXIX.

I. INTRODUCTION.

1. As is well known, the duration of the preliminary tremors of an earthquake at a given station depends on the distance of the latter from the origin of disturbance. Now an examination of numerous diagrams obtained in Tokyo shows further that the seismic disturbances proceeding from a given locality or neighbouring places are in many cases almost similar to one another, in such a way that individual vibrations can be identified in the different diagrams.

2. The seismograms described in the following pages, which are intended to be the first series of the kind, are some of the typical horizontal pendulum records obtained in Tokyo between 1898 and 1904. The different earthquakes are provisionally divided into the following nine groups:—

(i) Local earthquakes, or those whose origin was in the vicinity of Tokyo, say, at an epicentral distance of under 100 km.

(ii) Earthquakes which originated in the province of Echigo.

(iii) Earthquakes which originated off the southern coast of the peninsula of Izu.

(iv) Earthquakes which originated off the north-eastern coast of the Main Island, or off the south-eastern coast of Hokkaido.

(v) Kyushyu and Ōshima (Lyu Kyu) Earthquakes.

(vi) Ceram and New Guinea Earthquakes.

(vii) Alasca Earthquakes.

(viii) Central America Earthquakes.

(ix) Asia Minor and Balkan Earthquakes.

The above classification is by no means exhaustive, my present object being simply to give some of the more important examples.

3. The seismograms were obtained mostly from the three horizontal pendulums set up in the "Earthquake-proof House" in the University Compound at Hongo. The specifications of the different pendulums,* which I shall denote as *A*, *B* and *C* instruments, are as follows.*

Instrument A: EW component.

Period of free oscillation = 28 sec.

Multiplication of the pointer = 10.

Weight of the heavy bob = 14 kg.

Length of the horizontal strut = 1m.

Vertical distance between the point of support and the point of suspension = 2.5m.

Instrument B: NS component.

Period of free oscillation = 17 sec.

Multiplication of the pointer = 8.2.

(In other particulars *B* was exactly similar to *A*.)

Instrument C: EW component.

Period of free oscillation = 120 sec.

Multiplication of the pointer = 10.

Weight of the heavy bob = $7\frac{1}{2}$ kg.

Length of the horizontal strut = 1m.

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* These three instruments as well as the pendulum *D* noted below are the same as those referred to in the *Publications*, No. 5.

Vertical distance between the point of support and the point of suspension = 2.5m.

The period of free oscillation of the *C* instrument was changed in July 1900 to 62 sec., while its heavy bob was replaced in Dec. 1901 by another whose weight was 44 kg., the multiplication ratio of the pointer being at the same time increased to 15. The *B* instrument was substituted in Feb. 1902 by another similar in construction to the improved form of the *C* instrument; the period of free oscillation being raised to 48.5 sec. and the multiplication ratio of the pointer to 20.

In a few cases, the description refers to the diagrams given by a horizontal pendulum apparatus at Hitotsubashi, also in Tokyo, whose construction is as follows.

Instrument D: EW component.

Period of free oscillation = 29.7 sec.

Multiplication of the pointer = 8.4.

Weight of the heavy bob = 6.4 kg.

Length of the horizontal strut = 75 cm.

Vertical distance between the point of support and the point of suspension = 75 cm.

4. In the following pages, the times are given in the 1st Normal Japan Time, or that of *long.* 135° E.

The *intensity* of the ordinary, or non-destructive, macroseismic motion is indicated in the usual way as *slight*, *weak*, or *strong*. A *slight* shock is one which is very feeble; a *weak* shock is one whose motion is moderately severe but not so intense as to cause general alarm; and finally a *strong* shock is one which is sufficiently sharp and causes some small damage such as stopping of pendulum clocks, overflowing of liquids, throwing down of articles from shelves, slight cracking of walls, falling down of roof tiles, etc.

The notations $2a$ and T denote the two elements of the earthquake motion, as follows:—

$2a$ = Range of motion, or double amplitude of the vibration;

T = Complete period of vibration.

In many cases I have given the average value of T, or the mean period deduced from a number of similar consecutive vibrations in the different portions of the earthquake motion.

II. LOCAL EARTHQUAKES.

5. Pl. VI gives the earlier portions of the EW component (*A* instrument) diagrams * of the following six local earthquakes:—

Eqke.	Date.	Time of occurrence at Hongo (Tokyo).	*Intensity* of motion in Tokyo.
		h m s	
No. 1	April 23, 1901.	3 8 30 a.m.	*Weak.*
No. 2	June 23, 1902.	7 42 42 a.m.	,,
No. 3	Dec. 31, ,,	2 38 58 p.m.	,,
No. 4	Aug. 4, 1904.	9 49 17 p.m.	,,
No. 5	April 5, 1902.	7 23 12 p.m.	,,
No. 6	,, 6, ,,	2 13 30 a.m.	,,

The position of the origin and the area of disturbance of each of these six earthquakes, whose isoseismal lines are shown in Pls. VII to XII, are given in the following table.

* Owing to the violence of motion, the *steady mass* of the horizontal pendulum was throwu in each case more or less into its own oscillations, which can, however, easily be recognized, the period being about 30 sec.

TOKYO LOCAL EARTHQUAKES.

Eqke.	Position of earthq. origin.*				Dimensions, and direction of the longer axis, of		
	Latitude. N.	Long. E.	Distance from Tokyo.	Direction from Tokyo.	*Strong* motion area.	*Weak* motion area.	*Slight* motion area.
			km		km km	km km	km km
No. 1	35°29′	139°44′	13	S15°E	118×255 (N20°E–S20°W)	325×650	440×830
No. 2	35°26′	139°50′	37	S14°E	170×100 (N26°E–S26°W)	360×360	520×520
No. 3	35°59′	139°55′	53	N28°E	152×80 (N20°E–S20°W)	275×300	580×580
No. 4	35°43′	139°54′	14	E	79×40 (N15°W–S15°E)	180×115	280×270
No. 5	35°26′	139°45′	30	S	50×15 (N—S)	135×98	265×265
No. 6	35°31′	139°49′	23	S16°E	—	140×80 (N20°E-S20°W)	260×180

The first three earthquakes, whose areas were extensive, were the severest local shocks in recent years. Again the four earthquakes, Nos. 1, 2, 5 and 6, originated in the Tokyo Bay, while the two remaining ones had inland origins.

6. A glance at Pl. VI shows that all the seismograms are very similar to each other, the preliminary tremor being followed in each case by a sudden single prominent maximum vibration, whose period varied, with a single exception, between 2.1 and 3.5 sec. The amplitudes and the periods of these vibrations were as follows.

* The position of the origin has in each case been inferred from the isoseismal lines.

Earth-quake No.	Maximum Vibration.				Total duration of the 1st and 2nd preliminary tremors
	1st displacement. (Motion toward E).	2nd displacement. (Motion toward W).	Ratio of 2nd to 1st displ.	Complete period of vibration.	
	mm.	mm.		sec.	sec.
1	4.2	6.9	1.65	3.5	13
2	5.7	7.0	1.23	3.5	9
3	2.6	3.0	1.15	2.1	7
4	2.3	2.9	1.26	3.1	9
5	1.5	1.8	1.20	2.1	8
6	0.85	1.1	1.29	(Quick).	8
			(*mean.*) **1.30**		

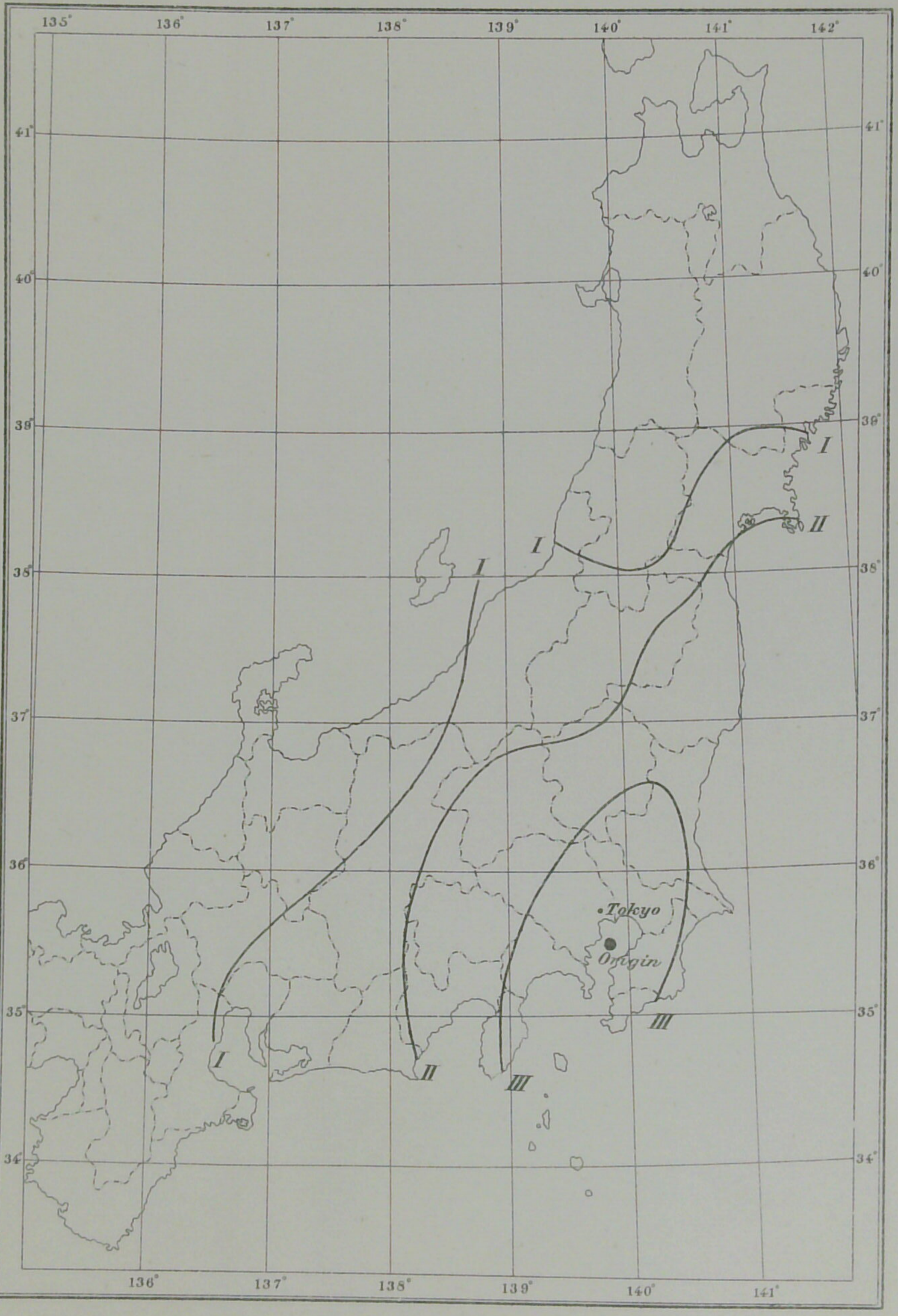
Thus it will be seen that in these local earthquakes, the 1st displacement of the maximum vibration was, irrespective of the variation in the position of the epicentre directed always toward E. The initial movement was thus directed, in so far as the EW component is concerned, *toward* the origin of disturbance; the counter, or the greatest, displacement being consequently directed toward W, or away from the origin. The 1st displacement is to be regarded as a *single* amplitude, and the 2nd one as the double amplitude. The latter displacement was, however, not equal to twice of the former, the mean ratio of the two displacements being only as 1·3 : 1. This fact seems to show that the elasticity of the ground is not perfect with respect to the vibrations of this nature.

The durations of the preliminary tremors of the six earthquakes varied between 7 and 13 sec. The discussion of the duration of the preliminary tremor in relation to the epicentral distance and the focal depth of a local earthquake is reserved for a future occasion.

7. The ordinary seismograph observations at the Central Meteorological Observatory of some of the earthquakes considered above were as follows.

Fig. 7. Earthquake of April 23, 1901 ; 3h 8m 30s a.m.

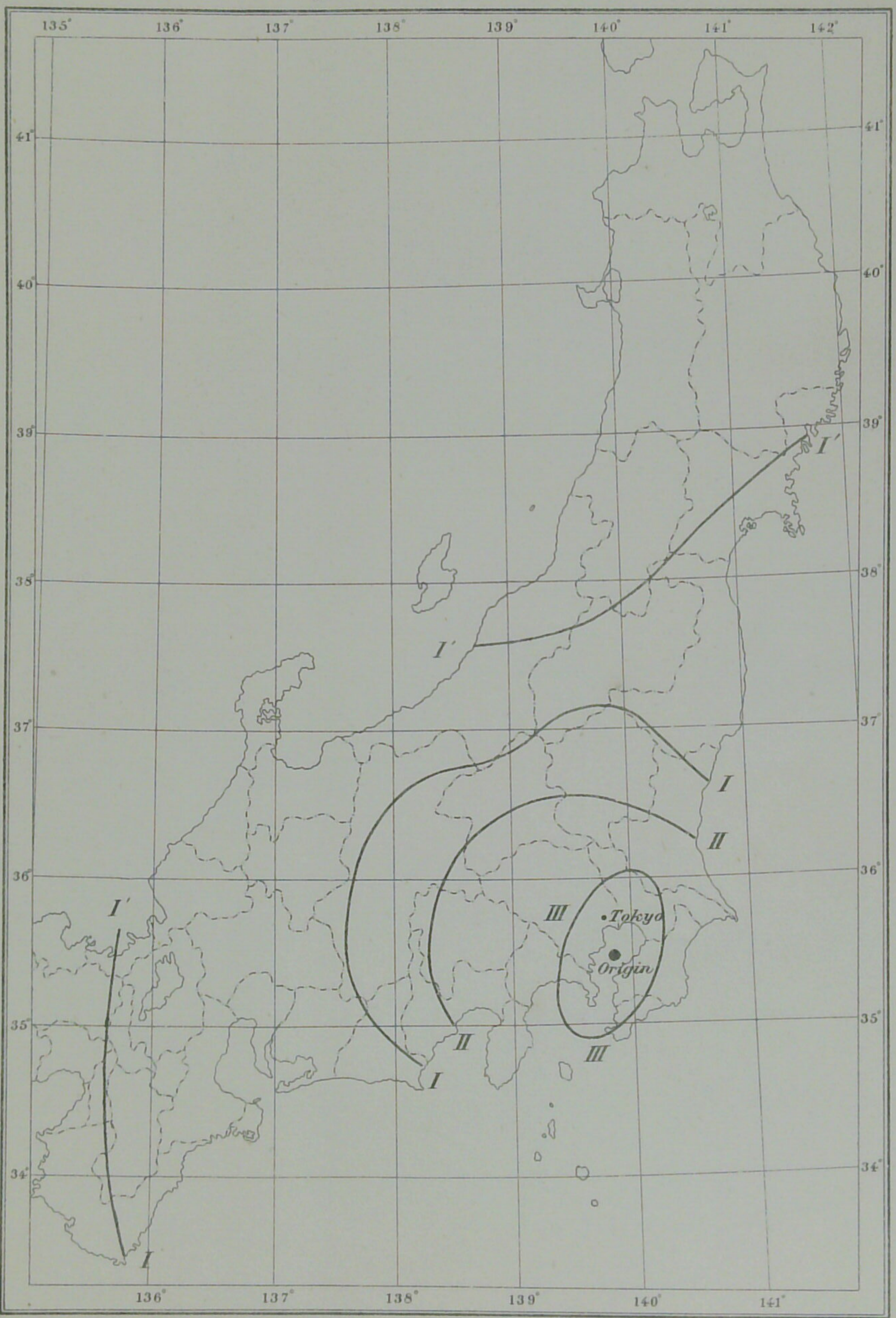
I I ... Boundary of area of "slight" motion.
II II .... " " "weak" "
III III ..... " " "strong" "



Boundary of provinces.

Fig. 8. Earthquake of June 23, 1902 ; 7h 42m 42s a.m.

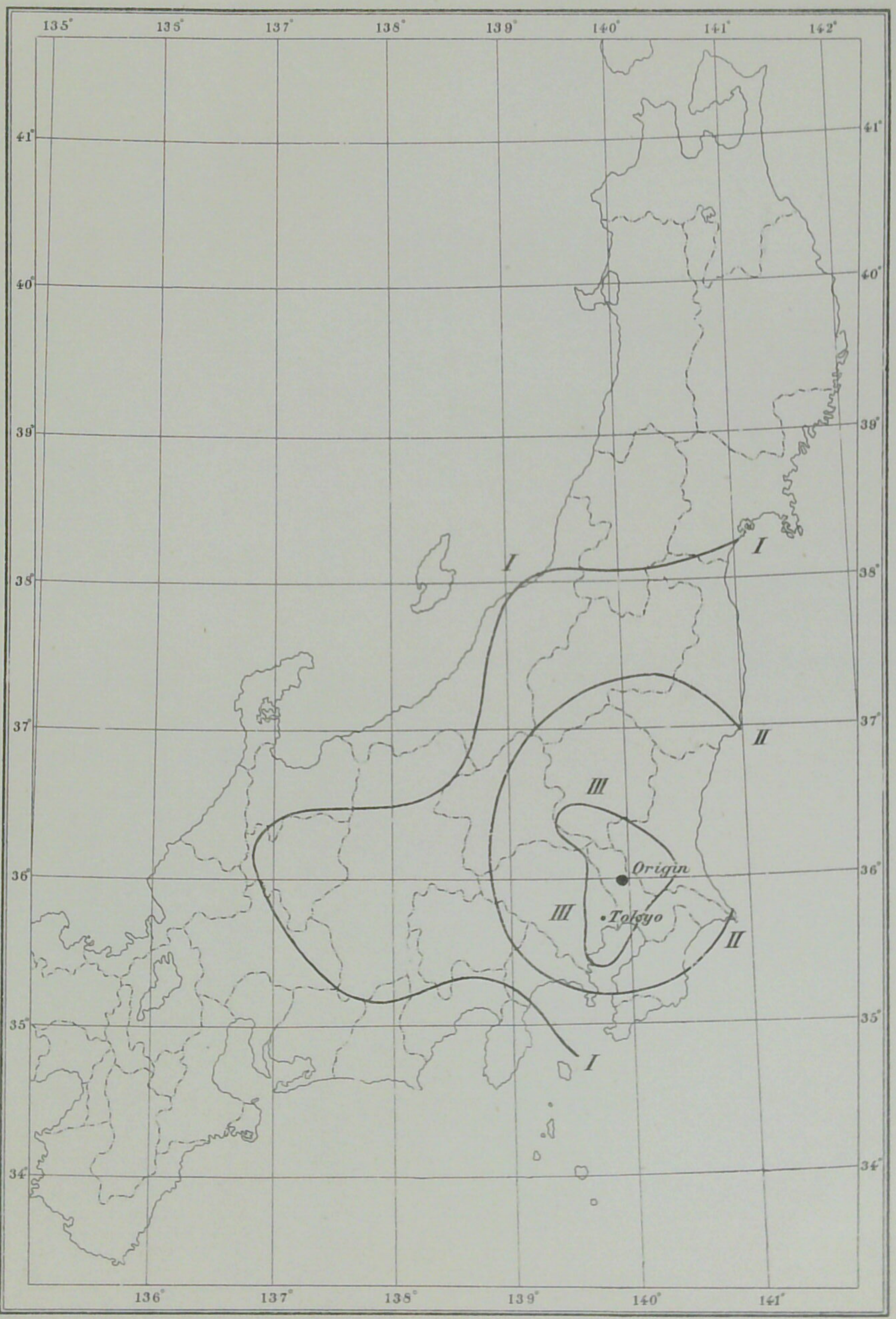
I′ I′ ..... Boundary of area of slight *unfelt* motion
I I ..... „ „ "slight" motion.
II II ..... „ „ "weak" „
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 9. Earthquake of Dec. 31, 1902 ; 2h 38m 58s p.m.

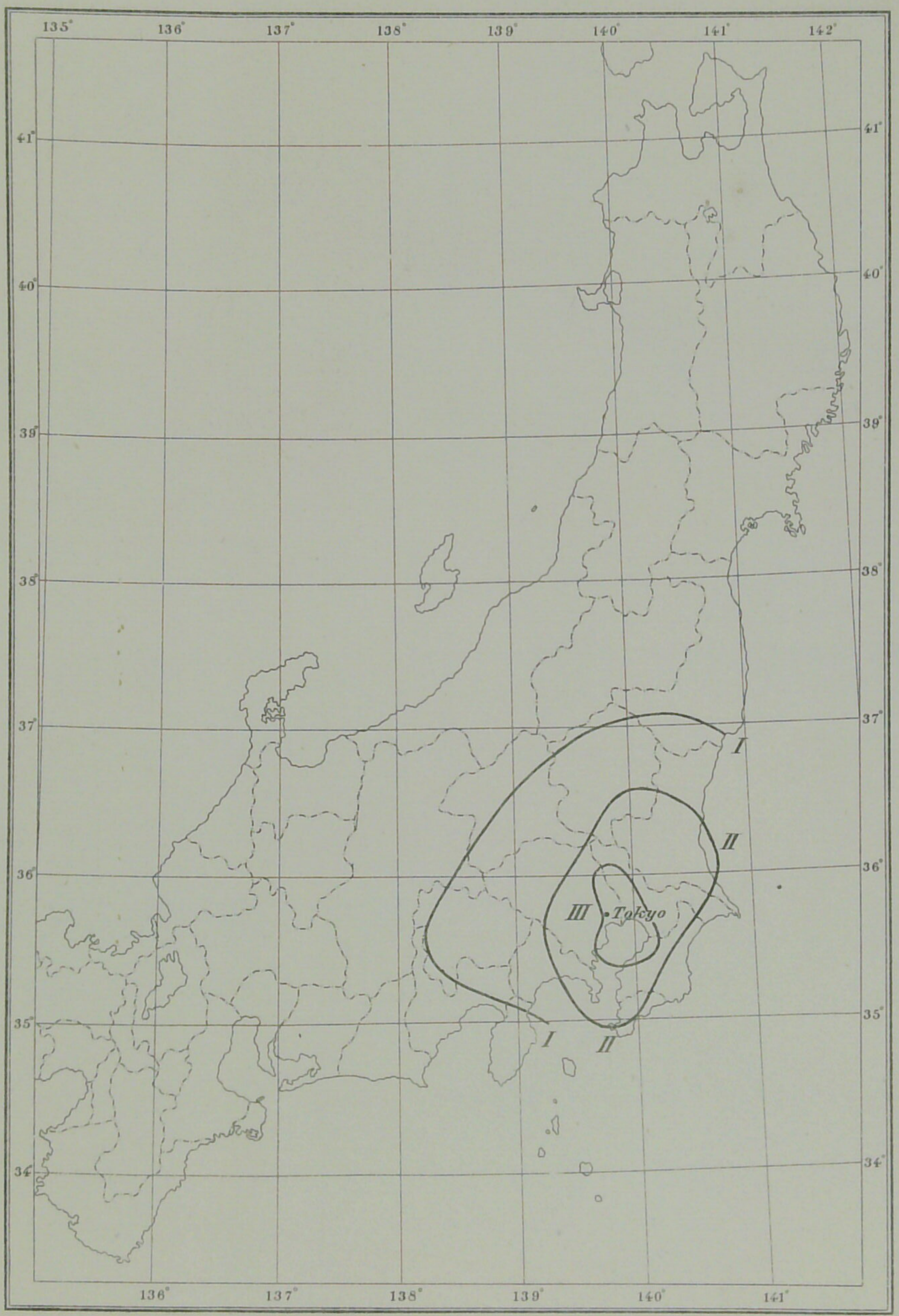
I I ..... Boundary of area of "slight" motion.
II II ..... „ „ "weak" „
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 10. Earthquake of Aug. 4, 1904 ; 9h 49m 17s p.m.

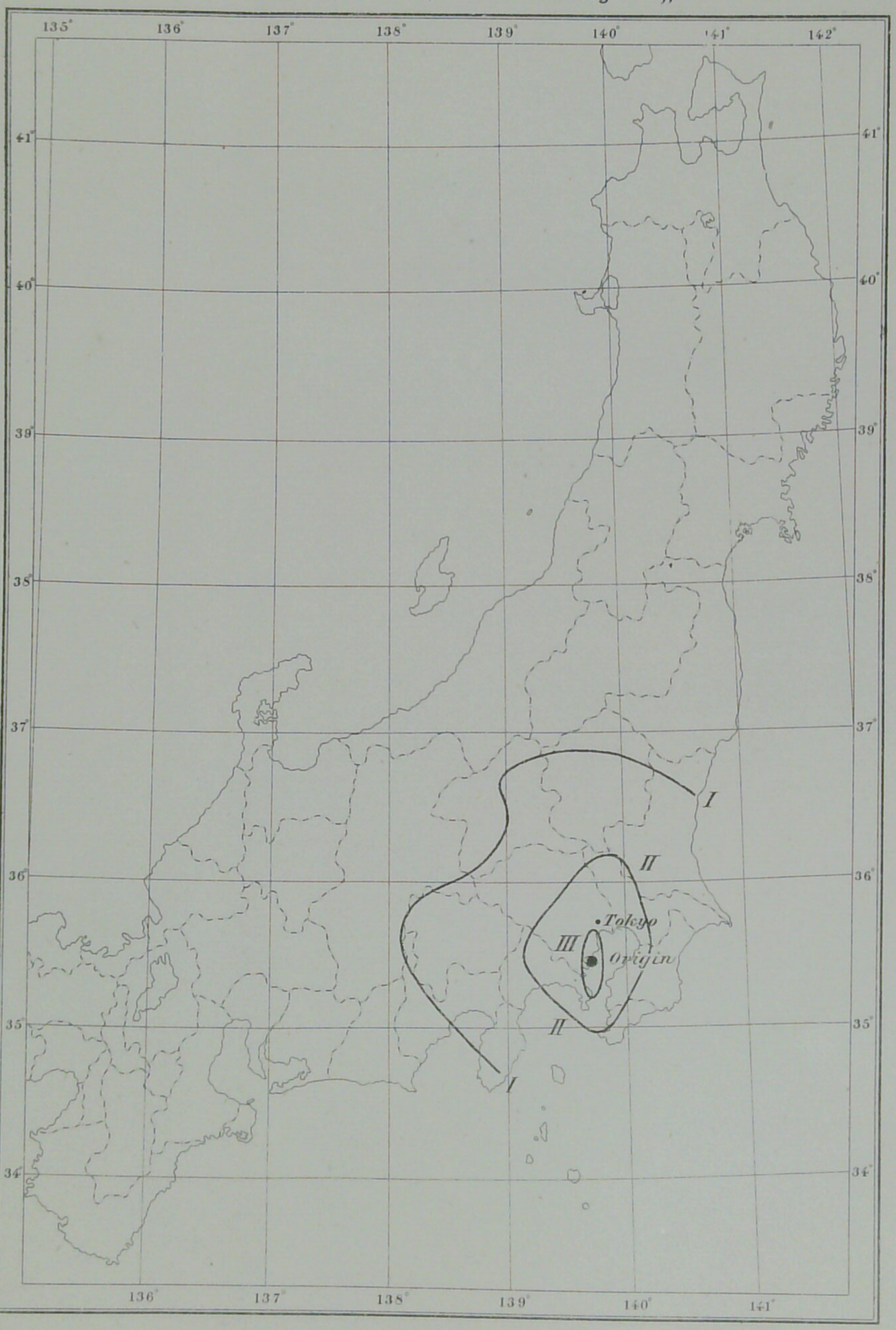
I I ..... Boundary of area of "slight" motion.
II II ..... " " "weak" "
III III ..... " " "strong" "



Boundary of provinces.

Fig. 11. Earthquake of April 5, 1902 ; 7h 23m 12s p.m.

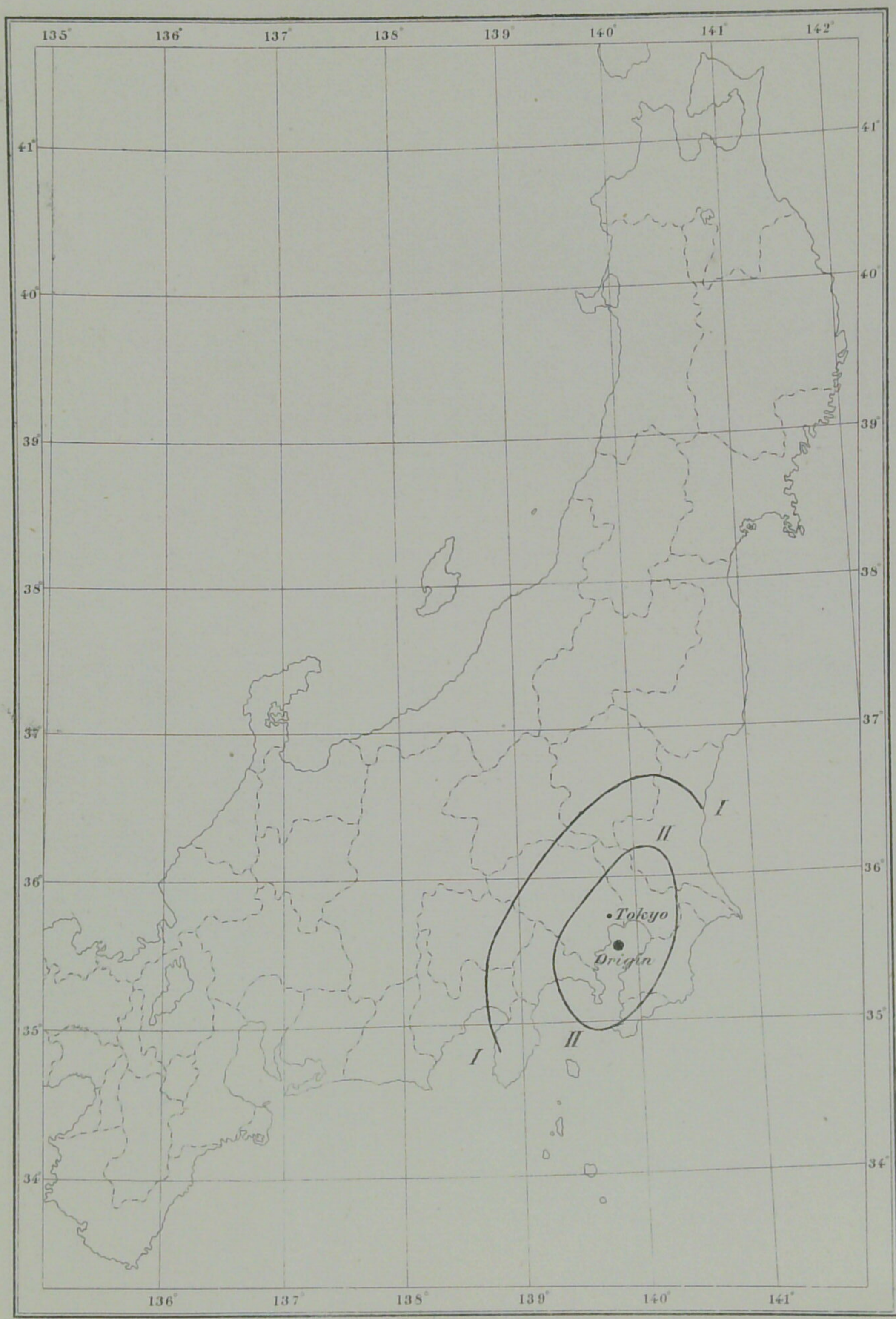
I I .... Boundary of area of "slight" motion.
II II ..... „ „ "weak" „
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 12. Earthquake of April 6, 1902; 2h 13m 30s a.m.

I I .....Boundary of area of "slight" motion.
II II ..... „ „ "weak" „



Boundary of provinces.

Eqke No. 2. June 23, 1902.

Duration. 3 m 50 s.

Max. hor. mot. $2a=5.9$ mm ; T $=0.5$ s.

Direction of max. hor. mot. WSW--ENE.

Eqke No. 3. Dec. 31, 1902.

Duration. 3 m 10 s.

Max. hor. mot. $2a=3.8$ mm ; T $=1.0$ s.

Direction of max. hor. mot. SE--NW.

Max. vert. mot. $2a=0.6$ mm ; T $=0.8$ s.

REMARK. The earthquake began with small movements, the above mentioned maximum vibration having occurred 6 sec. after the commencement. The shaking was more or less active during 35 sec.

Eqke No. 4. Aug. 4, 1904.

Duration. 4 m 15 s.

Max. hor. mot. $2a=4.6$ mm ; T $=1.0$ s.

Direction of max. hor. mot. SE—NW.

Max. vert. mot. $2a=0.5$ mm ; T $=0.8$ s.

REMARK. The earthquake began with small movements, the above mentioned maximum horizontal motion having suddenly occurred 8 sec. after the commencement. The maximum vertical motion occurred 1 sec. later than the corresponding horizontal one. Both components of motion remained active for 20 sec.

III. EARTHQUAKES WHICH ORIGINATED IN THE PROVINCE OF ECHIGO.

8. Pls. XIII and XIV give respectively the NS and the EW components of the following two severe earthquakes:

Eqke.	Date.	Time of occurrence in Tokyo.	Intensity of motion in Tokyo	Position of earthquake origin.			
				Latitude. (N)	Longitude. (E)	Distance from Tokyo.	Direc-toin from Tokyo.
		h m s				km	
No. 7	May 26, 1898.	3 00 00 a.m.	*Weak.*	36° 52′	138° 55′	147	N30°W.
No. 8	May 8, 1904.	4 23 49 a.m.	„	36 53	138 48	154	N33°W.

The earthquake of May 26, 1898, originated in the province of Echigo, near the town of Muikamachi. In the meizoseismal area, the shock caused much damage to buildings, although none of the latter was actually thrown down to the ground. The earthquake of May 8, 1904, which was somewhat less severe, originated in approximately the same district as the previous one. The isoseismal maps of the two earthquakes are given in Pl. XV and Pl. XVI.

NS COMPONENT DIAGRAMS. PL. XIII.

9. ***Eqke. No. 7. May 26, 1898.*** (Fig. 13)

The very first displacement of 0.5 mm. was directed toward N. For the next 40.7 sec., there were 4 gradually increasing vibrations, whose avarage T was 10.2 sec., and whose max. $2a$ was 8.8 mm; these being superposed by quick macro-seismic movements whose max. $2a$ was 3.6 mm. For the next 19.4 sec., there were three and one-half well-defined vibrations, whose average T was 5.5 sec.; the 1st and the last vibrations were the largest and had respectively the $2a$'s of 11.1 and 11.9 mm, the least $2a$ being 9.4 mm. For the next 25.1

sec., the motion was smaller and there predominated two and one-half slow vibrations of an average T of 10.0 sec.; the $2a$ of the middle vibration, which was the smallest, being 6.9 mm. For the next 20.2 sec., the motion became again quick and consisted of four and one-half vibrations, whose average T was 4.5 sec.; of these the 2nd vibration had the max. $2a$ of 12.5 mm, the least $2a$ being 8.0 mm. For the next 15.5 sec., the motion was small and consisted of 4 quick vibrations of an average T of 3.9 sec., whose max. $2a$ was 5.8 mm. For the next 23.2 sec., the motion consisted of 3 slow vibrations of an average T of 7.7 sec., whose max. $2a$ was 3.3 mm; these being superposed by smaller movements of about half period. For the next 22.6 sec., the motion consisted of five and one-half nearly equal quick vibrations whose average T was 4.1 sec., and whose max. $2a$ was 5.15 mm. So far the motion was most active.

For the next 5m 46s, maximum movements took place occasionally; the 2nd vibration had the greatest $2a$ of 4.4 mm, while the 5 vibrations, which were nearly equal and occurred at the end of this phase, had a max. $2a$ of 1.85 mm. During the first 1m 41s, the average T was 4.0 sec., the movements being often superposed by others of double period. During the remaining 4m 5s, the average T was 5.7 sec. At epochs of minimum motion, there were also vibrations whose average T was 10.4 sec.

Thereafter the motion rapidly decreased, the vibrations of an average T of 6.8 sec. being mixed with those of an average T of 4.4 sec., and others still quicker.

From the above description, it will be seen amongst others that the most active part, or the earlier 2m 50s of the principal portion, consisted of three maximum groups of quick movements, each preceded by a number of slower vibrations; the average T's of the two series of vibrations being as follows:—

1st max. group	5.5s	
2nd „ „	4.5	....*Mean*, 4.7s$=p_1$;
3rd „ „	4.1	

1st min. group 10.0s
2nd „ „ 10.0
3rd „ „ 7.7
} ... *Mean*, 9.3s=p_2.

Thus we see that $p_2=2p_1$, or the period of the slow vibrations was double that of the quick ones. The approximate time interval between the 1st and 2nd maximum groups was 46 sec., and that between the 2nd and 3rd ones 56 sec. The three largest vibrations, marked *f*, *g*, and *i* in the diagram, occurred respectively 61, 92 and 165 sec. after the commencement of the earthquake.

10. ***Eqke No. 8. May 8, 1904.*** (Fig. 14.)

The "preliminary tremor," whose duration was 20.4 sec., began with a small displacement of 0.11 mm toward S, followed by a counter motion of 0.73 mm toward N. Then there followed two nearly equal vibrations (max. $2a$ =1.54 mm) of which the first had a T of 11.5 sec.

The "principal portion" began with a displacement of 2.4 mm toward S, followed by a counter motion of 3.0 mm toward N. For the first 23 sec., the motion was comparatively small (max. $2a=3.45$ mm) and had an average T of 2.2 sec. There were also some slow vibrations.

Then there appeared, for the next 122 sec., 18 well-defined slow vibrations, whose average T was 6.8 sec., and whose first displacement of 2.6 mm was directed toward N. These vibrations, which form the most active part of the earthquake, were arranged in two groups, each of which gradually reached their maximum; the two greatest vibrations of 8.8 and 7.15 mm having occurred respectively 66 and 105 sec. after the commencement of the earthquake. A 3rd max. $2a$ of 3.75 mm took place 130 sec. after the same commencement. At epochs of minimum motion, there were also some slow vibrations.

For the next 2 m 45 s, the motion consisted essentially of vibrations (max. $2a=1.4$ mm) of an average T of 6.8 sec., mixed with others (max. $2a=2.45$ mm) of an average T of 3.1 sec.

For the next 5 m 28 s, the vibrations were well defined and had an average T of 7.1 sec., the max. $2a$ being 1.0 mm.

Thereafter, the motion consisted of vibrations of an average T of 6.4 sec., mixed with those of an average T of 4.7 sec.

"End portion." The average T was 7.4 sec.

In the principal portion, after the most active phase, the maximum groups occurred at an average interval of 1 m 3 s. The maximum vibration, marked i, whose $2a$ was 2.4 mm, occurred 2 m 43 s after the commencement of the earthquake.

EW COMPONENT DIAGRAMS. PL. XIV.

11. *Eqke No. 7. May 26, 1898.* (Fig. 15.)

The "preliminary tremor," whose duration was 17 s, began with a small displacement of 0.2 mm toward W. This was followed by a vibration of $T=10.1$ sec., whose two displacements were 0.7 and 1.6 mm directed respectively toward E and toward W. The succeeding motion of 0.7 mm was directed toward E. These movements were superposed by smaller ones.

The "principal portion" began with a sudden displacement of 2.75 mm toward W, followed by a well defined vibration, whose two displacements were as follows:—

1st displacement = 4.95 mm, toward E;
2nd „ = 6.1 „ , „ W.

For the 1st 57 sec. of the principal portion, the motion was on the whole constant and consisted of vibrations with an average T of 4.7 sec., whose max. $2a$ was 8.45 mm; these being mixed with vibrations of an average T of 2.25 sec., whose max. $2a$ was 6.1 mm. There were also some slow vibrations, whose average T was 11.8 sec.

Then there followed two large vibrations with an average T of 7.3 sec.; the 1st and 4th displacements being respectively 7.95 and 9.5 mm. The next motion, which was greater than 20.0 mm, was directed toward E, and the recording pointer was thrown out of the smoked paper.

12. *Eqke No. 8. May 8, 1904.* (Fig. 16.)

The "preliminary tremor" began with a very slight motion to-

ward E, followed by a counter motion of 0.34 mm toward W. Then there followed a slow vibration ($2a=0.65$ mm) whose T was 11.5 sec. The next displacement was small and directed toward E. The superposed macro-seismic vibrations had an average T of 0.79 sec., there being also movements whose average T was about 2.0 sec.

The "principal portion," whose total duration was 9m, began with a sudden displacement of 2.5 mm toward W, followed by a well defined vibration ($T=2.3$ sec.), whose two displacements were respectively 5.2 mm toward E and 5.8 mm toward W. For the next 34.2 sec., the motion was on the whole constant and consisted of 3 slow vibrations with an average T of 11.4 sec., of which the 2nd one had the greatest $2a$ of 5.65 mm; these movements being superposed by vibrations with an average T of 2.45 sec., and others still quicker. For the next 1m 24s, the motion was most active and consisted of 3 groups of well defined vibrations with an average T of 6.2 sec., of which three maximum movements of 7.5, 8.25, and 3.9 mm took place respectively 59s, 1m 36s, and 2m 8s after the commencement of the earthquake; these being respectively the 1st, 2nd, and 1st vibrations of the three successive maximum groups. For the next 2m 6s, the motion remained on the whole constant and consisted of vibrations of an average T of 5.3 sec., (max. $2a=3.1$ mm), mixed up with others of $T=3.3$ sec. Further on the average T was 7.2 sec.

13. From the above descriptions as well as from Plates XII and XIII, it will be seen that the diagrams of the two earthquakes are almost perfectly identical with each other, the only difference being that the motion in the 2nd earthquake was slightly smaller than that in the 1st. The corresponding vibrations in the two seismograms are marked by same alphabets.

14. The ordinary seismograph observations at the Central Meteorological Observatory were as follows.

Eqke No. 7. May 26, 1898.

Duration. 2m 10s.

Severe Echigo Earthquakes.

EW Component. Multiplication=10. [*A-Instrument.*]

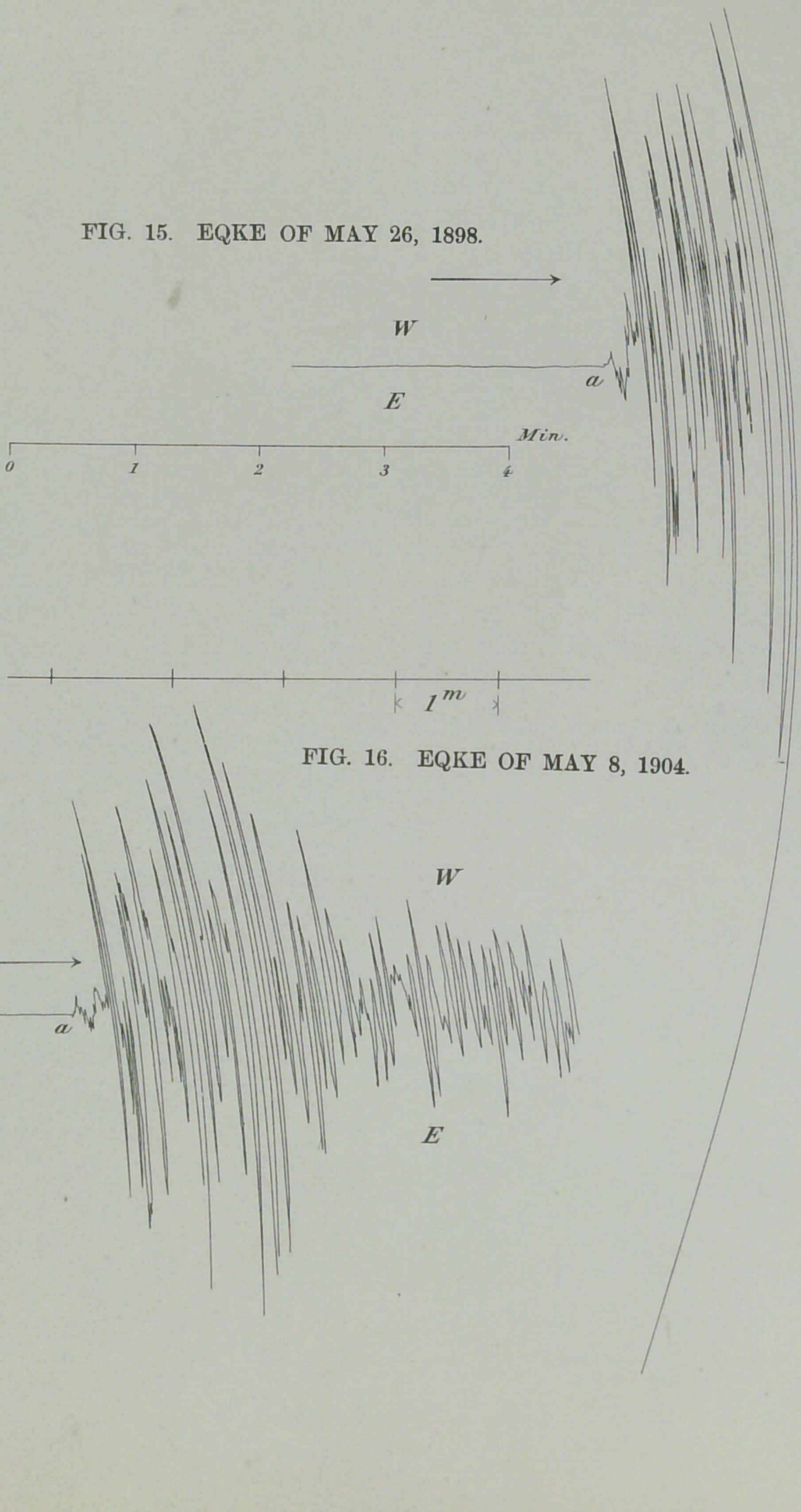
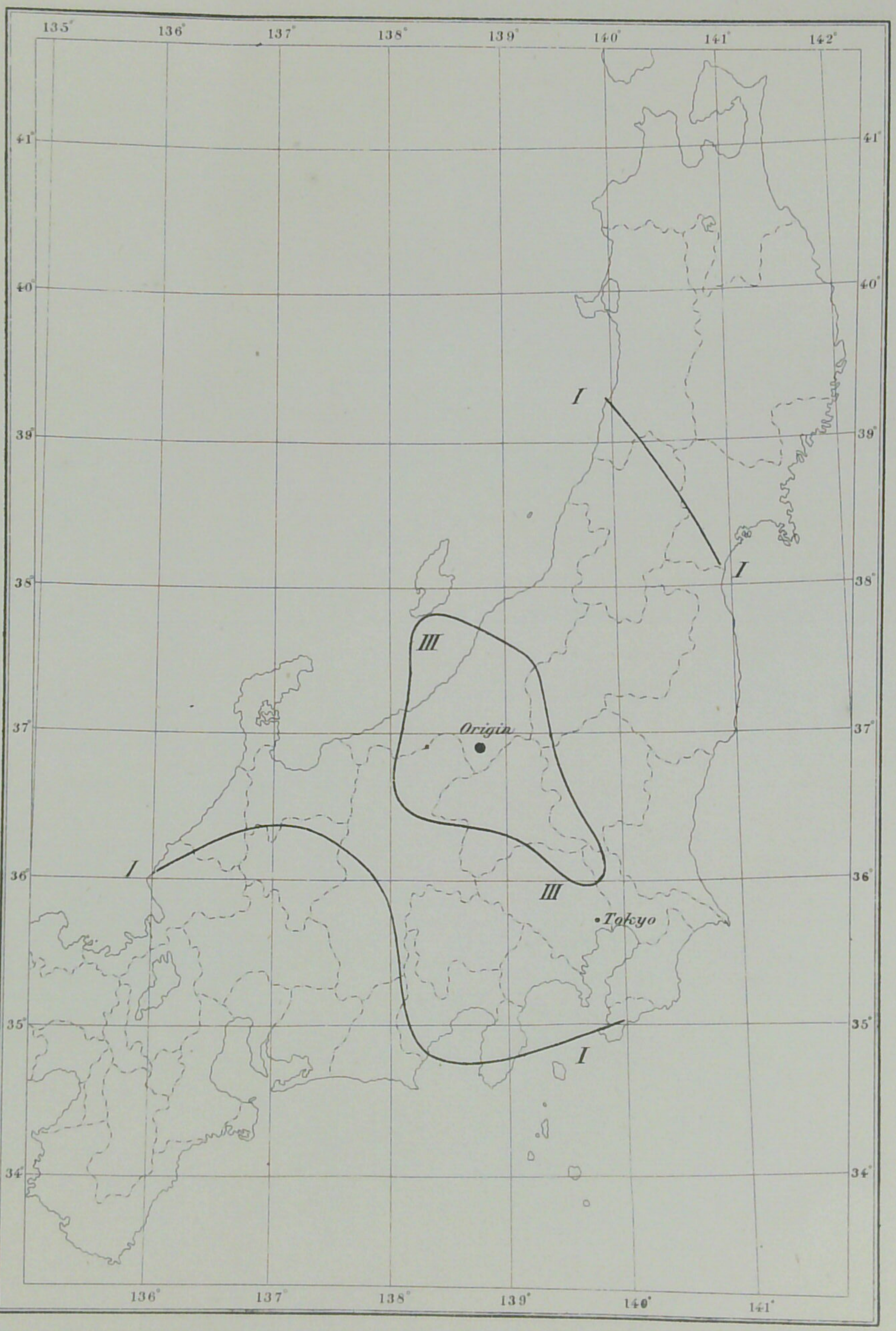


FIG. 15. EQKE OF MAY 26, 1898.

FIG. 16. EQKE OF MAY 8, 1904.

Fig. 17. Earthquake of May 26, 1898 ; 3h 0m 0s a.m.

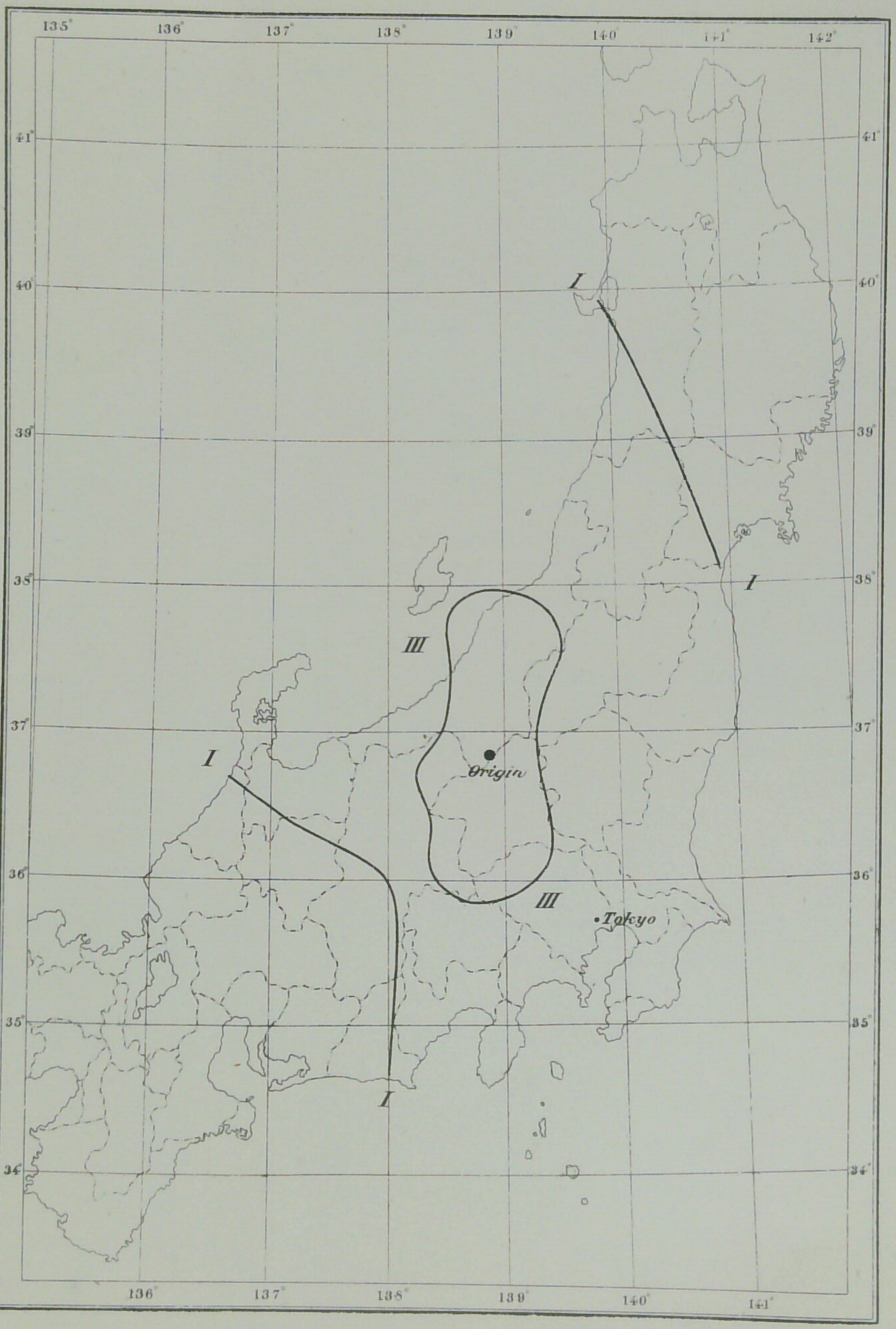
I I .....Boundary of area of "slight" motion.
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 18. Earthquake of May 8, 1904 ; 4h 23m 49s a.m.

I I .... Boundary of area of "slight" motion.
III III ..... „ „ "strong" „



Boundary of provinces.

Max. hor. mot. $2a=1.8$ mm; $T=0.5$s.
Direction of max. hor. mot. NW-SE.
Max. vert. mot. $2a=0.2$ mm; $T=0.2$s.
REMARK. The earthquake began with very small horizontal movements and the max. hor. motion occurred suddenly 16s after the commencement; the max. vert. motion having occurred simultaneously. The vibrations were active for about 15 sec.

Eqke No. 8. May 8, 1904.
Duration. 7m 50s.
Max. hor. mot. $2a=4.8$ mm; $T=1.4$s.
Direction of max hor. mot. NW-SE.
Max. vert. mot. $2a$, small.
REMARK. The preliminary tremor, whose duration was 20s, was suddenly followed by the max. hor. vibration; the motion remaining active for 1m 10s.
It may be remarked that the direction of the maximum horizontal motion approximately coincided in each case with the direction of the line joining Tokyo with the centre of disturbance.

IV. EARTHQUAKES WHICH ORIGINATED OFF THE COAST OF THE IZU PENINSULA.

15. Pls. XVII and XVIII give the diagrams of the following two earthquakes:—

No.	Date.	Time of occurrence in Tokyo.	Intensity of motion in Tokyo.
		h m s	
9	Nov. 5, 1900.	4 41 42 p.m.	*Weak.*
10	„ 9, „	2 55 3 a.m.	„

The earthquake of Nov. 5, 1900, which was a very large one was severely felt in the islands of Mikura, Miyake and Kozu, where many landslips took place. According to Mr. N. Fukuchi, who specially investigated this earthquake, the origin was situated between the Jenishima island and the Inanba Rock at about *latitude* 33° 43′, and *longitude* 139° 6′, or at a distance of about 230 km to the S15°W from Tokyo. The earthquake of Nov. 9th was one of the after-shocks of the above earthquake.

The areas of disturbance of the two earthquakes are shown in Pls. XIX and XX.

EQKE NO. 9. NOV. 5, 1900.

16. Pl. XVII gives the records obtained from the (*A*) and (*C*) instruments. The following descriptions relate to these diagrams as well as to those obtained from the (*B*) and (*D*) instruments.

EW Component at Hitotsubashi: (D) instrument. (Fig. 19.)

The "preliminary tremor," whose duration was 26.6 sec., began with a slow period displacement, whose simple-period was 8.3 sec. This was followed by a vibration of $T=17.2$ sec., whose two displacements were as follows:

1st displacement = 1.75 mm, toward E;
2nd „ = 1.5 „ „ „ W.

The average T of the superposed macro-seismic vibrations was 1.11 sec., the max. $2a$ being 0.46 mm.

The "principal portion" began with a well defined vibration ($2a$ = 5.9 mm), whose 1st displacement was directed toward E. This was followed by 5 and one-half smaller vibrations with an average T of 1.45 sec., lasting together 9.4 sec. Then there appeared quite suddenly a slow vibration of $T=27.2$ sec., whose two displacements were as follows:—

1st displacement = 15.5 mm, toward W;
2nd „ = 29.5 „ „ „ E.

The next motion was still greater and the pointer went out of the record receiver.

17. ***EW Component at Hongo : (A) instrument.*** (Fig. 20.)

The total duration was about 4 h.

The principal portion lasted 13 m 22 s. In consequence of the violence of motion the pendulum was thrown into large proper oscillations, whose max. $2a$ reached 23 mm.

The "end portion." The motion was active and nearly constant during the first 5 m 35 s, the average T being 6.7 sec., and the max. $2a$ being 1.3 mm. The maximum movements occurred at an average interval of 37.2 sec. During the next 5 m 40 s, the motion was small (max. $2a=0.7$ mm), the average T being 7.2 sec. For the next 5 m 24 s, the motion became again smaller, but remained on the whole constant (max. $2a=0.42$ mm), the average T being about 8.1 sec. The subsequent vibrations had an average T of 8.2 sec.

18. ***NS Component at Hongo : (B) instrument.***

The earthquake began with a displacement of 0.11 mm directed toward S. For the first 25 sec., the motion was small and consisted of 3 vibrations, whose average T was 8.3 sec., the 3rd one having the greatest $2a$ of 0.75 mm. So far the superposed macro-seismic vibrations remained small, the max. $2a$ being 0.27 mm. Then there appeared a large displacement of 2.4 mm directed toward S, followed by a well defined vibration ($T=8.0$ sec.), whose $2a$ was 2.8 mm. Then there followed 7 large and rapidly increasing vibrations with an average T of 7.1 sec.; the $2a$ of the 1st vibration being 7.2 mm, and that of the last one 20.1 mm. The next motion was still larger and the pointer got out of the record receiver, toward N. After about $1\frac{1}{2}$ minutes the pointer again entered on the record receiver, the motion being then very active, so that the pendulum was for 8m 10s at full swing. During the next 4m 5s, the pendulum oscillation gradually lessened.

The "end portion." The motion was well defined and had an average T of 6.8 sec. The max. $2a$, which occurred at the commencement, was 1.4 mm.

19. Comparing the EW and NS component diagrams, we see that the first quick-period maximum vibration, which occurred after the termination of the preliminary tremor, consisted of the following two displacements:—

4.8 mm, toward E;
1.75 „ , „ S.

Again the 2nd and large displacement of the first slow period vibration was made up of the following two components:—

greater than 20.0 mm, toward E;
8.6 „ , „ S.

EQKE NO. 10. NOV. 9, 1900. PL. XVIII.

20. ***EW Component at Hongo: (C) instrument.***

The duration of the earthquake was more than two hours.

The "1st preliminary tremor," whose duration was 56 sec., consisted of small vibrations of macroseismic character.

The "2nd preliminary tremor," whose duration was 43 sec., began with a displacement of 0.16 mm toward E, followed by a large counter motion of 0.29 mm toward W. The subsequent motion was small (max. $2a=0.15$ mm) and consisted of vibrations with an average T of 0.96 sec., superposed by slower ones of $T=3.1$ sec. The end of this phase was marked by a single vibration ($2a=1.1$ mm) whose T was 9.3 sec.

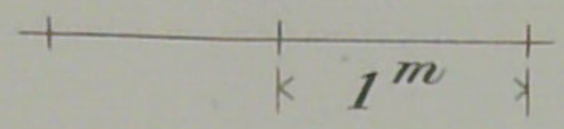
The "principal portion," whose duration was 14m 35s, began with a motion of 4.75 mm directed toward E, followed by a vibration of $T'=27.6$ sec., whose two displacements were as follows:—

1st displacement=10.5 mm, toward W,
2nd „ =12.2 „ , „ E.

During the next 51.6 sec., there were 4 vibrations with an average T of 12.9 sec., of which the 2nd had the greatest $2a$ of 17.6 mm. Then the pointer got out of the smoked paper, toward W; it entered again on the record-receiver 2m 26s after the commencement of the principal portion. For the next 45.2 sec., there was a group of 6

Izu Earthquakes. EW Component.

Multiplication=10. [*A-Instrument.*]



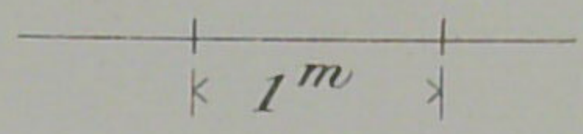


FIG. 20.
EQKE OF NOV. 9, 1900 ;
$2^h\ 55^m\ 3^s$ A.M.

FIG. 19.
EQKE OF NOV. 5, 1900 ;
$4^h\ 41^m\ 42^s$ P.M.

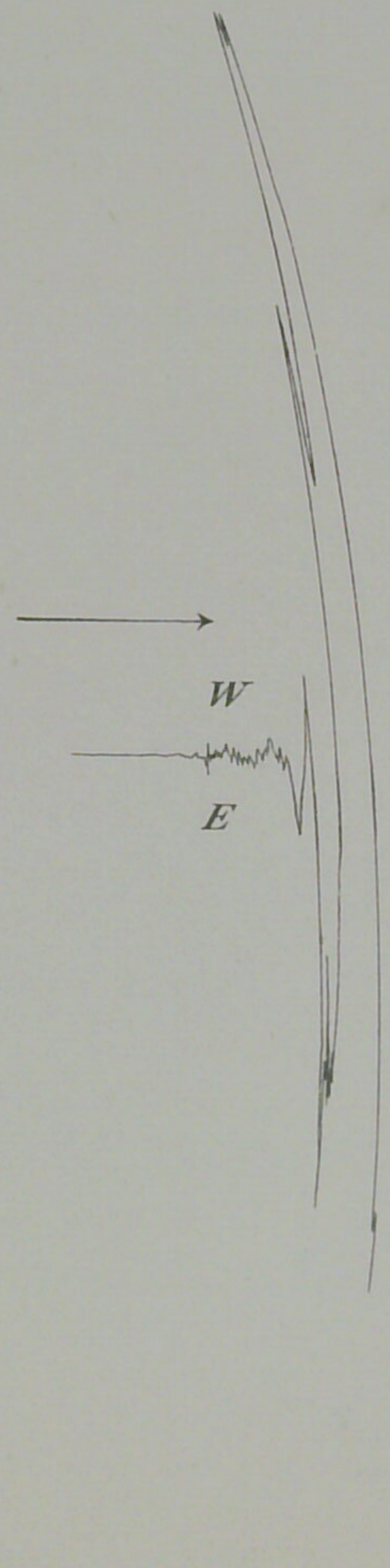
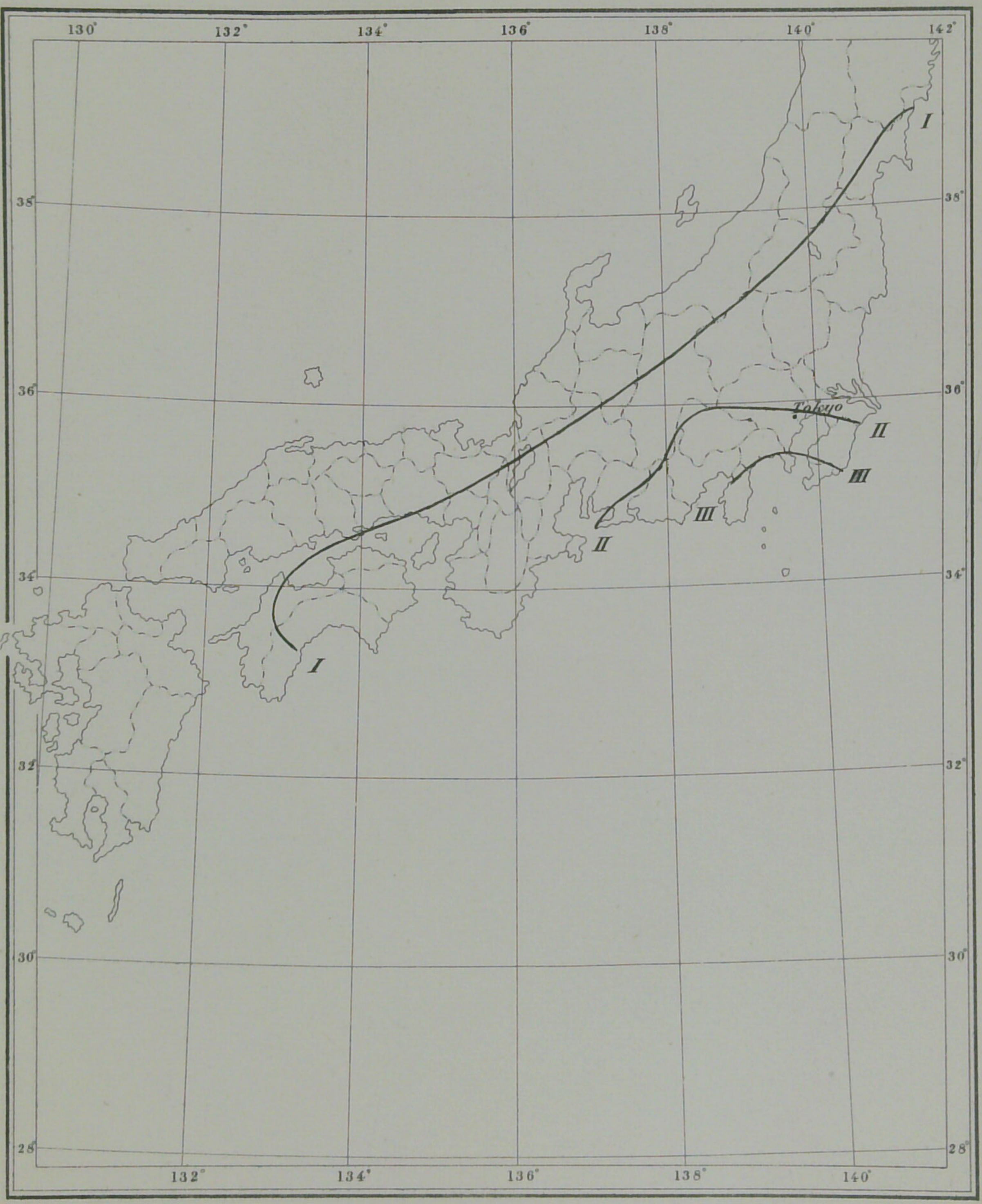


Fig. 22. Earthquake of Nov. 5, 1900 ; 4h 41m 42s p.m.

I I ..... Boundary of area of "slight". motion.
II II ..... „ „ "weak" „
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 23. Earthquake of Nov. 9, 1900 ; 2h 55m 3s a.m.

I I .....Boundary of area of "slight" motion.

II II ..... „ „ "weak" „

Boundary of provinces.

large vibrations, of which the 4th had the greatest $2a$ of 17.0 mm, the average T being 7.9 sec. For the next 49 sec., there was another group of 6 large vibrations, of which the 4th had the greatest $2a$ of 17.5 mm, the average T being 7.5 sec. For the next 43.8 sec., there was a third group of 6 large vibrations with an average T of 7.8 sec., of which the 4th had the greatest $2a$ of 14.1 mm; the $2a$ of the last vibration being 8.0 mm.

So far the motion was most active, and the different max. $2a$'s did not much vary. There were during this interval of 5m 0s altogether 5 groups of maximum movements, (including a group which evidently occurred while the pointer was out of the record receiver). The vibrations of the 1st group were slow in period. The mean interval between the successive maximum groups was 1m 0s; the max. $2a$'s of the 1st, 3rd, 4th, and 5th groups having occurred respectively 44.7s, 3m 4s, 3m 56s, and 4m 45s after the commencement of the principal portion.

For the next 5m 32s, the motion was small (max. $2a=5.65$ mm), but remained on the whole constant, the average T being 8.4 sec. During this interval there were 5 different maximum groups, which occurred at an average interval of 1m 6s; the successive max. $2a$'s having occurred 5m 46s, 6m 55s, 8m 10s, 8m 50s, and 10m 10s after the commencement of the principal portion. The 5th maximum motion was the last but one vibration.

During the remaining 4m 12s of the principal portion, the motion was again much smaller than before, but remained on the whole constant; the max. $2a$ was 2.5 mm, and the average T was 7.9 sec.

The "end portion." The motion was comparatively large for the first 14m 55s, during which the average T was 7.8 sec., and the $2a$ slowly decreased, as follows:—

Max. $2a$ near the commencement, ...0.9 mm,

" " " " end ,.....0.6 " .

Thereafter the motion became much smaller, the max. $2a$ being only 0.24 mm. The average T was 9.3 sec.

V. EARTHQUAKES WHICH ORIGINATED OFF THE NORTH-EASTERN COAST OF THE MAIN ISLAND OR OFF THE SOUTH-EASTERN COAST OF HOKKAIDO.

21. Pls. XXI to XXIV contain the earlier portions of the EW component diagrams of the following earthquakes, which originated off the NE coast of the Main Island or off the SE coast of Hokkaido.

Eqke No.	Date.	Time of occurrence at Tōkyō.	Intensity of motion at Tokyo.
		h m s	
11	Aug. 5, 1900	1 21 26 p.m.	*Weak.*
12	Aug. 29, „	11 31 29 a.m.	*Slight.*
13	May 8, 1899	0 28 54 p.m.	„
14	Nov. 4, 1901	4 56 15 p.m.	*Weak.*
15	„ „ „	11 38 42 p.m.	*Slight.*
16	May 2, 1902	8 32 2 p.m.	„
17	Sept. 30, 1901	7 21 0 p.m.	*Weak.*
18	Jan. 30, 1902	11 1 43 p.m.	*Slight.*
19	Jan. 31, „	10 42 58 a.m.	„
20	July 11, 1899	7 15 44 a.m.	„
21	Feb. 1, 1900	4 21 7 a.m.	„

EQKES NOS. 11, 12 AND 13. PL. XXI.

22. The three earthquakes Nos. 11, 12 and 13, took place all off the north-eastern coast of the Main Island, at varying distances and directions from Tokyo. The areas of disturbance of these earthquakes are shown in Pls. XXV—XXVI. The position of the epicentre and the duration at Tokyo and Miyako of the total preliminary tremor of each of these three earthquakes were as follows.

Earth-quake.	Duration of prel. tremor.		Position of earthquake origin.			
	at Tokyo.	at Miyako.	Latitude.	Longitude.	Distance* from Tokyo.	Distance* from Miyako
No. 11.	m s 1 43	m s 0 48	(N) 38°	(E) 142°	km 788	km 390
No. I2.	1 35	0 47	$39\frac{2}{3}$	$146\frac{1}{3}$	724	381
No. 13.	0 39	0 19	$40\frac{2}{3}$	$146\frac{1}{3}$	322	178

23. ***Eqke No. 11. Aug. 5, 1900; 1h 21m 26s p.m. EW Component; (C) instrument.*** (Fig. 24.)

The total duration was 15 m 50 s.

The "preliminary tremor" lasted 39 sec. For the first 15 sec., the motion was very small and consisted of quick macro-seismic vibrations with an average T of 0.67 sec., superposed by slower vibrations with an average T of 3.0 sec., whose max. $2a$ was 0.14 mm. Then there followed a single slow vibration of $T=24$ sec., which occupied the whole remainder of the preliminary tremor, and which consisted of the following two displacements:—

1st displacement = 1.2 mm, toward W,
2nd „ = 1.7 „ „ E.

The max. $2a$ and the average T of the superposed quick vibrations were respectively 0.7 mm and 1.6 sec.

The "principal portion," whose duration was 17m 3s, began with a well defined vibration of $T=7.1$ sec., whose 1st displacement was directed toward W. The motion was most active for the 1st 5m 46s, during which time the amplitude remained on the whole nearly equal. During the earlier 2m 9s of this epoch, the motion consisted principally of 34 vibrations with an average T of 3.8 sec., of which the greatest motion of 3.15 mm took place 1m 50s after the commencement of the principal portion. These were mixed up with vibrations whose average T was 6.3 sec., and whose three maximum movements

* Calculated from the duration of the prel. tremor.

of 4.3, 3.6, and 3.8 mm occurred respectively 0m 22s, 1m 7s, and 1m 38s, from the commencement of the principal portion. There were also more or less distinct traces of slow vibrations with an average T of 15.2 sec., whose max. $2a$ was 4.7 mm; the 1st displacement of the 1st vibration, whose T was 15.2 sec., being directed toward W. There were also quick superposed movements of $T=2.1$ sec., whose max. $2a$ was 2.3 mm. The subsequent motion became simpler on account of the lessening of quick vibrations, and began with 3 well defined movements which lasted 25.8 sec., and had an average T of 8.6 sec., the 3rd vibration having the greatest $2a$ of 4.35 mm. For the next 3m 15s, the average T was 6.1 sec., the two max. $2a$'s of 3.6 and 2.7 mm having occurred respectively 3m 50s from the commencement of the principal portion and at the end of the most active part. The superposed vibrations had an average T of 3.3 sec.

During the next 5m 5s, the motion was much smaller but remained on the what constant, and consisted of 43 regular vibrations with an average T of 7.1 sec., the max. $2a$ being 1.75 mm. The superposed quick vibrations were slight.

During the remaining 6m 14s of the principal portion, the motion was smaller than before, but remained on the whole constant; the average T was 7.1 sec. and the max. $2a$ was 0.75 mm.

The "end portion." The max. $2a$ was 0.28 mm. The average periods deduced from 150 vibrations at the commencement and from an equal number of vibrations near the end were 8.1 and 9.4 sec. respectively.

24. ***Eqke No. 12. Aug. 29, 1900; 11h 31m 29s a.m. EW Component; (C) instrument.*** (Fig. 25.)

The "preliminary tremor," whose duration was 1m 31s, consisted of vibrations with an average T of 11.7 sec. (max. $2a=0.4$ mm), superposed by small vibrations with an average T of 2.7 sec.

The "principal portion." During the 1st 1m 15s the motion was comparatively small and consisted of 8 vibrations with an average T of 9.4 sec., the last but one vibration having the max. $2a$ of 17.5

mm. There were also some superposed quick vibrations. For the next 3m 45s, the motion was most active and consisted of vibrations with an average T of 5.9 sec., of which the 4 max. $2a$'s of 3.2, 3.25, 2.45, and 2.7 mm occurred respectively 3m 16s, 3m 58s, 5m 0s, and 6m 11s, from the commencement of the earthquake; these movements were superposed by vibrations with an average T of 10.6 sec., mixed up sometimes with small vibrations whose average T was 3.5 sec.

Thereafter the motion became much smaller and remained nearly constant for the next 5m 3s; the vibrations whose average T was 6.8 sec. (max. $2a$=1.3 mm) being mixed up with those whose average T was 9.3 sec.

For the next 6m 0s, the motion was again smaller and nearly constant (max. $2a$=0.74 mm), the average T being 11.3 sec. There were also vibrations with an average period of 6.1 sec.

In the "end portion," the motion consisted of regular vibrations with an average period of 10.0 sec.

25. ***Eqke No. 13. May 8, 1899; 0h 28m 54s p.m. EW Component; (A) instrument.*** (Fig. 26.)

The following description is taken from the *Publications*, No. 6, pp. 71–72.

The "preliminary tremor" lasted 1m 45s in the EW and 1m 41 s in the NS component, and consisted of well defined slow vibrations, whose average T was 10.1 and 11.5 sec. in these two components respectively.

The max. $2a$ was 0.14 mm in the EW and 0.23 mm in the NS component; the very first motion of the earthquake being 0.1 mm toward E and also 0.1 mm toward N. The superposed small vibrations had an average T of 1.2 sec.

The "principal portion" lasted $8\frac{1}{4}$ m and consisted at first of quick vibrations, which there suddenly made their appearance and whose average T was 0.58 sec.; the max. $2a$ being 0.25 mm in each component. These were superposed by slower waves with an average T of 8.2 sec., whose max. $2a$ of 1.3 mm in the EW and 1.1 mm in the

NS component occurred 3m 47s from the beginning of the earthquake. From about 0h 32m the motion became regular, the average T being 6.9 s.

The "end portion." The average T measured, from 8 successive groups of 50 vibrations, in the EW component, commencing at 0h 39m 15s, was as follows:—8.2; 8.8; 9.0; 8.7; 9.6; 9.3; 9.8; and 9.4 sec.; the general mean value being 9.1 sec.

EQKES NOS. 14, 15, AND 16. PL. XXII.

26. The two earthquakes on Nov. 4, 1901, at 4.56.15 p.m. and 11.38.42 p.m., originated off the coast of the peninsula of Awa and Kazusa. The centre of the 1st earthquake was at a distance of about 210 km from Tokyo, at *lat.* 34°¾ N, *long.* 141°⅔ E. The centre of the 2nd earthquake was near that of the 1st, at a slightly greater distance from the coast, about 250 km from Tokyo.

The 1st earthquake was felt *weakly* in Tokyo and the vicinity, while the 2nd was felt *weakly* only at Chōshi.

The diagrams of the two earthquakes are very similar to each other; some of the prominent corresponding vibrations are marked *a*, *b*, *c*, *d*, *e*, *f*, *g*.

27. *Eqke No. 14. Nov. 4, 1901; 4h 56m 15s p.m. EW Component; (A) instrument.* (Fig. 27.)

The "preliminary tremor" lasted 24 sec.

The "principal portion." The motion was most active for 3 m 45 s, and consisted, during the first 1 m 40 s of 35 vibrations with an average T of 2.85 sec., the last one having the greatest $2a$ of 3.6 mm. These were superposed by vibrations with an average T of 6.5 sec. During the next 2 m 3 s, the average T was 4.0 sec., the max. $2a$ being 2.8 mm. The subsequent vibration had an average T of 4.2 sec.

28. *Eqke No. 15. Nov. 4, 1901; 11h 38m 42s p.m. EW Component; (A) instrument.* (Fig. 28.)

The "preliminary tremor" lasted 29 sec.

The "principal portion." The motion was most active for 3m

35s, and consisted during the first 2m 0s of 14 vibrations with an average T of 8.6 sec., superposed by those with an average T of about 3.3 sec. The succeeding vibrations had an average T of 4.3 sec., the max. $2a$ being 1.8 mm. Later on the average T was 4.2 sec.

29. *Eqke No. 16. May 2, 1902; 8h 32m 2s p.m. EW Component; (A) instrument.* (Fig. 29.)

This earthquake was felt *weakly* at Aomori, and *slightly* at Ishinomaki and Akita.

The duration of the "preliminary tremor" was 1m 11s.

The "principal portion." During the first 2m 28s, there were 11 well defined vibrations, of which the first two had an average T of 16.5 sec., and the remaining 9 that of 12.8 sec.; the 2nd vibration having the greatest $2a$ of 2.8 mm. Then there appeared quicker vibrations with an average T of 7.0 sec.; the 3rd vibration having the max. $2a$ of 2.4 mm. The two maximum movements above mentioned took place respectively 1m 30s and 3m 50s after the commencement of the earthquake.

Later on vibrations of an average T of 12.0 sec. were mixed with those of an average T of about 7 sec.

EQKES NOS. 17, 18 AND 19. PL. XXIII.

30. All these three earthquakes originated off the north-eastern coast of the Main Island, the approximate positions of their origins being as follows.

Eqke.	Position of eqke origin.				Mean radius of area of disturbance of		
	Latitude. (N)	Longitude. (E)	Distance from Tokyo.	Direction from Tokyo.	*Strong* motion.	*Weak* motion.	*Slight* motion.
			km		km	km	km
No. 17.	38° 57′	143° 31′	474	N 42°E	330	450	650
No. 18.	39° 9′	143° 31′	496	N 40°E	280	430	620
No. 19.	40° 50′	144° 13′	680	N 33°E	—	350	530

The position of the origin of Eqke No. 17 has been determined from the durations of the preliminary tremor at Tokyo, Osaka, and Mizusawa; while those of Eqkes Nos. 18 and 19 have been inferred each from the isoseismal map and the duration of the preliminary tremor as observed in Tokyo. The isoseismal maps of the three earthquakes are given in Pls. XXVIII, XXIX, and XXX.

The preliminary tremors of the three earthquakes were in character very similar to one other, the motion consisting in each case of small vibrations superposed by a slow movement whose T was about 40 sec. Again the 1st displacement of the principal portion was always directed toward E. The corresponding phases of motion are indicated by the letters a, b, c, d.

31. ***Eqke No. 17. Sept. 30, 1901; 7h 21m 0s p.m. EW Component; (A) instrument.*** (Fig. 30.)

The duration of the "preliminary tremor" was 60 sec.

The most active part of the "principal portion," which lasted 3 m 25 s, was confused by the proper oscillations of the pendulum. Thereafter the motion consisted at first of vibrations, whose average T was 3.3 sec., superposed by slower ones with an average T of about 6.3 sec. The subsequent vibrations had an average T of 7.2 sec.

In the "end portion," the average T was 9.7 sec.

32. ***Eqke No. 18. June 30, 1902; 11h 1m 43s p.m. EW Component; (A) instrument.*** (Fig. 31.)

The duration of the "preliminary tremor" was 63 sec.

During the first 2 m 35 s of the "principal portion," the record was confused by the proper oscillation of the pendulum. Thereafter, the average T was 4.5 sec. Later on the vibrations became regular and had an average T of 7.0 sec.

In the "end portion" the average T was 10.5 sec.

33. ***Eqke No. 19. Jan. 31, 1902; 10h 42m 58s a.m. EW Component; (A) instrument.*** (Fig. 32)

The duration of the "preliminary tremor" (at Tokyo) was 89 sec., which corresponds to a radial distance of 680 km. The duration of

the preliminary tremor at Osaka and Mizusawa were respectively 136 and 38 sec., corresponding to radial distances of 1020 and 310 km.

In the 3rd and subsequent phases of the "principal portion," the T was 6.4 sec.

In the "end portion," the average T was about 11.8 sec.

EQKES NOS. 20 AND 21. PL. XXIV.

34. Pl. XXIV gives the earlier portions of the EW component diagrams of the following two earthquakes:—

Eqke No. 20. July 11, 1899; 4.40.7 p.m.

Eqke No. 21. Feb. 1, 1900; 4.21.7 a.m.

As will be seen from Pls. XXXI and XXXII, the two earthquakes had nearly similar disturbance areas, having been felt throughout the latter only *weakly* or *slightly*. The origines were evidently in the vicinity of each other, the only difference being that Eqke No. 20 was somewhat greater than Eqke. No. 21.

The two diagrams, fig. 33, I and II, were given respectively by the A instrument and by a horizontal pendulum of portable form whose multiplication ratio was 5. Again the two diagrams, fig. 34, I and II, were given respectively by the A instrument at Hongo and D instrument at Hitotsubashi. It will be observed that in each case different instruments gave practically similar records.

By comparing fig. 33 with fig. 34, it will be observed that the diagrams of the two earthquakes are, on the whole, similar to one another, with this marked difference: namely, the directions of the very first displacement and the well defined slow vibration which followed it, at the commencement of the principal portion, were opposite in the two earthquakes.

35. ***Eqke No. 20. July 11, 1899; 4h 40m 7s p.m.***
(Fig. 33, II.)

The following description is taken from the *Publications*, No. 6, pp. 74–75.

The "preliminary tremor" lasted 2m 23s in the EW and also 2m 23s in the NS component, the very first displacement being 0.1 mm towards E and 0.15 mm towards N. The motion consisted of very small vibrations with an average T of about 2.4 sec., superposed by slower ones whose average T was 4.4 and 4.2 sec. in the EW and NS components respectively.

There were also still slower movements, whose average T was 10.7 sec. and whose max. $2a$ was 0.2 mm in the EW and 0.3 mm in the NS component.

The "principal portion" lasted 5m 40s. For the first 2m 5s the motion was on the whole constant, and consisted of well defined vibrations with an average T of 9.5 sec., divided into max. and min. groups; the max. movements in the EW component being as follows:—

$2a = 2.7$ mm, occurred at 4h 42m 21s;
„ 2.9 „ 4 43 21;
„ 2.7 „ 4 44 9.

For the next 1m 55s, the motion was on the whole constant, and consisted of comparatively regular vibrations of an average T of 6.0 sec., the max. (*abs.*) $2a$ of 3.3 mm occurring at its beginning. In the NS component the motion in this part of the earthquake was disturbed somewhat by the proper oscillation of the pendulum.

The "end portion." The average T was at first 8.0 sec. and towards the end 9.6 sec.

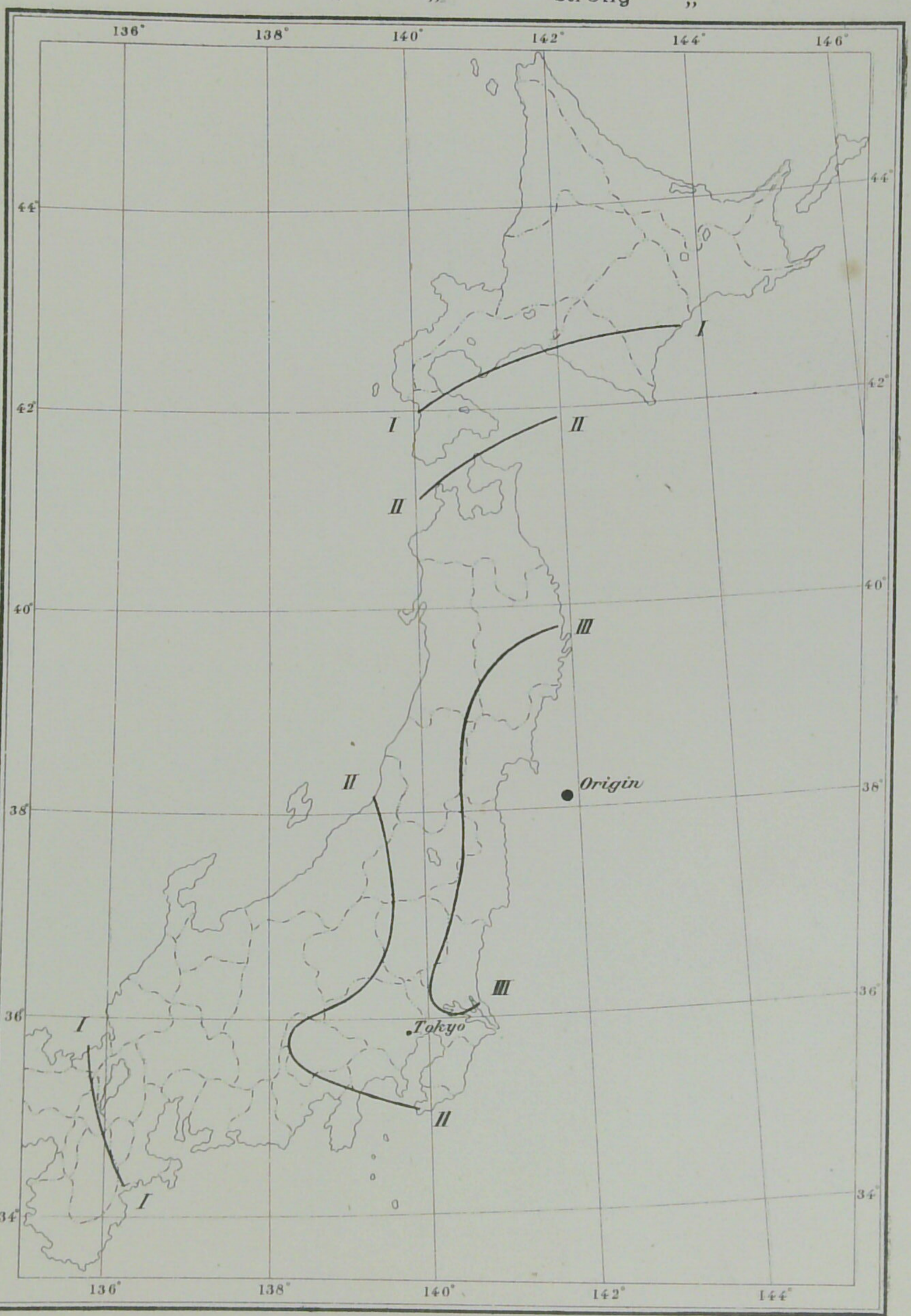
36. ***Eqke No. 21. Feb. 1, 1900; 4h 21m 7s a.m. EW Component; (A) instrument.*** (Fig. 34, I.)

The "preliminary tremor" lasted 2m 25s.

The "principal portion" lasted 5m 30s. During the first 2m 45s, the motion remained on the whole nearly constant and had an average T of 7.9 sec.; the very first displacement of 0.3 mm being directed toward W. The next vibration, which was the maximum, had a period of 8.8 sec., its two displacements being 1.2 and 1.4 mm, respectively directed toward E and toward W. During the remaining

Fig. 35. Earthquake of Aug. 5, 1900; 1h 21m 17s p.m.

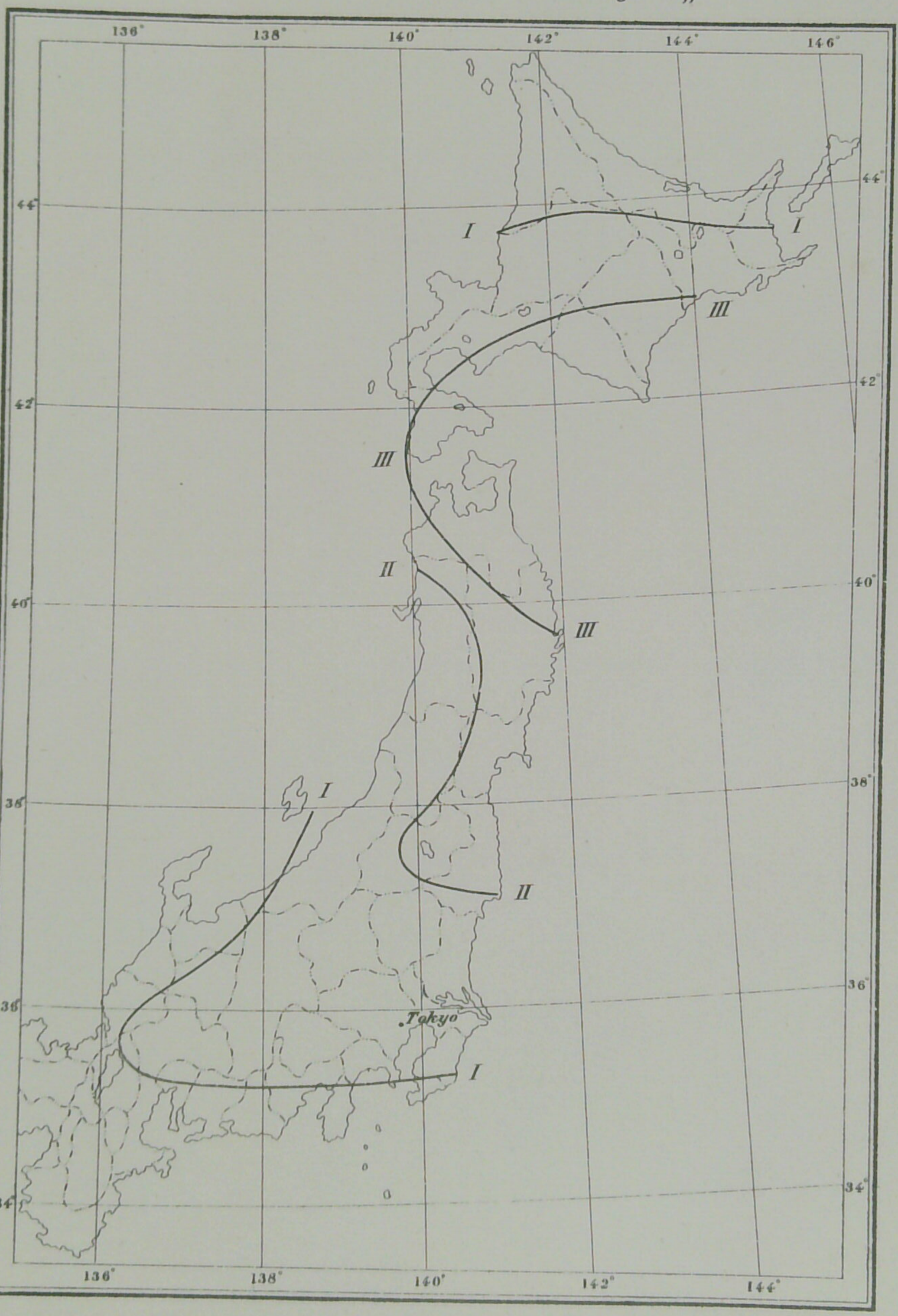
I I .... Boundary of area of "slight" motion.
II II ..... " " "weak" "
III III ..... " " "strong" "



Boundary of provinces.

Fig. 36. Earthquake of Aug. 29, 1900 ; 11h 31m 20s a.m

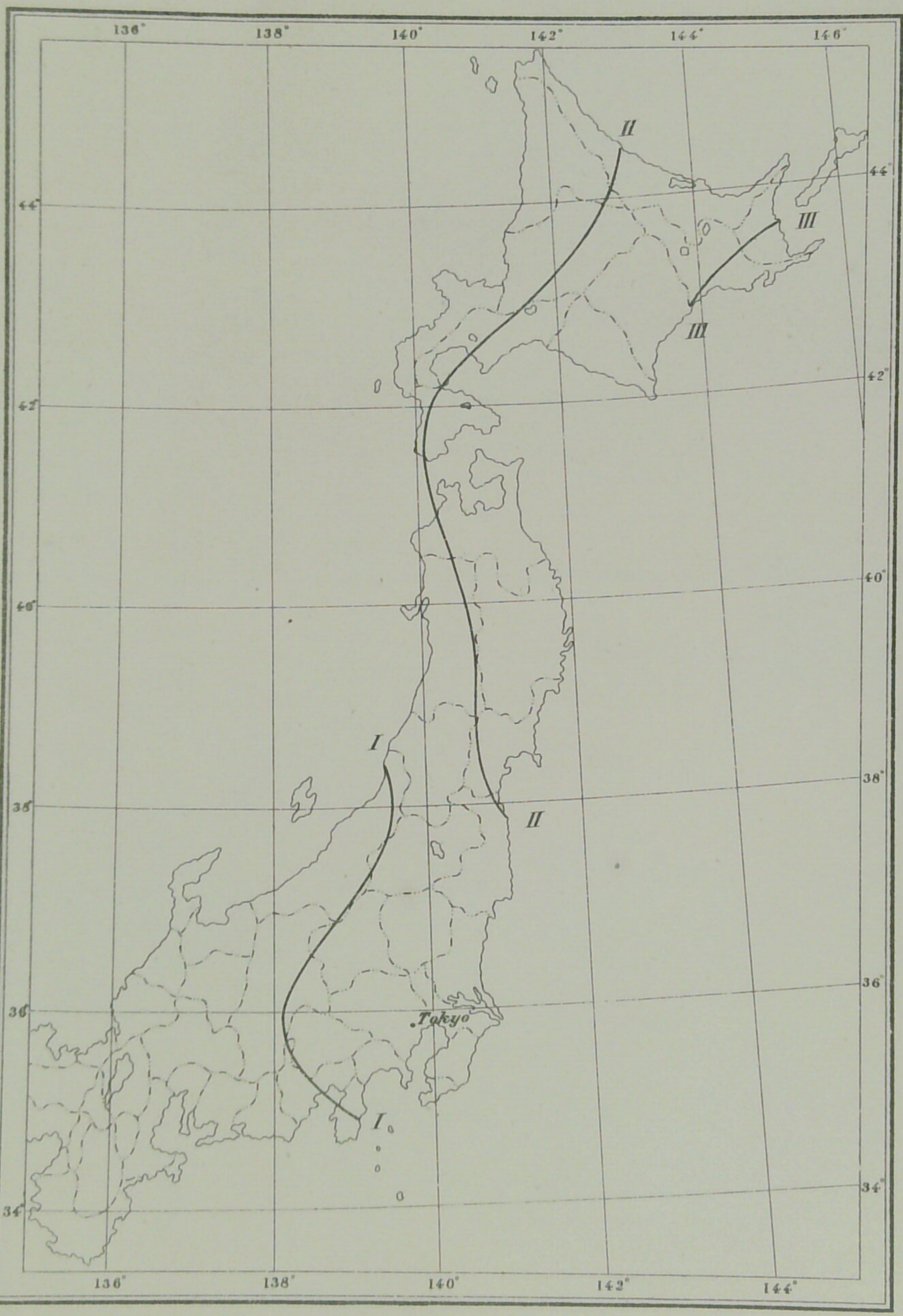
I I ..... Boundary of area of "slight" motion.
II II ..... " " "weak" "
III III ..... " " "strong" "



Boundary of provinces.

Fig. 37. Earthquake of May 8, 1899 ; 0h 28m 54s p.m.

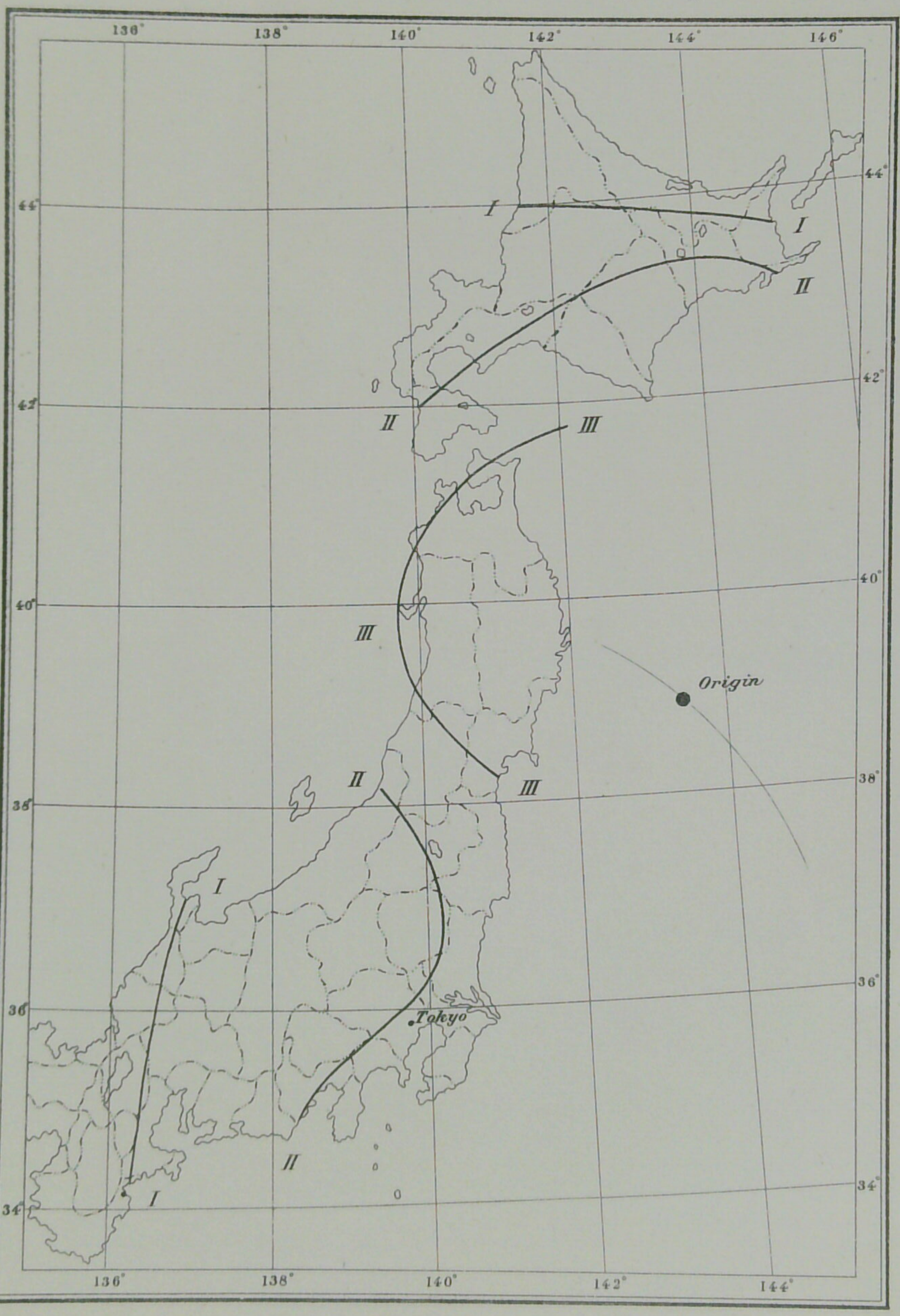
I I .... Boundary of area of "slight" motion.
II II ..... „ „ "weak" „
III III ..... „ „ "strong" „



Boundary of provinces.

Fig. 38. Earthquake of Sept. 30, 1901 ; 7h 21m 0s p.m.

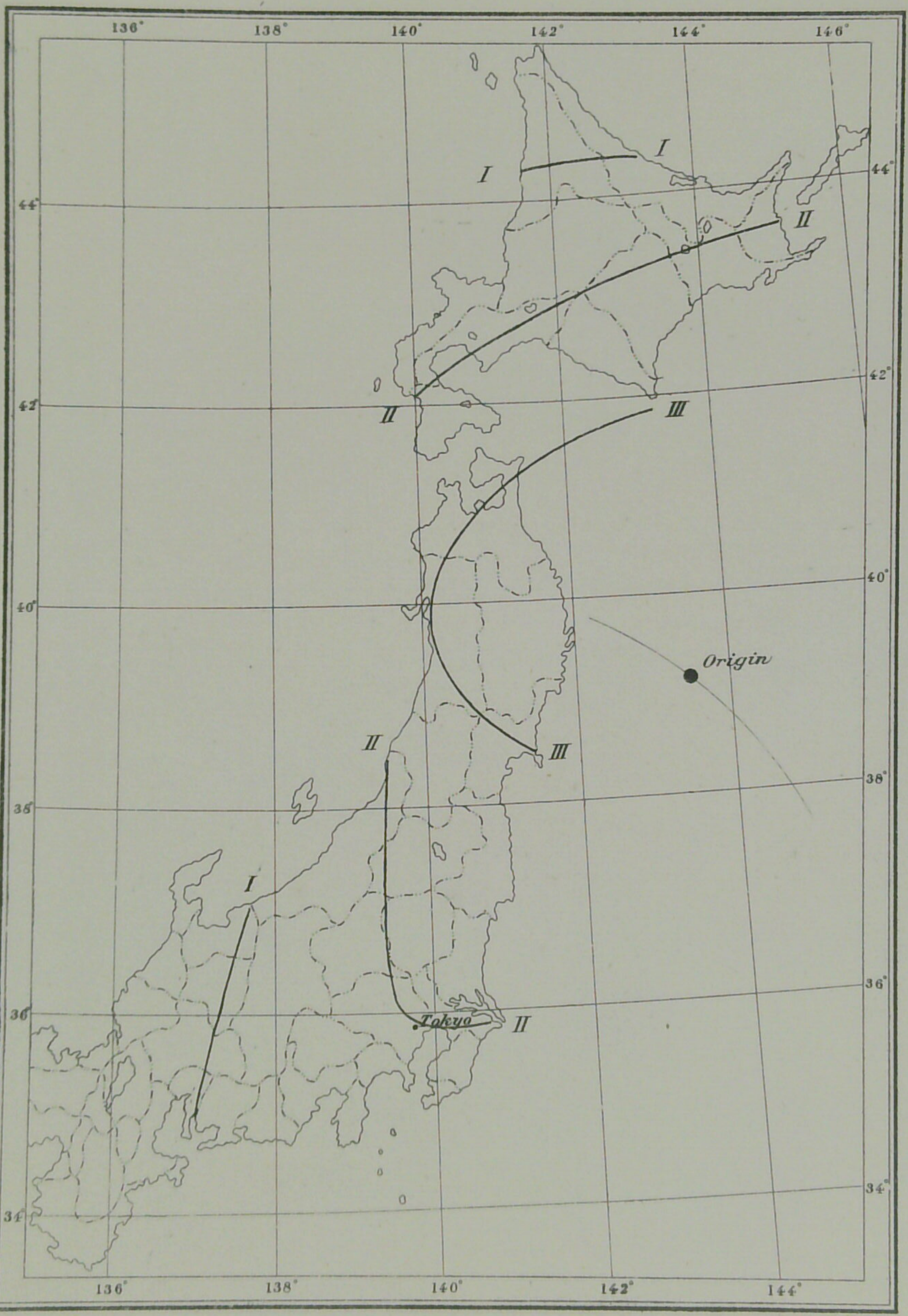
I I .... Boundary of area of "slight" motion.
II II .... " " "weak" "
III III .... " " "strong" "



Boundary of provinces.

Fig. 39. Earthquake of Jan. 30, 1901 ; 11h 1m 43s p.m.

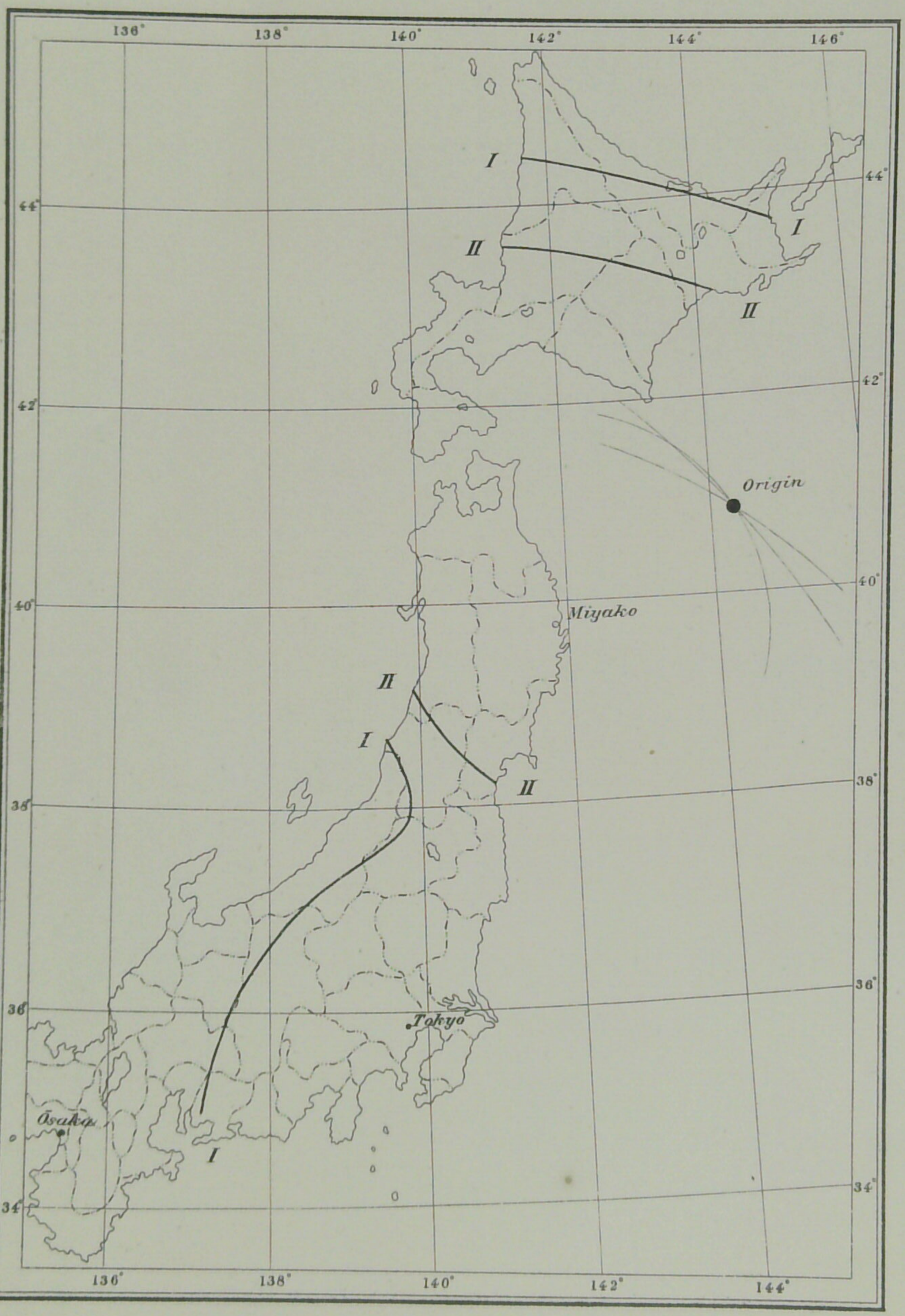
I I .... Boundary of area of "slight" motion.
II II .... " " "weak" "
III III .... " " "strong" "



Boundary of provinces.

Fig. 40. Earthquake of Jan. 31, 1900 ; 10h 42m 58s a.m.

I I .... Boundary of area of "slight" motion.
II II ..... „ „ "weak" „



Boundary of provinces.

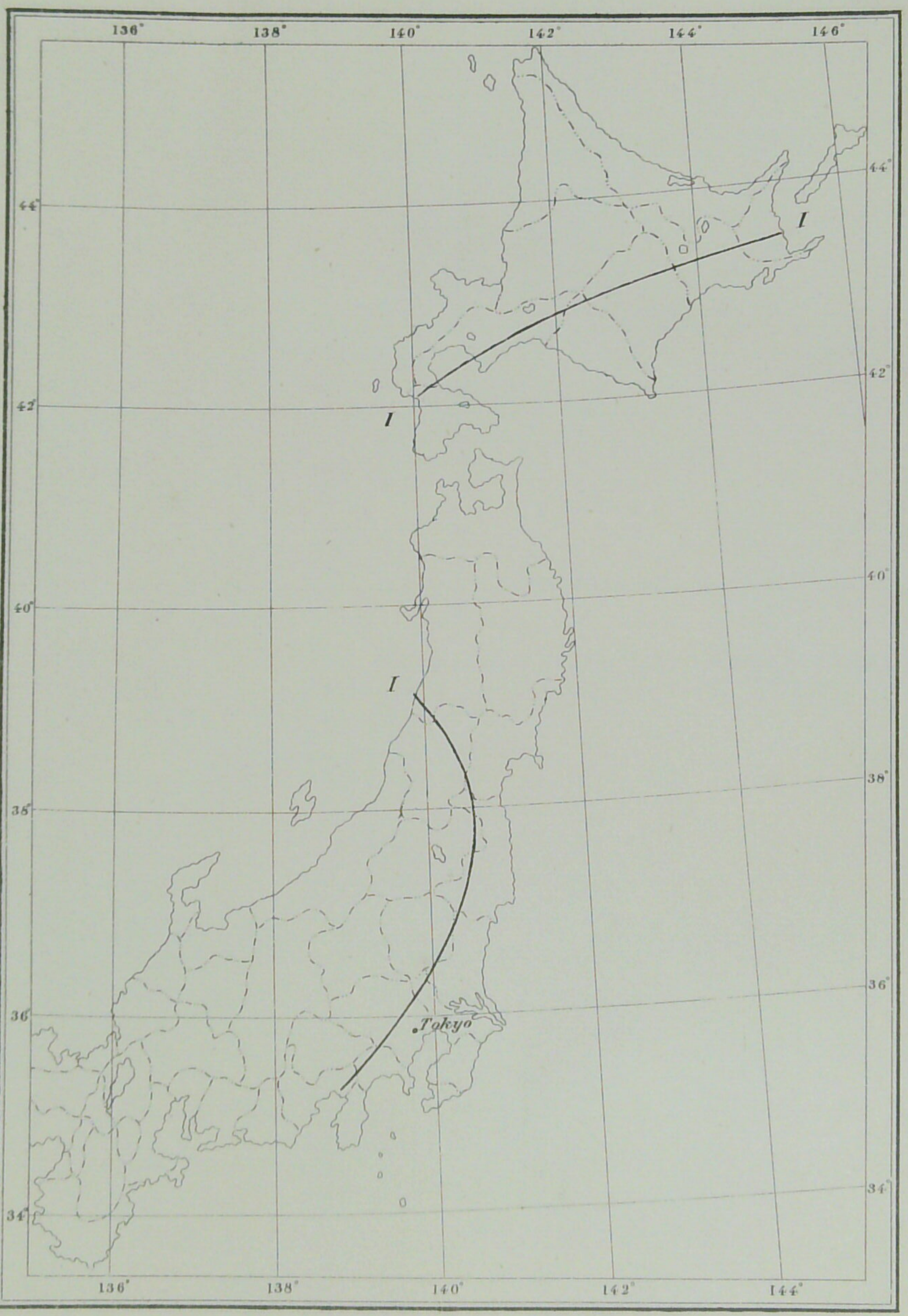
Fig. 41. Earthquake of July 11, 1899 ; 4h 40m 7s p.m.

I I ..... Boundary of area of "weak" and "slight" motion.

Boundary of provinces.

Fig. 42. Earthquake of Feb. 1, 1900 ; 4h 21m 7s a.m.

I I..... Boundary of area of "slight" motion.



Boundary of provinces.

2m 45s of the principal portion, the motion was smaller but remained nearly constant (max. $2a = 0.6$ mm), the average T being 7.2 sec.

In the "end portion," the average T was 7.4 sec.

VI. KYUSHYU AND ŌSHIMA (LYU-KYU) EARTHQUAKES.

37. Pl. XXXIII contains the earlier portions of the EW component diagrams of the following four earthquakes:—

Eqke No. 22. Nov. 25, 1899; 3h 45m 24s a.m.
„ No. 23. „ „ ; 3 58 48 a.m.
„ No. 24. June 24, 1901; 4 6 19 p.m.
„ No. 25. Aug. 25, 1904; 6 2 31 a.m.

The first two earthquakes originated in Kyushyu, while the two last originated off the Island of Ōshima (Lyu-Kyu).

Each of the diagrams of the 4 earthquakes described below has been obtained from the *C* instrument at Hongo.

KYUSHYU EARTHQUAKES. NOS. 22 AND 23. NOV. 25, 1899; 3^h 45^m 24^s AND 3^h 58^m 48^s A.M. (Fig. 43.)*

38. The first of these two earthquakes was the greatest which shook Kyushyu in recent years. In the two provinces of Bungo and Hyuga a few houses were overthrown and the ground was slightly cracked. The origin was probably inland and situated at about *long.* $131°\frac{1}{4}$ E and *lat.* $32°\frac{3}{4}$ N.

The "preliminary tremor," whose duration was 1m 42s, consisted

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* See the *Publications*, No. 6, pp. 134–138.

of 13 vibrations with an average T of 8.2 sec., the max. $2a$ being 0.5 mm. There were also some slight traces of very slow vibrations.

The "principal portion" began with an abrupt displacement of 2.2 mm towards W. Then followed a large vibration (marked $c'd'e'$) of $T=35.4$ sec., whose two displacements were respectively 6.4 mm towards E, and 6.5 mm towards W.

The next vibration was small, ($2a=3.0$ mm), its T being 22 sec. The next 5 vibrations were nearly equal in amplitude the last but one vibration having the max. $2a$ of 6.4 mm (marked $m'n'o'$); the first 3 having an average T of 23.3 sec., and the last two an average T of 17 sec. These slow waves which together lasted about 3 min. were superposed by small quick vibrations, apparently continued from the preliminary tremor. From 3h 49m 53s, or 4m 38s after the beginning of the earthquake, quicker waves became prominent; the motion consisting essentially of the following two types:—

(i) Vibrations with an average T of 8.0 sec., whose max. $2a$ of 2.7 mm occurred at about 3h 51m 15s.

(ii) Vibrations with an average T of 17.0 sec.; the maximum motion (marked b') of this type, ($2a=6.4$ mm), occurred at 3h 49m 25s, forming the last but one wave of the principal portion, or at 2m 28s after the commencement of the latter.

The exact commencement of the 2nd earthquake was obscured by the end portion of the first. The long period maximum vibration (marked b''), however, appeared at 3h 58m 39s, or 11m 42s after the occurrence of the corresponding wave in the 1st earthquake; the max. $2a$ (marked $c''d''e''$) being 2.9 mm and the period 31.3 sec. Then followed 6 well defined waves with an average T of 23 sec.; the slow vibrations together lasting 3 min. The absolute max. motion (marked $m''n''o''$) ($2a=3.6$ mm), whose T was 17.6 sec., occurred at 3h 15m 56s, or 2m 32s after the commencement of the principal portion and was the last but one of the latter. The movements marked $b'c'd'e'$.. ..$o'p'....q'$ in the 1st earthquake correspond to those marked $b''c'$ $d''e''....o''p''....q''$ in the 2nd.

The two earthquakes were thus exactly similar to each other; there being in each case first a maximum vibration of a very slow T of 35.4 to 31.3 sec. (mean 33.4 sec.), and subsequently another maximum wave whose T was about half of that of the first, namely, about 17s. The time intervals between $c'd'e'$ and $m'n'o'$ and between $c''d''e''$ and $m''n''o''$ were respectively 2m 3s and 2m 2s; while the time differences between $c'd'e'$ and $c''d''e''$ and between $m'n'o'$ and $m''n''o''$ were each 11m 35s.

In the "end portion" of the 2nd earthquake the average T, measured from 80 vibrations, was 8.1 sec.

ŌSHIMA EARTHQUAKES. NOS. 24 AND 25.
JUNE 24, 1901, AND AUG. 25, 1904. (Figs. 44 and 45.)

39. The 1st earthquake, whose origin was probably situated at a point *lat* 29° N and *long.* 132° E, was felt *violently* in the Island of Ōshima, and *weakly* in the greater portion of Kyushyu. (See Pl. XXXIV.) The origin of the 2nd earthquake which was felt *weakly* only at Ōshima and Miyazaki (province of Hyuga, in Kyushyu) and *slightly* at some other places, was probably situated a little to the E or SE of that of the 1st earthquake.

The number of the after shocks which followed these two earthquakes during the succeeding 30 days were 25 and 40 respectively. The observation of these after-shocks which were mostly slight unfelt ones, were as follows.

AFTER-SHOCKS OF THE ŌSHIMA EARTHQUAKE OF JUNE 24, 1901.

Observed at the Ōshima Met. Observatory.

Date.	Time of occurrence.	Intensity.	Date.	Time of occurrence.	Intensity.
June 24	4.h 16.m 00.s p.m.	Weak.	June 26	5.h 03.m 00.s p.m.	Slight.
,, ,,	5. 42. 00. ,,	Slight.	,, ,,	5. 05. 00. ,,	,,
,, ,,	10. 40. 00. ,,	Strong.	,, 28	5. 15. 00. ,,	,,
,, ,,	11. 03. 00. ,,	Slight.	,, 30	10. 13. 00. a.m.	,,
,, ,,	11. 44. 00. ,,	,,	July 1	3. 42. 00. ,,	,,
,, 25	0. 41. 00. a.m.	,,	,, 4	3. 08. 00. ,,	,,
,, ,,	0. 54. 00. ,,	,,	,, 7	0. 40. 00. p.m.	,,
,, ,,	1. 15. 00. ,,	,,	,, 10	1. 58. 00. ,,	,,
,, ,,	3. 01. 00. ,,	,,	,, 15	10. 58. 00. a.m.	,,
,, ,,	3. 50. 00. ,,	,,	,, 22	9. 05. 00. ,,	,,
,, ,,	5. 12. 00. ,,	,,	,, ,,	5. 28. 00. p.m.	,,
,, 26	11. 16. 00. ,,	,,	,, 23	4. 16. 00. ,,	,,
,, ,,	3. 57. 00. p.m.	,,			

AFTER-SHOCKS OF THE ŌSHIMA EARTHQUAKE OF AUG. 25, 1904.

Observed at the Met. Observatory of Ōshima.

Date.	Time of occurrence.	Intensity.	Date.	Time of occurrence.	Intensity.
Aug. 25	6.h 26.m 49.s a.m.	Slight.	Aug. 26	6.h 54.m 25.s p.m.	Slight.
,, ,,	6. 34. 07. ,,	,,	,, ,,	8. 56. 50. ,,	,,
,, ,,	7. 00. 12. ,,	,,	,, 27	0. 16. 50. ,,	,,
,, ,,	7. 12. 49. ,,	,,	,, 28	8. 52. 10. a.m.	,,
,, ,,	7. 23. 12. ,,	,,	,, ,,	7. 08. 30. p.m.	,,
,, ,,	7. 28. 14. ,,	,,	,, 30	10. 32. 30. a.m.	,,
,, ,,	7. 54. 24. ,,	,,	,, ,,	11. 33. 30. ,,	,,
,, ,,	8. 53. 24. ,,	,,	,, ,,	11. 37. 35. p.m.	,,
,, ,,	9. 24. 51. ,,	,,	Sept. 6	6. 27. 40. ,,	,,
,, ,,	9. 32. 46. ,,	,,	,, ,,	9. 18. 17. ,,	,,
,, ,,	10. 18. 37.* ,,	,,	,, 7	1. 47. 15. a.m.	,,
,, ,,	10. 47. 44. ,,	,,	,, ,,	1. 57. 11. ,,	,,
,, ,,	11. 25. 28. ,,	,,	,, ,,	2. 10. 30. ,,	,,
,, ,,	0. 28. 04. p.m.	,,	,, ,,	5. 36. 16.* ,,	,,
,, ,,	0. 54. 45. ,,	,,	,, 8	0. 15. 07. ,,	,,
,, ,,	1. 09. 45. ,,	,,	,, ,,	3. 22. 05. ,,	,,
,, ,,	2. 09. 56. ,,	,,	,, 10	6. 09. 40. ,,	,,
,, 26	2. 45. 05. ,,	,,	,, 15	7. 39. 27. ,,	,,
,, ,,	3. 45. 50. ,,	,,	,, 16	0. 37. 29. ,,	,,
,, ,,	5. 10. 24. ,,	,,	,, 17	10. 53. 46. ,,	,,

(* The two earthquakes marked with "asterisks" were *sensible*, all the rest being *unfelt* ones.)

It will be observed that the diagrams of the two Ōshima earthquakes (figs. 44 and 45) are similar in many respects, especially in the appearance of a slow vibration immediatley after the preliminary tremor. Some of the principal corresponding vibrations in the two seismograms are marked by similar letters; the chief points of difference being that the vibrations, whose T was about 9 sec. predominated more in the earthquake of June 24, 1901, than in the earthquake of Aug. 25, 1904. The following are the analysis of the seismograms.

40. ***Eqke No. 24. June 24, 1901; 4h 6m 19s p.m.*** (Fig. 44.)

The "preliminary tremor" lasted 2m 15s, corresponding to a radial distance of 1020 km. The motion consisted of the following two series of vibrations:—

Average $T=3.8$ sec., max. $2a=0.32$ mm;
„ $=4.7$ „ „ „ $=0.59$ „ .

There were also traces of slow vibrations whose T was about 16.6 sec.

The "principal portion," whose duration was 22 min. began with a slow vibration (*cde*), whose T was 25.7 sec., and whose 1st and 2nd displacements were respectively 2.6 mm toward W and 3.3 mm toward E; the 2nd and greater displacement being, as in the cases of Alasca and Tokyo earthquakes, directed away from the origin. For the next 3m 30s, the motion consisted of vibrations with an average T of 15.2 sec., whose max. $2a$ of 4.5 mm took place at the end of this epoch; there being also some vibrations with an average T of 9.5 sec. Thereafter, the movements became quicker (average $T=8.0$ sec.) and were most active during the next 2m 51s; the three max. $2a$'s of 4.4, 3.6, and 4.4 mm (marked *f*, *g*, and *h*) having taken place respectively at the beginning, near the middle, and at the end of this epoch, namely, at 6m 14s, 7m 31s, and 8m 41s from the commencement of the earthquake. For the next 7m 45s, (between the vibrations marked *h* and *k*,) during which the motion was on the whole constant, the average T was 8.3 sec. and 4 max. $2a$'s of 1.9

to 2.15 mm occurred in the latter part of this epoch; there being at first also some vibrations with an average T of 16.1 sec. For the next 7m 23s (between the vibrations marked k and l), the motion consisted of 52 well defined movements with an average T of 8.5 sec., whose max. $2a$ was 1.56 mm.

The "end portion." The average T measured about 1 hour after the commencement of the earthquake, was 8.4 sec. There were also some vibrations whose average T was 12.6 sec.

41. *Eqke No. 25. Aug. 25, 1904; 6h 2m 31s a.m.* (Fig. 45.)

The "preliminary tremor" lasted 2m 17s, corresponding to a radial distance of 1030 km. The motion consisted of the following two series of vibrations:—

Average $T=6.4$ sec., max. $2a=0.55$ mm;
„ $=3.1$ „ „ „ $=$ — .

There were also traces of slow vibrations, whose T was about 32 sec.

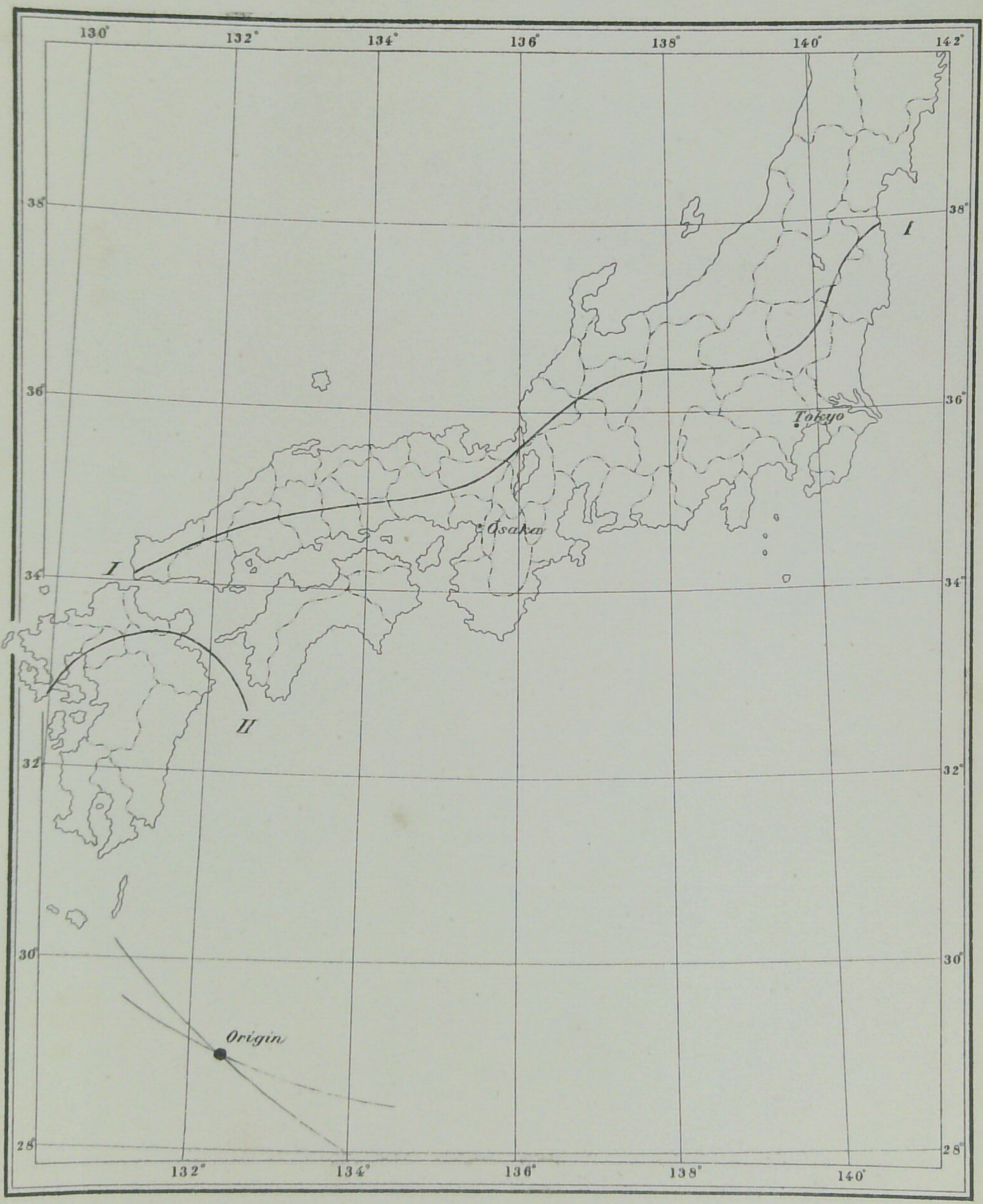
The "principal portion," whose duration was 22m 40s, began with a slow vibration of $T=24.5$ sec., whose two displacements were 3.0 mm toward W, and 3.24 mm toward E. For the next 3m 21s, the motion consisted of the following three sets of vibrations:—

Average $T=10.4$ sec., max. $2a=4.7$ mm;
„ $=15.8$ „ „ — ;
„ $=18.5$ „ „ „ $=4.65$ „ ;

the last maximum movement having occurred at the end of this epoch. For the next 3m 28s, the motion was most active and had an average T of 9.1 sec.; the 3 nearly equal max. $2a$'s of 7.4, 6.9, and 7.6 mm (marked f, g, and h), having taken place respectively at the commencement, middle, and end of this epoch, namely, 6m 29s, 7m 36s, and 9m 6s after the commencement of the earthquake. The occurrence of these 3 maxima is similar to the case of the Echigo earthquakes of May 26, 1898, and of May 8, 1904. (See §§ 9, 10 and 12.) For the next 7m 46s (between the vibrations marked h and k), the motion was on the whole constant and consisted of 51 well

Fig. 46. Earthquake of June 24, 1901 ; 4h 6m 19s p.m.

I I ..... Boundary of area of "slight" motion.
II II ..... „ „ "weak" „



Boundary of provinces.

defined vibrations with an average T of 9.2 sec., there being a series of max. $2a$'s of 3.8 to 4.2 mm. For the next 7m 40s, the motion was again nearly uniform, (max. $2a = 2.65$ mm), the average T being 8.7 sec.

In the "end portion," the average T measured about 1 hour after the commencement of the earthquake was 8.6 sec. There were also at several places vibrations whose average T was 13.1 sec.

42. A comparison of figs. 43 with figs. 44 and 45 shows that the character of motion and the prevailing periods in the Kyushyu earthquakes were nearly equal to those in the Ōshima earthquakes.

VII. CERAM AND NEW GUINEA EARTHQUAKES.

43. Pl. XXXV gives the earlier portion of the EW component diagrams of the following two earthquakes:—

Eqke No. 26. Sept. 30, 1899; 2h 11m 0s a.m.
,, No. 27. July 29, 1900; 4 8 42 p.m.

The 1st earthquake was the great disturbance which caused much damage along the southern coast of Ceram and in the neighbouring islands. Its origin was situated off the southern coast of Ceram, at about *long.* 129° E, *lat.* 6° S.

The origin of the 2nd earthquake was, according to Professor Milne, situated off the south-eastern coast of New Guinea, say, to S 15° E from Tokyo.

The duration of the total preliminary tremor of the Ceram earthquake was 9m 25s, and that of the New Guinea earthquake was 12m 22s (meaned from Hongo and Hitotsubashi diagrams), and corresponding radial distances were, according to the formula of the

preliminary tremor,* respectively 4410 and 5570 km, so that the origin of the former earthquake was about 1000 km nearer to Tokyo than that of the latter. Further the origins of these two earthquakes were respectively to the S 15° W and S 15° E of Tokyo. Notwithstanding these differences in distance and direction the diagrams of the two earthquakes obtained in Tokyo were very similar to one another. The ratio of the durations of the 1st and 2nd preliminary tremors are for each of the earthquakes as 1.6 : 1.

Among the vibrations identified in the two diagrams, which are marked by the same letters, the most conspicuous ones are the slow movement (*cd*) at the commencement of the principal portion, and the quicker vibrations (*jkl*) at the commencement of the 3rd phase of the same portion. Owing, however, to the greater distance of the origin of the New Guinea earthquake, and to the greater separation of the different phases from each other, there are a number of vibrations (such as *i'*) in its diagram, which do not find its equivalents in the diagram of the Ceram earthquake. The following are the analysis of the seismograms.

CERAM EARTHQUAKE. NO. 26. SEPT. 30, 1899.
EW COMPONENT; (A) INSTRUMENT. (Fig. 47.†)

44. The "1st preliminary tremor," whose duration was 5m 46s, consisted of vibrations with an average T of 8.9 sec., superposed by smaller ones with an average T of 3.6 sec.

The "2nd preliminary tremor," whose duration was 3m 39s, consisted of vibrations with an average T of 8.4 sec., superposed more or less distinctly by some slow vibrations.

The "principal portion" lasted about 10m and began with the conspicuous maximum vibration, whose T was 38 sec., and whose 1st and 2nd displacements were respectively 3.3 mm toward W and 5.4 mm toward E.

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* The *Publications*, No. 13.

† The description of the seismogram is taken from the *Publications*, No. 6.

The movements which followed this maximum were far smaller, their average T being 20 sec.

The "end portion." The average T, measured at about 1h after the commencement of the earthquake, was 12 sec.

NEW GUINEA EARTHQUAKE. NO. 27. JULY 29, 1900.

(D) INSTRUMENT. (Fig. 48.)

45. The following description refers to the EW component obtained at Hitotsubashi. The diagram is almost wave for wave perfectly identical with that given by the A instrument at Hongo.

The "1st preliminary tremor" lasted 7m 48s, the amplitude remaining on the whole constant. During the first 4m 25s, the motion consisted of vibrations with an average T of 10.4 sec. (max. $2a=0.28$ mm), superposed by those of an average T of 4.8 sec. (max. $2a=0.18$ mm); at the commencement there were also some vibrations whose average T's were 20.5 and 1.25 sec. During the remaining 3m 30s, the average T was 9.3 sec., and the max. $2a$ was 0.29 mm; there being also some small vibrations.

The "2nd preliminary tremor," lasted 4m 29s, the $2a$ being quite large and remaining on the whole constant throughout. The motion consisted principally of the following two series of vibrations:—

Average $T=26.8$ sec., max. $2a=1.13$ mm;
„ $T=10.0$ „ , „ $=0.58$ „ .

The "principal portion" lasted 29m 20s. The 1st vibration was very slow and had a T of 46.8 sec. ($2a=1.8$ mm), being superposed by 4 small vibrations with an average T of 10.6 sec. The T of the 2nd vibration was 31.2 sec., its $2a$ being 3.3 mm. For the next 1m 57s, there were 4 small vibrations (max. $2a=1.0$ mm), whose average T was 29.2 sec. For the next 2m 19s, the amplitude remained nearly the same as before, but the T became much quicker, the average value being 18.5 sec. For the next 1m 32s, there was a

maximum group of 4 vibrations with an average T of 22.9 sec., the 2nd having the greatest $2a$ of 4.3 mm. (This group probably marks the commencement of the 3rd phase of the principal portion.) Thereafter, the period quickened, and the vibrations were very nearly free from superpositions, and the motion during the rest of the principal portion consisted of a succession of maximum groups, which occurred at tolerably regular intervals. The $2a$'s and times of occurrence of these groups, commencing with the above-mentioned one, counted as No. 1, were as follows:—

No. of Max. Group.	Max. $2a$.	Time of occurrence, after the No. 1 Group.	
	mm	m.	s.
1	4.3	—	—
2	2.9	2	2
3	2.1	3	20
4	3.3	5	15
5	1.4	7	0
6	1.3	8	57
7	1.9	9	55
8	1.4	12	31
9	1.4	14	28
10	0.81	16	56
11	1.06	18	58
12	0.9	21	0
13	1.06	23	10

The above 13 maximum groups thus occurred at an average interval of 1m 56s. Each group comprised on the average about 40 vibrations, the 1st (in a few cases, the 2nd) vibration being the maximum one. The average T of the vibrations was 14.3 sec.

The "end portion." The $2a$ in the end portion was much smaller than in the principal portion. There were several max. $2a$'s (the abs. greatest, 6.0 mm) at intervals. Thus during the first 27m 50 s, there were 9 more or less distinct maximum groups, which occurred at an

average interval of 3m 6s. During this epoch the motion consisted of vibrations with an average T of 15.4 sec., mixed up with those of average T's of 11.3 sec. and 8.7 sec. Thereafter the motion became more regular and much smaller; the average T's deduced from 8 successive series each of 50 to 100 vibrations being as follows:—

10.3	sec.
10.5	,,
9.2	,,
9.6	,,
9.8	,,
9.6	,,
9.7	,,
9.9	,,

General mean, 9.8 sec.

There were at several places slower vibrations, whose average T's deduced from 4 successive series each of 20 to 90 vibrations, were as followes:—

14.6	sec.
14.1	,,
15.2	,,
14.6	,,

General mean, 14.6 sec.

At about 34m 40s after the end of the earthquake, that is to say, at 8h 43m 20s, there appeared very slight movements which lasted 1h 24m. At first the average T was 7.3 sec., but later on it was 13.9 sec. These vibrations are probably the same earthquake movements propagated along the major arc of the earth.

VIII. ALASCA EARTHQUAKES.

46. Figs. 49, 50, and 51, Pl. XXXVI give the earlier portions of the EW component diagrams of the following three Alasca earthquakes:—

Eqke No. 28. Sept. 4, 1899; 9h 31m 50s a.m.
„ No. 29. „ 11, „ ; 6 50 58 a.m.
„ No. 30. Oct. 9, 1900; 9 37 14 p.m.

The diagrams of Eqkes Nos. 28 and 29 (Figs. 49 and 50)* were obtained from *A* instrument, (whose pendulum had a free period of 28 sec.). In fig. 49, the record between *q* and *x* (not given in the figure, which was very large, was evidently due to the proper oscillations of the *steady mass*. In fig. 50, the large vibrations between *p'* and *u* are also probably due to a similar cause of the instrumental movement. Bearing these points in mind, the two seismograms, (figs. 49 and 50) will be found to be much similar to each other.

The diagram of Eqke No. 30 (fig. 51), which was given by the *C* instrument (natural period, 62 sec.), and which is nearly free from instrumental errors, will be found also to be much similar to the other two seismograms. The corresponding vibrations in the three figures are marked by the letters *abcd*. . .*xyza'b'*.

The 1st displacement, *bc*, of the well defined vibration at the commencement of the 2nd preliminary tremor was, in each case, directed toward E, that is to say, toward the origin, and the counter movement *cc'* toward W.

The following descriptions of the EW component diagrams of the three earthquakes are taken from the *Publications*, No. 13.

EQKE NO. 28. SEPT. 4, 1899. EW COMPONENT;
(A) INSTRUMENT. (Fig. 49.)

47. The "1st preliminary tremor," whose duration was 7m 36s, consisted of vibrations with an average *T* of 7.9 sec. (max. $2a = 0.25$ mm), superposed by still smaller ones with an average *T* of 3.5 sec. (max. $2a = 0.15$ mm). There were also traces of slow vibrations with an average *T* of 18 sec. The motion at the commencement was small, but distinct, the amplitude remaining on the whole constant.

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* Full diagrams of the two eartl quakes on Sept. 4 and 11, 1899 are given in the *Publications*, No. 5.

The "2nd preliminary tremor" lasted 6m 47s and began with a motion of 0.46 mm toward W, followed by a well pronounced vibration, whose T was 34 sec., and which consisted of the following two displacements:—(1st) 2.5 mm toward E, (2nd) 4.1 mm toward W. During the rest of this epoch the amplitude did not much vary and was slightly smaller than that of the above introductory wave, the average T being 25.2 sec. The chief vibrations were superposed by smaller ones of $T=7.9$ sec. (max $2a=0.6$ mm).

The "principal portion" lasted 50m 33s. [1st phase]:—Duration =2m 35s. The motion began with two well defined slow vibrations of an average T of 34.5 sec., the first of which had a max. $2a$ of 5.6 mm; there being also traces of slow vibrations whose average T was 1m 6s. [2nd phase]:—Duration=3m 48s. The motion consisted of 7 large vibrations, which had an average T of 32.6 sec.; the 2nd vibration having the max. (abs.) $2a$ of 15.2 mm. [3rd phase]:—Duration=4m 42s. The motion consisted of 10 vibrations, whose average T was 24 sec., and whose 1st vibration had a max. $2a$ of 11.1 mm; the last but one vibration being a 2nd maximum ($2a=5.7$ mm). [4th phase]:—Duration=5m 28s. The motion consisted of well defined vibrations with an average T of 14.9s (max. $2a=5.0$ mm); there being 5 nearly similar maxima, of which the 5th was the last but one vibration of this epoch. [5th phase]:—Duration=7m 20s. The motion was smaller and consisted of regular vibrations with an average T of 13.8 sec. (max. $2a=3.0$ mm); there being 5 nearly similar maxima, of which the last occurred at the end of this epoch. During the remaining 26m 40s of the principal portion, the motion was again much smaller and nearly constant, the average T being 13.4 sec. (max. $2a=1.7$ mm); there being also more or less distinct traces of vibrations with an average T of 25 sec.

The "end portion." For the first 21m 20s, the vibrations was nearly constant in amplitude (max. $2a=0.7$ mm), and had an average T of 20.6 sec., superposed by smaller ones with an average T of 9.7 sec. For the next 26m 0s, the motion again remained nearly con-

stant (max. $2a=0.55$ mm), the principal average T being 10.5 sec. Hereafter the motion became very uniform and had an average T of 10.0 sec. ($2a=0.13$ mm).

EQKE NO. 29. SEPT. 11, 1899. EW COMPONENT;
(A) INSTRUMENT. (Fig. 50.)

48. Total duration = 4 hours.

The "1st preliminary tremor," whose duration was 7m 43s, consisted of small vibrations with an average T of 4.3 sec., superposed by larger ones with an average T of 9.3 sec. The motion was almost perfectly uniform throughout this epoch, the max. $2a$ being 0.35 mm.

The "2nd preliminary tremor," whose duration was 6m 30s, began with a displacement of 2.0 mm toward E, followed by a counter motion of 3.1 mm toward W; the 2nd, 3rd and 5th vibrations were also large, and the two latter had a max. $2a$ of 3.4 mm, the average T being 25.3 sec. During the rest of this epoch, the motion was smaller (max. $2a=1.1$ mm) and had an average T of 23.5 sec. There were also small quick vibrations (max. $2a=0.25$ mm), whose average T was 5.8 sec.

The "principal portion" lasted 38m 12s. [1st phase]:—Duration = 1m 29s. The motion consisted of 2 nearly equal slow vibrations with an average T of 44.5 sec., whose $2a$ was 2.3 mm. [2nd phase]:—Duration = 3 m 21 s. The motion consisted of 6 large waves, of which the first 2 had an average T of 37 sec., and the following 4 an average T of 32.5 sec., the 5th vibrations having the max. $2a$ of 10.5 mm. [3rd phase]:—Duration = 8m 48s. The motion consisted of regular and nearly equal quicker vibrations, whose average T was 20.7 sec.; the 4th and the last vibrations having the max. $2a$ of 3.2 mm. [4th phase]:—Duration = 8m 42 s. The motion was again smaller, but nearly constant throughout, and had an average T of 14.9 sec.; the 2 maximum movements of 2.1 and 1.7 mm having taken place respectively 1m 20s after the commencement, and the end, of this

epoch. [5th phase]:—Duration = 7m 43 s. The motion was markedly smaller, but nearly constant throughout, and had an average T of 13.4 sec.; there being a series of nearly equal maximum movements ($2a = 0.9$ mm). [6th phase]:—During the remaining 8m 9s of the principal portion, the motion was again nearly uniform, the principal average T being 14.4 sec. (max. $2a = 0.8$ mm).

The "end portion." The max. $2a$ at the commencement of this portion was 0.65 mm, the general average being 9.8 sec.

EQKE NO. 30. OCT. 9, 1900. EW COMPONENT; (A) AND (C) INSTRUMENTS. (Fig. 51.)*

49. Total duration = 4 hours.

The "1st preliminary tremor" lasted 7m 22s, the amplitude being greater during the first 4m 39s than during the remaining 2m 43s. The motion consisted essentially of slow vibrations with an average T of 14.2 sec., whose max. $2a$ of 0.54 mm occurred 2m 42s after the commencement. These were superposed by quicker vibrations with an average T of 3.7 sec. (max. $2a = 0.16$ mm). During the first 2m 4s, there were also very small but perfectly distinct quick vibrations with an average T of 1.5 sec. (max. $2a = 0.04$ mm).

The "2nd preliminary tremor" lasted 5m 5s, and began with a displacement of 0.7 mm toward E, followed by a counter motion of 1.43 mm toward W. The $2a$'s of the 2nd and 3rd vibrations were 1.1 mm and 1.78 mm respectively, the average T being 19.6 sec. During the remainder of this epoch, the motion was smaller and consisted essentially of vibrations with an average T of 24.8 sec., superposed throughout by quick vibrations with an average T of 7.8 sec. (max. $2a = 0.75$ mm).

The "principal portion" lasted 30m 14s. [1st and 2nd phases]:—Duration = 4m 5s. The motion began with a very slow vibration, whose $2a$ was 1.48 mm and whose T was 44.7 sec., superposed by quick vibrations with an average T of 7.5 sec. Then there followed

* The description refers principally to the diagram obtained from the (D) instrument.

the max. (abs.) group, consisting of 4 vibrations, which together lasted 2m 23s and had an average T of 35.7 sec.; the 2nd vibration having the max. $2a$ of 4.3 mm. The following 2 vibrations were smaller ($2a=0.8$ mm) and had an average T of 28.6 sec. [3rd phase]:—Duration=6m 14s. The motion consisted of nearly uniform vibrations with an average T of 21.4 sec, the max. $2a$ of 1.5 mm occurring at the commencement and the end of this phase. [4th phase.]:—Duration=6m 40s. The motion was slightly smaller than before, and had an average T of 18.2 sec.; the max. $2a$ of 1.43 mm having occurred at the end of this phase. [5th phase.]:—During the remaining 13m 15s of the principal portion, the motion remained on the whole constant and consisted of vibrations with an average T of 14.6 sec. (max. $2a=0.78$ mm), mixed up with traces of slow movements of an average T of 25.0 sec.

The "end portion." During the first 52m 30s, the motion consisted of vibrations with an average T of 22.0 sec. (max. $2a=0.45$ mm), superposed by others with an average T of 9.6 sec. (max. $2a=0.3$ mm). Thereafter the motion consisted of regular vibrations with an average T of 8.6 sec. Further on the average T was 9.5 sec.

IX. CENTRAL AMERICA EARTHQUAKES.

50. Pl. XXXVII gives the EW component diagrams of the following two Guatemala earthquakes:—

Eqke No. 31. April 19, 1902; 11h 38m 47s a.m.
„ No. 32. Sept. 23, „ ; 5 38 8 a.m.

It will be observed that the two seismograms are much similar to each other. Some of the vibrations identified in the two earthquakes are marked by the letters a, b, c, ... w, x, y; the similarity being particularly perfect in the cases of the movements in the earlier

portions of the principal portion, namely, those marked *g*, *h*, ... *s*, *t*.

The two seismograms are also in many respects similar to those of the Caracas earthquake of Oct. 29, 1900, given in Pls. XII and XIII of the *Publications*, No. 5. The following description of the diagram of the earthquake of April 19, 1902, is taken from the *Publications*, No. 13.

EQKE NO. 31. APRIL 19, 1902. EW COMPONENT;
(A) INSTRUMENT. (Fig. 52.)

51. Total duration $=2\frac{1}{2}$ hours.

The "1st preliminary tremor" lasted 15m 40s. During the first 4m 35s, the motion was small and consisted of vibrations with an average T of about 9.2 sec. During the next 6m 32s, the motion consisted of larger vibration with an average T of 6.9 sec. (max. $2a$ $=0.28$ mm), superposed by ill defined traces of slow movements with an average T of about 16.3 sec. During the remaining 4m 22s, the motion was again much larger (max. $2a=0.65$ mm) and had an average T of about 13.1 sec.; there being some traces of slow vibrations with an average T of 40.3 sec. (max. $2a=0.81$ mm).

The "2nd preliminary tremor" lasted 14m 40s. During the first 4m 10s, the motion was small and consisted of vibrations with an average T of 8.6 sec. (max. $2a=0.88$ mm), superposed by slow vibrations with an average T of about 27.8 sec. During the remaining 10m 30s of this epoch, the vibrations had an average T of 28.3 sec.; the two max. $2a$'s of 1.2 mm and 1.0 mm having occurred respectively 4m 10s and 8m 35s after the commencement of the 2nd preliminary tremor. There were also small vibrations whose average T was about 8.5 sec.

The "principal portion." [1st phase]:—Duration $=7$m 4s. The motion began with 6 well defined and nearly equal vibrations (max. $2a=0.7$ mm) of an average T of 38.7 sec., superposed by traces of small vibrations of an average T of 7.3 sec. During the next 3m

12s, the motion was small (max. $2a=0.25$ mm) and the average T was again 38.7 sec. [2nd phase]:—Duration=4m 13s. For the first 2m 13s, the motion was larger (max. $2a=0.94$ mm), the average T being 33.3 sec. Then followed 4 well defined vibrations which together lasted 2m 0s and had an average T of 26.7 sec.; the 2nd and 4th waves had each a max. $2a$ of 2.8 mm, while the 1st and 3rd ones had respectively $2a$'s of 1.4 and 2.0 mm. [3rd and subsequent phases.]:—During the first 3m 51s, the motion consisted of vibrations with an average T of 20.1 sec.; the last and the last but two vibrations having respectively the max. $2a$'s of 0.63 mm and 0.5 mm. For the next 9m 43s, the motion consisted essentially of vibrations with an average T of 34.3 sec., of which the max. $2a$ of 0.63 mm occurred 7m 45s after the commencement of this epoch. During the next 17m 58s, the average T was 21.6 sec., the max. $2a$ being 0.44 mm. Again, during the next 9m 22s, the principal average T was 18.7 sec., the max. $2a$ being 0.31 mm. Then the motion became again somewhat active and there appeared, during the next 13m 0s, slow vibrations whose average T was 28.4 sec. (max. $2a=0.31$ mm), mixed with movements with an average T of 18.4 sec. This group, which occurred at 1h 1m 36s p.m., or 1h 22m 49s after the commencement of the earthquake probably indicates the same seismic disturbance propagated along the other path round the earth. Thereafter the motion became gradually small and regular, the average T being 21.3 sec.

EQKE NO. 32. SEPT. 23, 1902. EW COMPONENT;
(A) INSTRUMENT. (Fig. 53.)

52. Total duration=3 hours.

The "1st preliminary tremor" lasted 14m 46s. During the first 5m 16s, the motion was small. During the next 5m 49s, the motion consisted of large and regular vibrations (max. $2a=0.1$ mm) of $T=7.0$ sec., mixed up with two series of small movements whose T's were respectively 4.3 and 11.6 sec. During the remaining 3m 45s, the motion was slightly larger (max. $2a=0.35$ mm) and had an

average T of 14.1 sec., there being also some superposed small vibrations.

The "2nd preliminary tremor" lasted 15m 44s. During the first 5m 26s, the motion was small (max. $2a=0.4$ mm) and had an average T of 11.4 sec.; there being also two series of small vibrations whose average T's were 8.9 and 30.4 sec. respectively. Then there appeared a prominent single slow vibration of $T=39.3$ sec., whose $2a$ was 0.88 mm. A 2nd conspicuous vibration of $T=24.0$ sec., whose $2a$ was 0.35 mm, occurred 10m 25s after the commencement of the 2nd preliminary tremor, the motion in the interval between these two maxima consisting of small quick vibrations. The remaining part of this epoch consisted of slow vibrations of $T=30.7$ sec., snperposed by those of $T=7.7$ sec.

The "principal portion." [1st phase]:—Duration=6m 51s. The motion began with a slow vibration of $T=43.5$ sec., whose $2a$ was 0.23 mm. This was followed by another vibration whose T and $2a$ were 35.5 sec. and 0.5 mm respectively. For the next 4m 56s, the motion was small, the average T being 37 sec. [2nd phase]. For the first 4m 22s, the motion was composed of 8 prominent vibrations: the 1st 5, which lasted 3m 0s, had an average T of 36 sec., while the remaining 3, which formed the most active part of the eathquake, had an average T of 26.5 sec.; the max. $2a$'s of these two groups of vibration being 0.75 and 2.95 mm respectively. Thereafter the motion was smaller, and the average T, deduced from 3 successive series each of 40 vibrations, were 20.9, 19.4, and 19.8 sec. respectively; there being some occasional maximum movements, as u ($2a=0.70$mm), v ($2a=0.45$ mm), w, x, and y.

The EW component diagram obtained from the (C) instrument is given in the *Publications*, No. 16.

X. *ASIA MINOR AND BALKAN EARTHQUAKES.*

53. Pl. XXXVIII gives the EW component diagrams of the Asia Minor and Balkan earthquakes, whose dates and times of occurrence (at Tokyo) were as followes:—

Eqke No. 33. Sept. 20, 1899; 11h 24m 27s a.m.
„ No. 34. April 4, 1904; 7 38 14 p.m.

The origins of these two earthquakes were in the vicinity of each other, their distances from Tokyo being consequently nearly equal.

The two diagrams are similar in many respects, the corresponding vibrations being indicated by the same letters.

EQKE NO. 33. SEPT. 20, 1899. EW COMPONENT;
(A) INSTRUMENT. (Fig. 54.)

54. Total duration = 1h 46m.

The "1st preliminary tremor," whose duration was 10m 19s, consisted of small vibrations with an average T of 6.0 sec. (max. $2a$ = 0.06 mm); superposed more or less distinctly by slower waves of T = 8.7 sec.

The "2nd preliminary tremor" lasted 12m 0s and consisted of regular vibrations of T = 10.5 sec. (max. $2a$ = 0.1 mm), superposed by some minute vibrations.

The "principal portion." [1st and 2nd phases]:—Duration = 12m 0 s. For the first 4m 35 s the motion consisted of small vibrations (max. $2a$ = 0.1 mm) with an average T of about 13.4 sec., superposed by some ill defined slow vibrations. For the next 4m 50s, the motion was more active and consisted of 7 nearly equal slow vibrations with an average T of 41.4 sec. (max. $2a$ = 0.12 mm), superposed by smaller vibrations of T = 10.8 sec. During the next 3m 9s, the motion consisted of 6½ well defined uniform vibrations with an average T of 29.0 sec. (max. $2a$ = 0.19 mm), superposed by some slight vibrations of T = 11.1 sec. [3rd phase]:—Duration = 11m 45s. The motion consisted, during the first 7m 18s, of vibrations with an average T

of 24.3 sec. (max. $2a=0.45$ mm), followed by a single large vibration (abs. max.) of $2a=0.9$ mm and of $T=16.7$ sec.; the movement during the remaining 4m 16s of this epoch having an average T of 18.3 sec. superposed by smaller vibrations. [4th phase.]:—During the remaining 8m 28s of the principal portion, the motion was much smaller and nearly constant, the average T being 13.4 sec. (max. $2a=0.2$ mm).

The "end portion." The motion consisted of small regular vibrations, whose average T was 13.9 sec. (max. $2a=0.05$ mm).

EQKE NO. 34. APRIL 4, 1904. EW COMPONENT;
(A) INSTRUMENT. (Fig. 55.)

55. There were two earthquakes, whose times of occurrence (at Tokyo) were respectively 7h 15m 16s and 7h 38m 14s p.m.; the motion before the commencement of the 2nd earthquake being very small.

The following description refers chiefly to the EW component diagram obtained from the (C) instrument.

1st Earthquake.

The "1st preliminary tremor," which lasted 11m 15 s, consisted of vibrations (max. $2a=0.02$ mm) with an average T of 5.1 sec., mixed up with slight *pulsatory oscillations.*

The "2nd preliminary tremor" was larger at its commencement than at the end. The average T was 7.7 sec.

2nd Earthquake.

The "1st preliminary tremor" lasted 10m 24s. The motion was much greater in the first half (max. $2a=0.038$ mm) than in the second half of this epoch. The average T was 5.9 sec.

The "2nd preliminary tremor" lasted about 12 m 0 s. The motion consisted essentially of the following 3 kinds of vibrations:—

(i) Average $T=17.1$ sec., max. $2a=0.17$ mm;
(ii) „ $=10.4$ „ , „ $=0.12$ „ ;
(iii) „ $=7.3$ „ , „ $=0.06$ „ .

The "principal portion." [1st and 2nd phases]:—Duration = 10m

25s. For the first 5m 35s, the motion consisted of 4 slow vibrations, whose average T was 54.0 sec. For the next 3m 0s, there were 5 vibrations of $T=36$ sec. The remaining 1m 49s was made up of 4 vibrations with an average T of 27.3 sec., the last 2 having the max. $2a$ of 0.14 mm. Throughout this epoch there were superpositions of small vibrations whose average T were 9.6 to 12.9 sec. [3rd phase]:— Duration=9m 5s. For the first 1m 13s, the motion was small. For the next 1m 28s, the motion was most active and consisted of 5 regular vibrations with an average T of 17.6 sec.; the last vibration having the max. $2a$ of 0.74 mm. For the next 3m 15s, the motion was small (max. $2a=0.28$ mm), the average T being 14.0 sec. For the next 2m 29s, the motion, which had an average T of 15.7 sec., was again larger, the last vibration having the max. $2a$ of 0.74 mm. For the remaining 40 sec., the motion was small. [4th and subsequent phases]:—The predominating vibrations had an average T of 11.1 sec., these being superposed by slower ones of T=about 19 sec.

In the "end portion," vibrations of $T=8.3$ sec. were superposed by those of $T=17.8$ sec.

Summary of Results.

56. The miscellaneous remarks given below are based principally on the seismograms described in the preceding pages, as well as on the diagrams of the following six earthquakes:—

Eqke	No. 1′.	June 7, 1904;	5h	19m	32s	p.m.
,,	No. 2′.	March 7, 1899;	9	55	29	a.m.
,,	No. 3′.	Jan. 6, 1900;	4	6	24	a.m.
,,	No. 4′.	Aug. 22, 1902;	0	9	33	p.m.
,,	No. 5′.	Jan. 20, 1900;	3	52	39	p.m.
,,	No. 6′.	Oct. 29, 1900;	6	29	22	p.m.

Eqke No. 1′ originated off the north-eastern coast of the Main Island. Its EW component diagram together with a description have already been given in this volume, pp. 1—3.

Eqke No. 2′ was a large disturbance which originated off the eastern coast of the Kii peninsula. In Osaka and the two provinces of Yamato and Kii considerable damage was produced. The EW component diagram of this earthquake is given in the *Publications*, No. 5. The determination of the epicentre is treated of in the *Publications*, No. 13, p. 92.

Eqkes Nos. 3′ and 5′ had their origins respectively in Sumatra and Mexico. Eqkes Nos. 4′ and 6′ were the great Turkestan and Caracas disturbances, whose EW component diagrams are given in the *Publications*, Nos. 13 and 5 respectively.

The seismographic analysis of the 4 distant earthquakes, Nos. 3′ to 6′, is given in the *Publications*, No. 13.

XI. DIRECTION OF MOTION.

57. *Earthquakes of Group* (i).

In the EW component diagrams of the different Tokyo local earthquakes, (§ 6), the preliminary tremor was abruptly followed by the maximum vibration, whose T varied between 2.1 and 3.5 sec., giving an average value of 2.9 sec. The 1st and 2nd displacements of the maximum vibration were always directed respectively towards the east and toward the west; the origin of disturbance being situated in each case, so far as the EW direction is concerned, to the east of the place of observation (Tokyo). The 2nd displacement or the maximum range of motion, was on the average 1.3 times greater than the 1st displacement, which is to be regarded as the semi-range or single amplitude.

58. *Earthquakes of Groups* (ii) *to* (ix).

From the uniformity of the character of motion in the Tokyo local shocks (§ 57), we may suppose that the direction at a given station of the 1st displacement of the maximum vibration, or of the decided displacement at the commencement of the "1st preliminary tremor," the "2nd preliminary tremor," or the "principal portion," must be directed, in the cases of *strong* earthquakes originating at a given district, always toward, or always away from, the centre of disturbance; provided the causes of the different earthquakes be similar to one another. I shall provisionally denote these two kinds of earthquakes respectively as "1st type earthquake" and "2nd type earthquake."

59. *1st Type Earthquakes.*

In the majority of the earthquakes examined in the preceding pages, the 1st well pronounced displacement (single amplitude, a) was, so far as the EW component is concerned, directed toward the origin; and the counter or greater displacement (double amplitude, $2a$) directed away from the latter; as shown in the following table, in

which the different earthquakes are divided into two groups A and B, according as the origins were in a westerly direction or an easterly direction, from Tokyo.

TABLE I.

DIRECTION OF MOTION. (*EW Component.*)

1st TYPE EARTHQUAKES.

Earthquake.		Movement at the Commencement of the		
No.	Origin.	1st Prel. Tremor.	2nd Prel. Tremor.	Princ. Portion.
		[A]		
7.	Echigo.	mm. 1st displ. $a=0{\cdot}2$; W. 2nd „ $2a=0{\cdot}7$; E. 3rd „ $2a=1{\cdot}6$; W.	———	mm. 1st displ. $a=2{\cdot}75$; W. 2nd „ $2a=4{\cdot}95$; E. 3rd „ $2a=6{\cdot}1$; W. (Pointer went off, toward E.)
8.	Echigo.	mm. 1st displ. $a=0{\cdot}34$; W. 2nd „ $2a=0{\cdot}65$; E.	———	1st displ. $a=2{\cdot}5$; W. 2nd „ $2a=5{\cdot}2$; E. 3rd „ $2a=5{\cdot}8$; W.
2′.	Kii.	———	———	1st displ. $a=4{\cdot}5$; W. 2nd „ $2a=6{\cdot}7$; E. 3rd „ $2a=6{\cdot}7$; W.
22.	Kyushyu.	———	———	1st displ. $a=2{\cdot}2$; W. 2nd „ $2a=6{\cdot}4$; E. 3rd „ $2a=6{\cdot}5$; W.
24.	Ōshima.	———	———	1st displ. $a=2{\cdot}6$; W. 2nd „ $2a=3{\cdot}3$; E.
25.	Oshima.	———	———	1st displ. $a=3{\cdot}0$; W. 2nd „ $2a=3{\cdot}24$; E.
26.	Ceram.	———	———	1st displ. $a=3{\cdot}3$; W. 2nd „ $2a=5{\cdot}4$; E. 3rd „ $2a=5{\cdot}0$; W.
27.	New Guinea.	———	1st displ. $a=0.6$; W. 2nd „ $2a=1.35$; E. 3rd „ $2a=1{\cdot}0$; W.	1st displ. $a=1{\cdot}5$; W. 2nd „ $2a=2.9$; E. 3rd „ $2a=2{\cdot}4$; W.

TABLE I. (*Continued.*)

Earthquake.		Movement at the Commencement of the		
No.	Origin.	1st Prel. Tremor.	2nd Prel. Tremor.	Princ. Portion.
		[B]		
20.	Off the N. E. Coast of Main Island.	——	——	mm. 1st displ. $a=0{\cdot}6$; E. 2nd „ $2a=2{\cdot}75$; W. 3rd „ $2a=2{\cdot}75$; E.
28.	Alasca.	——	mm. 1st displ. $a=2{\cdot}5$; E. 2nd „ $2a=4{\cdot}1$; W. 3rd „ $2a=3{\cdot}3$; E.	——
29.	Alasca.	——	mm. 1st displ. $a=2{\cdot}0$; E. 2nd „ $2a=3{\cdot}1$; W. 3rd „ $2a=1{\cdot}8$; E.	——
30.	Alasca.	——	mm. 1st displ. $a=0{\cdot}6$; W. 2nd „ $2a=0{\cdot}6$; E.	——

Thus in the earthquakes of Class A, or those of Groups (ii), (v), and (vi), the 1st decided displacement was always directed towards he west; while in the earthquakes of Class B, or those of Groups (i) and (vii), it was directed towards the east. In the earthquakes of Groups (viii) and (ix), the motion was not so large as in the above-mentioned groups, and the vibration at the commencement of each phase was not sufficiently well defined so as to enable us to distinguish between the 1st displacement (a) and the 2nd displacement ($2a$).

60. ***2nd Type Earthquakes.***

The following table gives examples of those earthquakes in which the 1st decided displacement was directed away from the origin of disturbance; the division into A′ and B′ classes being in the same sense respectively as A and B classes in Table I.

TABLE II. DIRECTION OF MOTION. (*EW Component.*)

2nd TYPE EARTHQUAKES.

Earthquake.		Movement at the Commencement of the		
No.	Origin.	1st Prel. Tremor.	2nd Prel. Tremor.	Princ. Portion.
		[A′]		
9.	Izu.	——	——	mm 1st displ. $a=4.9$; E.
10.	Izu.	——	mm 1st displ. $a=0.16$; E. 2nd „ $2a=0.29$; W.	1st displ. $a=4.75$; E. 2nd „ $2a=1.05$; W. 3rd „ $2a=1.22$; E. (Pointer went off, toward W.)
		[B′]		
11.	Off the N.E. coast of Main Island.	mm 1st displ. $a=1\,2$; W. 2nd „ $2a=1.7$; E.	——	——
21.	„	——	——	1st displ. $a=0.3$; W. 2nd „ $2a=1.2$; E. 3rd „ $2a=1.4$; W.
1′	„	1st displ. $a=0.37$; W. 2nd „ $2a=0.57$; E.	——	1st displ. $a=1.2$; W. 2nd „ $2a=3.2$; E. 3rd „ $2a=3.4$; W.

Thus in the earthquakes of A′ class, the 1st decided displacement was directed toward the east, while in those of B′ class it was directed toward the west. The numerous fore and after shocks of the great Izu disturbance, Eqke No. 9, (Group iii), had also the same character: the 1st displacement in the "principal portion" of the EW component motion being in each case directed toward the east. (See the *Publications*, No. 13, p. 77.) The earthquakes of Group (iv) belong partly to the 1st type and partly to the 2nd type.

61. ***Comparison of the successive displacements.*** The following table gives, for the earthquakes of Groups (ii) to (ix), the range, or magnitude, of the 1st, 2nd, and 3rd displacements, which occurred at the commencement of the preliminary tremor or the prin-

cipal portion ; only those cases having been taken in which the displacements were well defined and large than 1 mm.

TABLE III. 1st, 2nd, and 3rd Displacements.

Eqke No.	Phase of motion.	1st displ. (a)	2nd displ. ($2a$)	3nd displ. ($2a$)	Ratio : 2nd displ. / 1st displ.	Ratio : 3rd displ. / 1st displ.
		mm	mm	mm		
7.	Princ. Portion.	2.75	4.95	6.1	1.8	2.2
8.	,,	2.5	5.2	5.8	2.1	2.3
8.*	,,	2.4	3.0	—	1.3	—
9.*	,,	2.4	2.8	—	1.2	—
10.	,,	4.75	10.5	12.2	2.2	2.6
11.	1st Prel. Tremor.	1.2	1.7	—	1.4	—
1′....	1st Prel. Tremor.	0.37	0.57	—	1.5	—
	Princ. Portion.	1.2	3.2	—	2.7	—
22.	Princ. Portion.	2.2	6.4	6.5	2.9	3.0
24.	,,	2.6	3.3	—	1.3	—
25.	,,	3.0	3.24	—	1.1	—
26.	,,	3.3	5.4	5.0	1.6	1.5
27.	,,	1.5	2.9	2.4	1.9	1.6
28.	2nd Prel. Tremor.	2.5	4.1	3.3	1.6	1.3
29.	,,	2.0	3.1	1.8	1.6	0 9
	Mean.	—	—	—	**1.8**	**1.9**

Thus the 2nd and 3rd displacements were very nearly equal to twice the 1st displacement, the average values of the ratios of the 2nd to the 1st and of the 3rd to the 1st being respectively 1.8 and 1.9. The 2nd and 3rd displacements are to be regarded as practically equivalent to one another. (For the case of the Tokyo local shocks the reader is referred to § 6.)

MACRO-SEISMIC MOVEMENTS.

62. For the sake of reference I give here the direction observations at Tokyo relating to the three severe earthquakes experienced at the latter, as well as some observations made at the Miyako Meteorological Observatory. The measurements in these cases were

* These two cases refer to the NS component diagrams, all the rest referring to the EW ones.

made by a "strong motion seismograph," or an ordinary macro-seismograph of Ewing or Gray-Milne type.

63. ***Earthquake Measurements in Tokyo.****

(*A*) Earthquake of Oct. 15, 1884; 4h 21m 54s a.m. (Hitotsubashi). This was a severe earthquake which caused some slight damage in Tokyo. The origin was at a distance of about 200 km to the S 60° E of Tokyo, namely, at *lat.* 35° N, and *long.* 141°½ E. The preliminary tremor was suddenly followed by a large vibration of $T=2.0$ sec., whose 2 displacements were as follows:—

1st displ..... $a=13$ mm, Direction S 60° E;
2nd „ .....$2a=42$ mm, „ N 60° W.

(*B*) Earthquake of Jan. 15, 1887; 6h 52m 0s p.m. (Hitotsubashi). This was also one of the severest earthquakes felt in Tokyo in recent years; the centre of the epi-focal region being at about 55 km to S 60° W from the place of observation. The 1st displacement of the principal portion was 27 mm and directed toward S 75° W. The average T was 0.97 sec.

(*C*) Earthquake of June 20, 1894; 2h 4m 10s p.m. (Hongo.) This was the most violent earthquake that shook Tokyo since the well known great catastrophe of the 2nd year of Ansei (1855). The meizoseismal tract, or epifocus, was a zone which extended in nearly NS direction from the vicinity of the town of Iwatsuki to the eastern part of Tokyo. The maximum vibration, which occurred immediately after the preliminary tremor, had a T of 1·8 sec., its 2 displacements being an follows.

1st displ..... $a=37$ mm, Direction N 85° E;
2nd „ .....$2a=73$ „ , Direction S 70° W.

64. ***Earthquake Measurements at Miyako.***†

(*D*) Earthquake of Jnne 17, 1896; 0h 46m 25s p.m. Intensity

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* See F. Omori: Macro-seismic measurements is Tokyo, III. The *Publications*, No. 11.

† See F. Omori and K. Hirata: Earthquake measurement at Miyako. The Jour. Sci. Coll. Imp. Univ. Tokyo, vol. XI, pp. 161—195. The three earthquakes here noted are those whose direction observations were made satistactorily.

"slight." The origin of the earthquake was about 170 km to ENE of Miyako. The maximum vibration, whose T was 1.7 sec., and which occurred at the beginning of the principal portion, consisted of the following 2 displacements:—

1st displ..... $a=2.9$ mm, Direction E 25° N;
2nd „ .....$2a=4.1$ mm, Direction W 25° S.

(*E*) Earthquake of Aug. 31, 1896; 4h 42m 15s p.m. Intensity, "strong." This earthquake was strongly felt in the two provinces of Ugo and Rikuchu and was one of the fore-shocks of the destructive earthquake, which took place on the same day at 5h 9m 55s p.m. The epicentre was at a distance of about 100 km to S 80° W from Miyako. The 2 displacements of the vibration at the commencement the principal portion were as follows:—

1st displ..... $a=5.1$ mm, Direction N 70° W;
2nd „ .....$2a=7.5$ mm, Direction S 83° E.

The next vibration, which was the maximum motion, was composed of the following 2 displacements:—

1st displ..... $a=9.0$ mm, Direction S 79° W;
2nd „ .....$2a=9.0$ mm, Direction N 79° E.

The average T of these vibrations was 1.0 sec.

(*F*) Earthquake of Feb. 7, 1897; 4h 35m 30s p.m. The earthquake consisted of 2 shocks with a time interval between them of about 1 minute, the intensity of the 1st shock being "weak" and that of the 2nd being "strong." The epicentre, or the central point of the meizoseismal area, was at a distance of about 130 km to S 60° W of Miyako. The first two displacements at the commencement of the principal portion were as follows:—

1st displ..... $a=5.5$ mm, Direction SW;
2nd „ .....$2a=17.0$ mm, Direction N 55° E.

The next displacement, which was the maximum motion, was as follows:—

$2a=28.0$ mm, Direction S 65° W.

65. From the two preceding §§, it will be seen that in the cases of the 6 earthquakes observed at Tokyo and Miyako the 1st decided *macro-seismic* displacement was always directed exactly, or approximately, toward the origin of disturbance; these earthquakes belong, therefore, to what has been termed the "1st type" disturbance (§ 58.). A comparison of the 1st and 2nd displacements is given in the following table.

TABLE IV. 1st and 2nd DISPLACEMENTS.

[Macro-seismic Motion.]

Eqke.	1st displacement. (a)	2nd displacement. ($2a$)	Ratio: $\frac{\text{2nd displ.}}{\text{1st displ.}}$
A	13.0 mm.	42.0 mm.	3.2
B	27.0	—	—
C	37.0	73.0	2.0
D	2.9	4.1	1.4
E	5.1	7.5	1.5
F	5.5	17.0	3.1
Mean.	—	—	**2.2**

The 2nd displacement was thus, in these cases, twice as large as the 1st.

66. The division of earthquakes into the "1st type" and the "2nd type" ones, or those respectively of the 1st *inward* motion and of the 1st *outward* motion (§ 58), is due probably to the difference in the nature of the subterranean disturbances which cause the earthquakes.

An earthquake of the "1st type," which seem to happen very often, may be produced, for instance, by the sudden collapsing of a subterranean cavity. That the 2nd motion will be greater than the 1st can easily be understood, as the earth particle is displaced to an approximately equal distance on the opposite side of the original position of equilibrium. The sudden crushing down of a horizontal stratum, or a depression may also produce an earthquake of the same type.

On the other hand an earthquake of the 2nd type may be produced for instance, by a sudden splitting asbunder, or widening, of a vertical cavity in the earth's crust, due to the expansive action of the steam or gases. In this connection it is interesting to remark that the earthquakes of Group (iii), or those which originated off the southern coast of the Izu Peninsula, all belonged to the "2nd type"; these shocks having probably a connection with the great volcanic chain of the Izu Islands.

It may be here noted that the 1st displacement becomes smaller and finally disappears with the increase of the epicentral distance. I have therefore confined myself in the preceding discussions, to those cases in which the vibrations were large and distinctly shown.

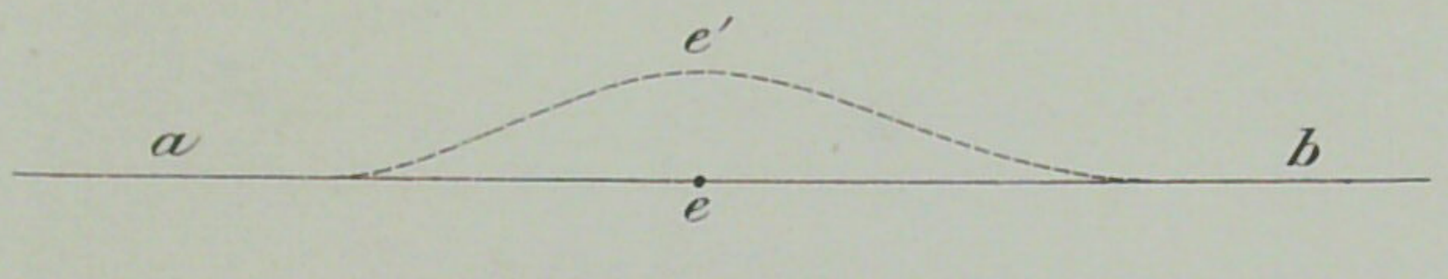
MINE EXPLOSION.

67. For the sake of reference, let us consider the vibrations of the ground caused by a mine explosion. The first motion of an earth particle may be inward or outward according to the depth of the mine and the distance of the place of observation from the latter.

(1) If the explosion takes place at the ground surface itself, the initial motion would be directed away from the origin. The 2nd or counter motion, directed towards the origin, would be, in the vicinity of the latter the greatest displacement. At a great distance, the motion would gradually reach the maximum, there being no single prominent vibration.

(2) Suppose the origin of explosion to be at some depth below the surface. Let $a\,c\,b$ (fig. 56) be the ground surface, c the origin of explosion, e the epicentre, an b the observing place. Now the effect of the explosion is to assert a sudden pressure on all sides. But, owing to the least amount of the resistance in the direction of the epicentre, the maximum projective effect is naturally produced at the latter; the surface layer being, in consequence, first thrown into a curve form such as $a\,e'\,b$. At b, therefore, the earth particle would be

Fig. 56.



Normal Vibration caused by a Mine Explosion.

Time: 1 tick interval=0.39 sec. *(a).....Commencement.*

Fig. 57.

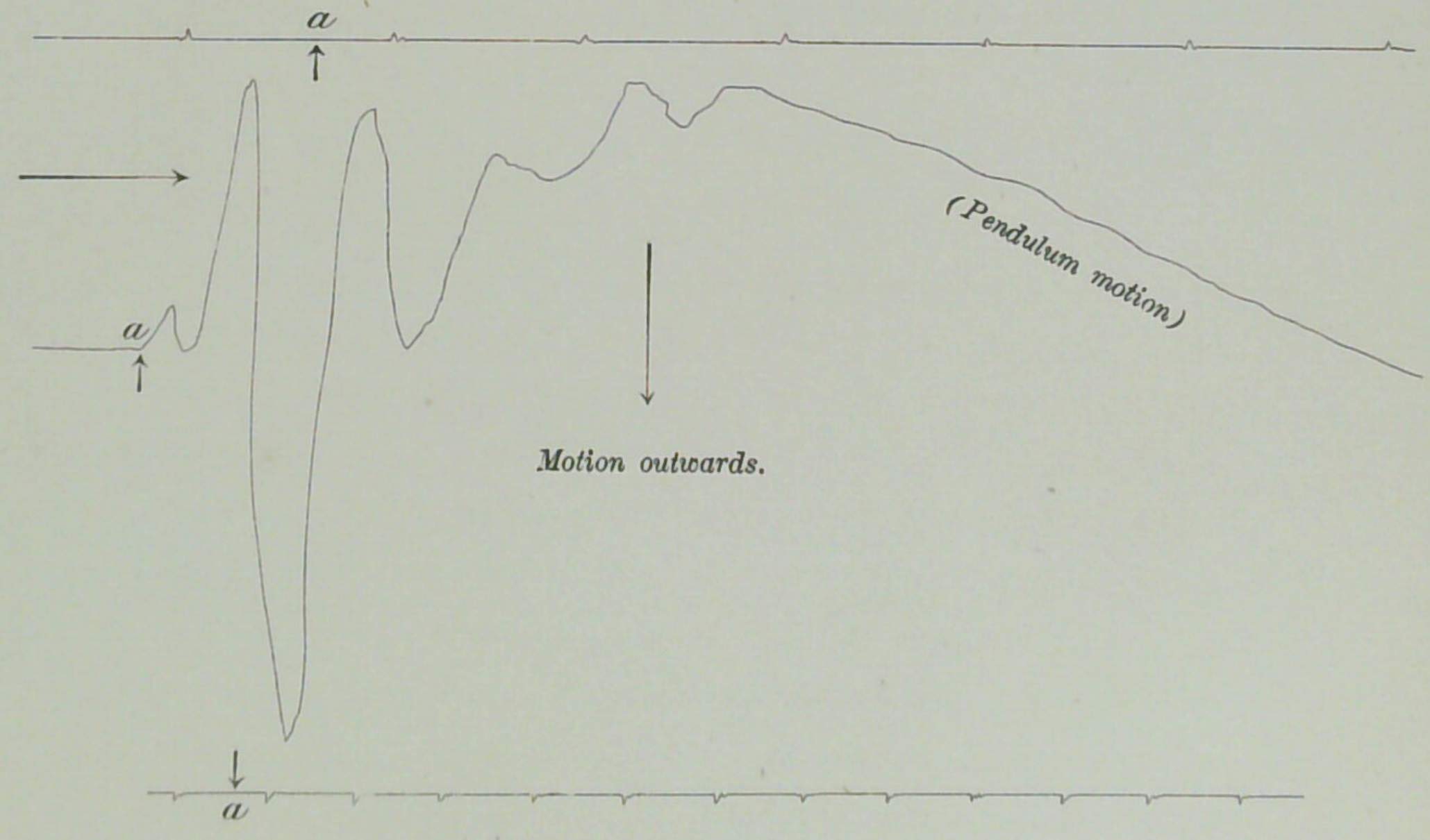
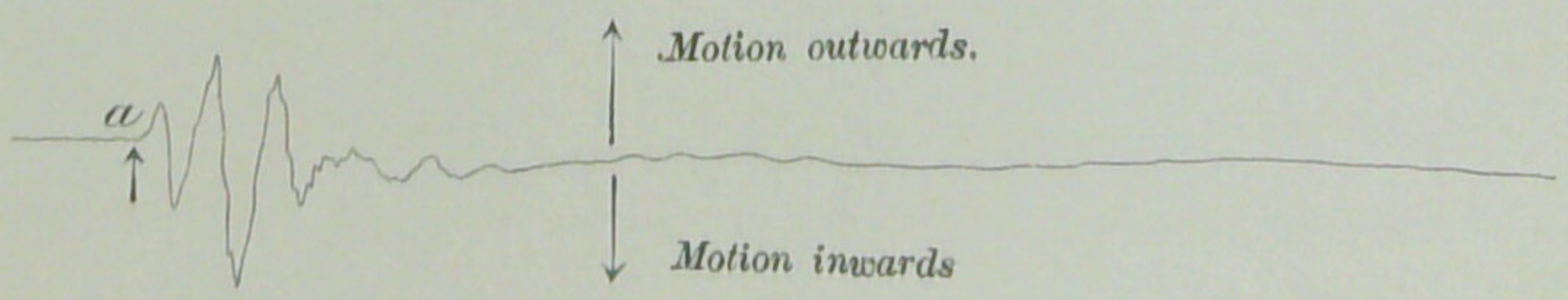


Fig. 58.



suddenly moved first toward the origin; the 2nd and greatest displacement being directed outwards.

With an increase in the distance, large vibrations do not occur at the commencement, the maximum being probably produced by the accumulation of motion. In such a case the small initial inward movement would not be shown, the 1st displacement being in consequence directed outwards.

In 1899, the present author, in conjunction with Dr. A. Imamura of the Seismological Institute, made at Akabane, a suburb of Tokyo, several measurements of the vibration of the ground caused by the explosions of different quantities of gunpowder, guncotton, and dynamite. Figs. 57 and 58 (Pl. XXXIX.), which relate to one of these experiments, show the normal component vibrations obtained at distances of 25.7 and 45.7 metres respectively from the epicentre; the cause of disturbance being 75 kilogrammes of gunpowder, exploded in a sandy soil at a depth of about 5 metres. It will be seen that, in fig. 57, the 1st decided displacement was directed toward the origin, the next one being the maximum. (In fig. 57, the end part of the diagram is slightly disturbed by the proper oscillations of the horizontal pendulum, with which the measurement was made. These, however, can on account of the slowness of period be easily distinguished from the real motion of the ground. The maximum vibration was 12.4 mm, its period being 0.25 sec.)*

68. The considerations in § 67, (2), may be applied to an earthquake which is caused by a volcanic explosion, or by a sudden widening of a horizontal fissure at some depth in the earth crust.

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* The reader is also referred to Professor Milne's paper on seismic experiments, *Trans. Seism. Soc. Japan*, Vol. 8. In Professor Milne's experiments, the motion recorded was not very large and the maximum vibration did not occur at the commencement; the initial displacement of the normal motion being mostly directed outwards.

XII. ON THE DURATION, PERIOD, AND AMPLITUDE OF THE EARTHQUAKE MOTION.

69. Table V gives for the different earthquakes of Groups (i) to (ix) as well as for the six earthquakes named in § 56 the following elements of motion:—

Total duration of the 1st and 2nd preliminary tremors;
Duration of the principal portion;
„ „ „ more active phase in the principal portion;
Period of vibration in the preliminary tremors;
„ „ „ „ „ principal portion;
„ „ „ „ „ end portion.

The period, or periods, of most active vibrations are printed in fat letters, while those of insignificant or superposed vibrations are enclosed within square brackets. The numerals in round brackets, namely, (1), (2), (3),...., prefixed to the different periods, indicate the order in which the latter successively appeared, in the earthquake motion.

The measurements, unless otherwise mentioned, relate to the EW component seismograms.

TABLE V. DURATION AND PERIOD OF VIBRATION.

Earthquake.		Duration of			Period of vibration in		
No.	Origin	Prel. Tremor.	Principal Portion.	Active Part.	Preliminary Tremor.	Principal Portion.	End Portion.
		m s	m s	m s	sec.	sec.	sec.
1–6.	Local.	0 9	—	—	—	**2.9**	—

TABLE V. (*Continued.*)

Earthquake.		Duration of			Period of vibration in		
No.	Origin.	Prel. Tremor.	Principal. Portion.	Active Part.	Preliminary Tremor.	Principal Portion.	End Portion.
		m s	m s	m s	sec.	sec.	sec.
7.	Echigo. (NS)	0 17	8 16	2 30	10.2	10·2 **4.7** 9.3	6.8 4.4
,,	Same eqke. (EW)	—	—	—	10.1	2.3 **7.3 ; 4.7** 11.8	—
8.	Echigo. (NS)	0 20	10 38	2 25	11.5	2.7 **6.8** 4.7	7.4
,,	Same eqke. (EW)	—	9 0	2 1	2.0 11.5	2.3 ; 2.9 5.3 **6.2** 11.4	7.2
9.	Izu. (NS).	0 25	14 43	—	8.3	**7.1**	6.8
,,	,, (EW).	0 27	13 22	—	1.1 17.2	27.2	7.4
10.	Izu. (EW).	1 39	14 35	5 0	0.96 3.1 9.3	(1) 27.6 (2) 12.9 (3) **7.7** ; 8.2	8.6
2′.	Kii.	0 46	16 30	6 44	13.7 17.8	**9.4** 7.5 2.3 33.0	8.0
1′.	Off the NE coast of Main Island.	0 58	—	4 40	6.4	**6.7**	6.7
11.	,,	0 39	17 3	5 43	(1) 0.67 ; [3.0] (2) 24.0 ; [1.6]	(1) 7.1 (2) 3.8 ; 6.3 [15.2 ; 2.1] (3) **7.2** ; [3.3]	8.8
12.	,,	1 31	16 3	5 0	11.7 [2.7]	(1) 9.4 (2) **5.9** ; [10.6 ; 35] (3) 6.8 ; [9.3] (4) 11.3 [6.1]	10 0
13.	,,	1 45	—	—	10.8 [1.2]	(1) **8.2** ; [0.58] (2) 6.9	9.1
14.	,,	0 42	—	3 45	—	(1) **2.9** ; [6.5] (2) 4.1	—

TABLE V. (*Continued.*)

Earthquake.		Duration of			Period of vibration in		
No.	Origin.	Preliminary Tremor.	Principal Portion.	Active Part.	Preliminary Tremor.	Principal Portion.	End Portion.
		m s	m s	m s	sec.	sec.	sec.
15.	Off the NE coast of Main Island.	0 29	—	3 35	—	(1) **8.6**; [3.3] (2) 4.3	—
16.	„	1 11	—	—	—	(1) **16.5** (2) 12.8 (3) **7.0** (4) 12.0; 7.0	—
17.	„	1 0	—	3 25	—	(1) — (2) 3.3; 6.3 (3) 7.2	9.7
18.	„	1 3	—	--	—	(1) — (2) 4.5 (3) 7.0	10.5
19.	„	1 29	—	—	—	— — 6.4	11.8
20.	„	2 23	5 40	—	2.4; 4.3 10.7	(1) **9.5** (2) **6.0**	8.8
21.	„	2 25	5 30	2 45	—	(1) **7.9** (2) 7.2	7.4
22.	Kyushyu.	1 42	22 0	8 0	8.2	(1) 35.4 (2) 23.3 (3) **17.0** (4) 8.0	—
23.	Kyushyu.	—	—	6 0	—	(1) 31.3 (2) 23.0 (3) **17.0**	8.1
24.	Oshima.	2 15	21 55	6 47	3.8 4.7 [16.6]	(1) 25.7 (2) **15.2** (3) **8.0**; 8.4 [16.1; 9.5]	8.4 [12.6]
25.	Oshima.	2 17	22 40	6 49	6.4 3.1 [32.0]	(1) 24.5 (2) 18.5; 15.8; 10.4 (3) **9.1**	8.6 [13.1]
26.	Ceram.	9 25	—	10 30	3.6 **8.7**	(1) **38.0** (2) **20.0**	12.0

TABLE V. (*Continued.*)

Earthquake.		Duration of						Period of Vibration in		
No.	Origin.	Preliminary Tremor.		Principal Portion.		Active Part.		Preliminary Tremor.	Principal Portion.	End Portion.
		m	s	m	s	m	s	sec.	sec.	sec.
27.	New Guinea.	12	17	20	20	12	21	**26.8**; **9.9** 1.25; 4.8 20.5	(1) 46.8 [10.6] (2) **31.2** (3) 29.6 (4) 18.5 (5) **22.9** (6) 14.3	**15.0** **9.8** [11.3; 8.7]
3′.	Sumatra.	12	32	24	39	9	50	**7.2** [13.0]	(1) 34.8; [7.7] (2) 24.1 (3) 20.1 (4) 16.0 (5) **12.9**	10.9
4′.	Turkestan.	13	30	42	0	23	12	8.2 [12.3; 3.3]	(1) 52.0 (2) 41.3 (3) 29.0 (4) **18.0** (5) 11.0 (6) 15.9; [9.0]	13.0
28.	Alasca.	14	23	50	33	25	53	**7.9**; [3.5; 18.0] 34.0 **25.2**	(1) **33.0**; [66.0] (2) **24.0** (3) 14.0; [25]	20.6 10.1
29.	Alasca.	14	13	38	12	22	20	5.1; [9.3] **24.4**	(1) 44.5 (2) 37.0 (3) **32.5** (4) **20.7** (5) 14.2	9.8
30.	Alasca.	12	27	30	14	17	0	(1) **19.6**; 14.2 [1.5; 3.7] (2) 24.8; [7.8]	(1) 44.7; [7.5] (2) **35.7** (3) 28.6 (4) 21.4 (5) 18.2 (6) 14.6; [25.0]	22.0; [9.6] 9.1
33.	Aidin.	22	19	32	13	24	50	(1)6.0; [8.7] (2) 10.5	(1) —; 13.4 (2) 41.4; [10.8] (3) 29.0; [11.1] (4) **24.3** (5) **17.5** (6) 13.4	13.9
34.	Saloniki.	22	24	—		15	0	6.6 **10.4** **17.1**	(1) 54.0 (2) 36.0 (3) 27.3; [9.6–12.9] (4) **17.9** (5) **14.9** (6) 11.1; [19]	8.3 [17.8]

TABLE V. *(Continued.)*

No.	Origin.	Duration of Preliminary Tremor.	Duration of Principal Portion.	Duration of Active Part.	Period of Vibration in Preliminary Tremor.	Period of Vibration in Principal Portion.	Period of Vibration in End Portion.
		m s	m s	m s	sec.	sec.	sec.
31.	Guatemala.	30 20	24 51	24 51	(1) 8.3 (2) 13.1 (3) **28.1** [16.3; 40.3]	(1) 38.7; [7.3] (2), (5) 33.8 (3) **26.7** (4), (6) 20.9 (7) 18.7	—
32.	Guatemala.	30 30	—	21 0	(1) 7.0; [4.3; 11.6] (2) 14.1 (3) 11.4; [8.9; 30.4] (4) **39.3** (5) 24.0 (6) 30.7; [7.7]	(1) 43.5 (2) **36.2** (3) **26.5** (4) 20.0	—
5′.	Mexico.	26 51	54 27	22 23	(1) 5.3 (2) 14.1 (3) 7.3; [15.3] (4) 14.1	(1) **32.7** (2) **21.0**; [10.1] (3) 15.5	15.5
6′.	Caracas.	32 31	28 23	28 23	(1) 7.7 (2) 14.8; [32.6]	(1) 56.0; [10.0; 2.9] (2) 45.4; [10.3] (3) 23.5 (small). (4) **31.2** (5) 25.8 (6) **23.5** (7) 21.4	17.9

TOTAL DURATION OF AN EARTHQUAKE.

70. The duration of an earthquake observed at a given place depends on the magnitude of the disturbance at the seismic origin, as well as on the distance from the latter. It is evident that the duration increases with the size of the earthquake. The effect of the distance on the duration, however, is twofold; namely, the increase in the distance diminishes the amplitude of vibration, probably in a ratio of inverse square, but lengthens the intervals between the successive phases of the earthquake motion, in a ratio of direct proportion.

The duration of a great earthquake observed at a *near* distance must be at least 3 hours, as the seismic motion is propagated from the origin to the observing place both along the minor arc and the major arc of the earth, and as the time taken by the vibrations in the 3rd phase of the principal portion in making one complete circuit of the earth is 3h 20m 46s; in some cases, the motion propagated along the minor arc coming back to the observing place after passing through the antipode of the latter *

The following table, based on the Tokyo horizontal pendulum observations contained in the *Publications*, Nos. 5, 6 and 13, gives the total duration of those comparatively near earthquakes, or those for which the duration of the preliminary tremor was less than 5 m, arranged in order of the same quantity.

TABLE VI. Durations of great earthquakes of near origin, observed in Tokyo.

[Earthquakes whose duration was greater than 1 hour.]

Date.	Time of occurrence.	Duration of Prel. Tremor.	Total duration.	Date.	Time of occurrence	Duration of Prel. Tremor.	Total duration.
	h m s	m s	h m		h m s	m s	h m
Nov. 5, 1900	4. 41. 42 p.m.	0. 27	4. 00	Dec. 4, 1898	1. 45. 32 a.m.	1. 38	1. 19
April 25, 1900	8. 18. 52 a.m.	0. 38	2. 22	Nov. 9, 1900	2. 55. 03 a.m.	1. 39	2. 00
Aug. 5, 1900	1. 21 17 p.m.	0. 39	3. 45	May 8, 1899	0. 28. 54 p.m.	1. 43	1. 20
Dec. 3, 1900	11. 07. 02 p.m.	0. 40	2. 00	March 24, 1899	1. 02. 35 p m.	1. 51	1. 09
May 12, 1900	3. 23. 18 a.m.	0. 40	2. 00	Aug. 4, 1900	1. 33. 40 p.m.	1. 51	1. 10
March 7, 1899	9. 55. 29 a.m.	0. 46	1. 30	Feb. 13, 1900	1. 27. 40 p.m.	1. 52	1. 26
March 12, 1900	10. 35. 01 a.m.	0. 46	1. 19	Nov. 25, 1899	3. 45. 24 a.m.	1. 54	2. 13
Nov. 13, 1900	7. 36. 11 a.m.	0. 54	1. 14	Oct. 4, 1899	5. 56. 22 p.m.	2. 00	1. 05
Nov. 11, 1899	2. 40. 24 a.m.	1. 14	1. 00	Jan. 18, 1900	4. 44. 44 p.m.	2. 00	1. 00
Aug. 2, 1900	11. 31. 20 a.m.	I. 35	2. 48	Dec. 7, 1900	4. 13. 05 p.m.	2. 13	2. 00

* See the *Publications*, No. 13, p. 123.

TABLE VI. (*Continued.*)

Date.	Time of occurrence.	Duration of Prel. Tremor.	Total duration.	Date.	Time of occurrence.	Duration of Prel. Tremor.	Total duration
	h m s	m s	h m		h m s	m s	h m
Feb. 1, 1900	4. 21. 07 a.m.	2. 18	1. 30	Aug. 29, 1900	3. 14. 09 p.m.	3. 29	2. 00
July 11, 1899	4. 40. 07 p.m.	2. 23	1. 20	Nov. 10, 1899	8. 58. 25 p.m.	3. 31	1. 00
July 14, 1899	11. 21. 00 a.m.	2. 30	1. 37	Nov. 23, 1899	6. 52. 39 p.m.	3. 32	4. 00
Dec. 25, 1900	2. 07. 44 p.m.	2. 30	3. 30	Nov. 12, 1899	7. 27. 13 a.m.	3. 45	1. 10
June 17, 1899	10. 09. 35 a.m.	2. 32	1. 19	July 12, 1899	11. 56. 26 p.m.	3. 48	1. 25
Dec. 10, 1899	11. 22. 21 p.m.	2. 34	1. 00	Feb. 5, 1900	7. 20. 19 p.m.	3. 52	1. 09
Nov. 21, 1900	4. 49. 13 p.m.	3. 09	3. 40	June 9, 1900	9. 12. 45 p.m.	4. 15	1. 17
July 24, 1899	10. 23. 33 a.m.	3. 10	1. 45	Aug. 14, 1900	5. 19. 39 a.m.	4. 50	3. 00

The mean results given in the following table have been deduced from 76 distant earthquakes whose analyses are contained in the *Publications*, Nos. 5, 6, and 13, and whose total preliminary tremor lasted more than 5 minutes.

TABLE VII. Duration of distant earthquakes whose preliminary tremor was longer than 5 minutes.

Earthquakes.	Average value of the			
	Total Prel. Tremor.		Total eqke duration.	
	m	s	h	m
21 eqkes, whose prel. tremor lasted from 5m 5s to 6m 58s.	6	8	0	53
18 eqkes, whose prel. tremor lasted from 7m 0s to 9m 55s.	8	47	1	38
17 eqkes, whose prel. tremor lasted from 10m 10s to 14m 43s.	12	27	2	14

Earthquakes.	Average value of the			
	Total Prel. Tremor.		Total eqke Duration.	
	m	s	h	m
12 eqkes, whose prel. tremor lasted from 15m 2s to 19m 55s.	17	27	1	22
8 eqkes, whose prel. tremor lasted from 20m 40s to 34m 56s.	26	0	1	39

According to the above table, which is to be regarded as giving only very rough data, the earthquakes, whose preliminary tremor lasted from 10 m to about 15 m, had the greatest mean duration of 2 h 14 m. Whether any similar result is obtained with more extensive materials, remains to be seen. In the meanwhile, if we divide the different earthquakes into two broad divisions, namely, earthquakes whose preliminary tremor lasted from 5m to 15m, and those whose preliminary tremor lasted from 15m to more than 30m, we get nearly equal values of the total duration for the two series of earthquakes.

Taking together Tables VI and VII, it may be inferred that the duration of an earthquake is longest at the vicinity of the origin of disturbance.

DURATION OF THE ACTIVE PART IN THE PRINCIPAL PORTION.

71. The duration of the more active part in the principal portion (denoted by Y_1) may vary with the magnitude of the earthquake and the distance from the origin of the latter, being virtually the length of a *phase* or phases of the seismic motion. Table VIII, which is based on Table V, gives the duration in question for the different earthquakes, arranged according to the length of the preliminary tremor ; for each of the earthquakes of near origin, the duration of the specially well pronounced phase (denoted by Y_2) is also given. Y_1 is generally not equal to, but less than, the duration of the "principal portion." In distant earthquakes, the duration Y_2 is not usually well defined.

TABLE VIII. DURATION OF THE MOST ACTIVE PART.

Earthquake.		Duration of Preliminary Tremor.		Duration of the			
No.	Origin.			Active part = y_1		Most Active part = y_2	
		m	s	m	s	m	s
7.	Echigo. (NS)	0	17	9	10	2	30
8.	,, (NS)	0	20	10	30	2	25
,,	,, (EW)		———	11	35	2	1
14.	Off NE coast of Main Island.	0	24	———		3	45
9.	Izu.	0	27	14	0	———	
15.	Off NE coast of Main Island.	0	29	———		3	35
11.	,,	0	39	11	20	5	46
2′.	Off E coast of Kii.	0	46	14	10	6	44
1′.	Off NE coast of Main Island.	0	58	9	0	4	40
17.	,,	1	00	11	0	3	25
18.	,,	1	3	13	40	———	
19.	,,	1	29	10	40	———	
12.	,,	1	31	11	0	5	0
10.	Izu.	1	39	14	35	5	0
22.	Kyushyu.	1	42	10	15	8	0
23.	,,	,,		———		6	0
24.	Ōshima.	2	15	21	55	6	47
25.	,,	2	17	22	40	6	49
20.	Off NE coast of Main Island.	2	23	5	40	———	
21.	,,	2	25	5	30	2	45
26.	Ceram.	9	25	10	30	———	
27.	New Guinea.	12	17	12	21	———	
3′.	Sumatra.	12	32	9	50	———	
30.	Alasca.	12	27	17	0	———	
4′.	Turkestan.	13	30	23	12	———	
29.	Alasca.	14	13	22	20	———	
28.	,,	14	23	23	53	———	
33.	Aidin.	22	19	24	50	———	
34.	Saloniki.	22	24	15	0	———	
5′.	Mexico.	26	51	22	23	———	
31.	Guatemala.	30	20	24	51	———	
32.	,,	30	30	21	0	———	
6′.	Caracas.	32	31	28	23	———	

In strong earthquakes of a near origin, such as the Echigo earthquakes, Nos. 7 and 8, the amplitude of vibrations in the most active part was very much larger than those in the other phases; the duration, Y_2, being in these cases, according to Table VIII, about $2\frac{1}{2}$ minutes. With earthquakes of a remoter origin, such as those of Izu, Kyushyu, Ōshima, and Kii, or the majority of those which originated off the north-eastern coast of the Main Island, the distinction between the vibrations of the most active part and those of the other phases was less marked; the duration Y_2 being longer than in the previous cases, and mostly included between about 5 and 8 minutes.

Again, according to Table VIII, the duration Y_1 for each of the different earthquakes of comparatively near origin, namely, Nos. 7–21, was, with 4 exceptions, fairly constant, and included between 9m 10s and 14m 35s; the 1st 13 earthquakes giving an average of 11m 36s. This value may be taken as a probable mean duration of the more decided part in the principal portion of a large earthquake of near origin.

In the three earthquakes of Ceram, New Guinea, and Sumatra origins, namely, Nos. 26, 27, and 3′, Y_1 varied between 9m 50s and 12m 21s, giving a mean of 10m 54s.

In 10 distant great earthquakes, Nos. 4′, 5′, 6′, 28,....34, the duration Y_1 was, except in two cases, nearly constant, varying between 21m and 28m 23s. For these earthquakes, Y_1 may be regarded as being equivalent to the sum of the durations of the 2nd and 3rd phases of the principal portion, that is to say, to $\left(1+\frac{49}{79}\right) y_1$ or $\left(1+\frac{49}{79}\right)\times\frac{y_1+y_2}{2}$, approximately, where y_1 and y_2 denote respectively the durations of the 1st and 2nd preliminary tremors. (See the *Publications*, No. 13, p. 115.)

The Turkestan and three Alasca earthquakes, Nos. 4′, 28, 29, and 30, give a mean Y_1 of 21m 48s; and the Mexico, Caracas, and two Guatemala earthquakes, namely, Nos, 5′, 6′, 31 and 32, give a mean Y_1 of 24m 9s.

PERIODS OF THE MOST ACTIVE VIBRATIONS IN THE DIFFERENT EARTHQUAKES.

72. From the description of the different seismograms given in §§ 5–55 it will be seen that the period of the predominating movements was comparatively short in earthquakes of near origin, while it was usually very long in those of distant origin. The following table, which is based on Table V, gives the period (denoted by T_0) of the greatest vibrations in the different earthquakes, arranged according to the length of the duration of the preliminary tremor (denoted by y).

TABLE IX. Periods of the greatest vibrations in the different earthquakes.

Earthquake.		Duration of total Preliminary Tremor = y.		Period of the greatest vibrations = T_0.	Mean value of T_0.
No.	Origin.				
			sec.	sec.	sec.
1—6.	Local.	(mean)	9	2.9	2.9
7—8.	Echigo.	(mean)	19	4.7; 6.9	4.7; 6.9
		m	s		
14.	Off NE coast of Main Island.	0	24	2.9	
9.	Izu.	0	27	7.1	
15.	Off NE coast of Main Island.	0	29	8.6	
2′.	Kii.	0	46	9.4	8.0; 2.9
1′.	Off NE coast of Main Island.	0	58	6.7	
17.	,,	0	60	—	
18.	,,	0	63	—	
16.	,,	1	11	7.0; 16.5	
19.	,,	1	29	—	
12.	,,	1	31	5.9	
10.	Izu.	1	39	7.7	
22.	Kyushyu.	1	42	17.0	8.2 (7 cases)
23.	,,	,,		17.6	16.6 (4 ,,)
13.	Off NE coast of Main Island.	1	45	8.2	6.0 (2 ,,)
24.	Ōshima.	2	15	8.0; 15.2	
25.	,,	2	17	9.1	
20.	Off NE coast of Main Island.	2	23	9.5; 6.0	
21.	,,	2	25	7.9	

TABLE IX. *(Continued.)*

Earthquake.		Duration of the total Preliminary Tremor = y.	Teriod of the greatest vibrations = T_0.	Mean value of T_0.
No.	Origin.			
		m s	sec. sec.	sec.
26.	Ceram.	9 25	20.0 ; 38.0	**20.3**
27.	New Guinea.	12 17	22.9 ; 31.2	12.9
3′.	Sumatra.	12 32	12.9 ; 34.8	31.2
4′.	Turkestan.	13 30	18.0	34.8
				38.0
28.	Alasca.	14 23	33.0 ; 24.0	
29.	,,	14 13	32.5 ; 20.7	
30.	,,	12 27	35.7	**25.0** (5 cases)
33.	Aidin.	22 19	17.5 ; 24.3	**32.4** (4 ,,)
34.	Saloniki.	22 24	17.6 ; 14.9	36.0 (2 ,,)
31.	Guatemala.	30 20	26.7	20.9 (2 ,,)
32.	,,	30 30	26.5 ; 36.2	17.6 (2 ,,)
5′.	Mexico.	26 51	21.0 ; 32.7	14.9 (1 case)
6′.	Caracas.	32 31	23.5 ; 31.2	

From the above table we see that in the six local shocks the mean value of T_0 was comparatively short and equal to 2.9 sec., the mean value of y being 9 sec. For the two Echigo earthquakes, whose y was on the average 19 sec., there were two different values of T_0, namely, 4.7 and 6.9 sec. For the Kii and Izu earthquakes and those of origins situated off the north-eastern coast of the Main Island, whose y was under about 1 min., the value of T_0 was on the average 8.0 sec.; only in one case T was equal to 2.9 sec., which is the period occurring in the local shocks. For the Izu, Kyushyu, and Oshima earthquakes, and some of those of origins situated off the north-eastern coast of the Main Island, whose y varied between about 1 min. and $2\frac{1}{2}$ min., the value of T_0 most frequently occurring was on the average 8.2 sec.; in some cases, however, T_0 was large and equal to 16.6 sec. With the Ceram, New Guinea, Sumatra, and Turkestan earthquakes, whose y varied between 9m 25s and 13m 30s, the average value of T_0 was 20.3 sec.; in these earthquakes, however, the prominent single vibration occurring at the commencement of the principal portion had often a very slow period, varying from 31.2 to

38.0 sec. In the distant earthquakes of Alasca, Aidin, Saloniki, Guatemala, Mexico and Caracas origins, the values of T_0 most frequently occurring were on the average 25.0 sec. or 32.4 sec.; in some cases T_0 being equal to 14.9, 17.6, 20.9 or 36.0 sec. The 2nd and the 3rd of these latter are identical with the values of T_0 occurring in the two preceding groups respectively.

From the above remarks, it will be seen that the value of the period T_0 lengthened with the duration of the preliminary tremor, y, that is to say, with the distance of the earthquake origin; the vibrations of $T_0=16.6$ sec. having first occurred with earthquakes whose y was longer than about 1 min. The predominance of the vibrations whose T_0 was 8 sec. nearly ceased with those distant earthquakes, for which y was longer than some 9 min. With this latter group of earthquakes the value of T_0 was increased to 20.3 sec.; while with earthquakes, whose y was greater than some 14 min., the value of T_0 was most frequently 25.0 or 32.4 sec.

The increase of the value of T_0 with the epicentral distance is probably not due to the prolongation of one and the same kind of vibration, as the latter radiates from the origin of disturbance. On the contrary this phenomenon is to be explained on the assumption that vibrations of shorter period are reduced in size much more quickly than those of slower period; the result is that vibrations of the macroseismic nature are almost entirely absent in the earthquake motion proceeding from a distant origin, while the movements of different slow periods become successively prominent at the varying radial distances. The supposition held by some seismologists that long-period vibrations are to be observed only at a great distance from the seismic centre is evidently untrue; some very slow vibrations having been observed in Tokyo on the occasion of near earthquakes, such as Izu, Kii, or Kyushyu earthquakes. I believe that slow vibrations generally appear in earthquakes which are sufficiently great.

PERIOD OF VIBRATION IN THE INITIAL PHASE OF THE PRINCIPAL PORTION.

73. The following table gives for the different earthquakes the periods in the inital phase of the principal portion.

TABLE X. Period of Vibration in the Initial Phase of the Principal Portion.

Earthquake.		Period.
No.	Origin.	
		sec.
10.	Izu.	27.6
22.	Kyushyu.	35.4
23.	,,	31.3
24.	Ōshima.	25.7
25.	,,	24.5
26.	Ceram.	38.0
27.	New Guinea.	46.8; 31.2
3′.	Sumatra.	34.8
4′.	Turkestan.	52.0; 41.3
28.	Alasca.	34.5; 32.6; 66.0
29.	,,	44.5; 37.0; 32.5
30.	,,	44.7; 35.7; 28.6
31.	Guatemala.	38.7; 38.7; 33.3
32.	,,	43.5; 35.5; 37.0; 36.0
5′.	Mexico.	32.7
6′.	Caracas.	56.0; 45.4
33.	Aidin.	41.4; 29.0
34.	Saloniki.	54.0; 36.0

Thus it will be seen that the slow period of vibration occurring in the 1st phase of the principal portion varied in the different earthquakes between 24.5 and 66.0 sec. It is probable that with improved instruments we shall be able to observe still slower vibrations. In the measurement of the earthquake motion, it must be remembered that very slow vibrations, which are affected to a considerable extent

by the friction existing in the different parts of the seismograph, will be recorded much smaller than their true size.

The different period contained in the above table may be divided into 7 groups whose mean values are as follows* :—

25.1	sec.,	deduced from	2 cases.
28.4	,, ,	,,	3 ,, .
32.3	,, ,	,,	6 ,, .
36.5	,, ,	,,	12 ,, .
41.4	,, ,	,,	2 ,, .
45.0	,, ,	,,	5 ,, .
54.0	,, ,	,,	3 ,, .

The successive difference between the first 6 of these periods varied from 3.3 to 4.9 sec., giving an average value of 4 sec. The difference between the last two periods, which is equal to 9.0 sec., is to be regarded as equivalent to double the common difference.

PERIODS OF VIBRATIONS IN THE PRELIMINARY TREMOR AND THE END PORTION.

74. The different periods in the preliminary tremor and the end portion, given in Table V, may be divided more or less definitely into 6 and 5 groups respectively, as follows† :—

Preliminary Tremor.	3.7	sec., deduced from	17	cases.
	8.9	,, , ,,	32	,, .
	14.0	,, , ,,	9	,, .
	17.6	,, , ,,	6	,, .
	25.1	,, , ,,	7	,, .
	32.3	,, , ,,	6	,, .
End Portion	4.4	,, , ,,	1	,, .
	8.6	,, , ,,	24	,, .
	13.4	,, , ,,	8	,, .
	17.9	,, , ,,	2	,, .
	21.3	,, , ,,	2	,, .

It will thus be seen that slow periods, whose average values are respectively 25.1 and 32.3 sec., also occurred in the preliminary tremor.

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* Excepting provisionally the value of 66 sec., which occurred only in one case.

† Excluding movements of macro-seismic nature.

In the end portion there were, only in a few cases, slow periods, whose average values were 17.9 and 21.3 sec. The period most frequently occurring in these two phases has, for distant earthquakes, a mean value of about 8.7 sec. The fact that this latter period is not markedly shown in the principal portion of distant earthquakes is probably due to the predominance of vibrations of long periods, the comparatively insignificant movements of short pericds being obliterated.

MEAN VALUES OF THE PERIODS OF VIBRATION.

75. The following table gives the mean values of the periods in the different portions of the earthquake motion, based on the results obtained in the three preceding §§; the figures within brackets suffixed to each mean value indicating the number of cases from which the latter has been deduced.

TABLE XI. Periods of Vibration in the different Parts of the Earthquake Motion.

Preliminary Tremor.	Initial Phase of Princ. Portion.	Most active Part of Princ. Portion.	End Portion.	*Mean.*
sec.	sec.	sec.	sec.	sec.
—	—	2.9 (6)	—	**2.9** (6)
3.7 (17)	—	4.7 (2)	4.4 (1)	**4.3** (20) $=t_1$
8.9 (32)	—	8.0(12); 6.9(2)	8.6 (24)	**8.5** (68) $=t_2$
14.0 (11)	—	—	13.4 (8)	**13.7** (17) $=t_3$
17.6 (6)	—	17.1 (6)	17.9 (2)	**17.5** (14) $=t_4$
20.3 (3)	—	20.6 (6)	21.3 (2)	**20.7** (11) $=t_5$
25.1 (7)	25.1 (2)	25.0 (5)	—	**25.1** (14) $=t_6$
—	28.4 (3)	—	—	**28.4** (3) $=t_7$
32.3 (6)	32.3 (6)	32.4 (4)	—	**32.3** (16) $=t_8$
—	36.5 (12)	36.0 (2)	—	**36.3** (14) $=t_9$
39.8 (2)	41.4 (2)	—	—	**40.6** (4) $=t_{10}$
—	45.0 (5)	—	—	**45.0** (5) $=t_{11}$
—	—	—	—	— — $=t_{12}$
—	54.0 (3)	—	—	**54.0** (3) $=t_{13}$

The mean values of the principal periods thus obtained are similar to those given in the *Publications*, Nos. 5 and 13, deduced rom more or less different materials of observation. I shall here introduce the notations t_1, t_2, ... t_{10}, t_{11}, t_{12}. . . . . to denote the successive mean values of period, in place of the notations P_1, P_2, etc., used formerly. Leaving out of consideration, for the present, the periods smaller than about 4 sec., which must be discussed in conunction with macro-seismic vibrations, we see that the mean common difference between the successive periods, t_1, t_2, ... , is **4.1** sec., being practically equal to t_1. Thus we have the following approximate relations:—

$$t_1 = \frac{t_2}{2} = \frac{t_3}{3} = \ldots\ldots = \frac{t_{10}}{10} = \frac{t_{11}}{11} = \ldots\ldots = \frac{t_n}{n},$$

where n denotes an integer, whose limiting value we do not know.

The two periods t_1 and t_2 are to be regarded as being equivalent respectively to the two fundamental periods Q_1 and Q_2 of the pulsatory oscillations,* and it is noteworthy that the t_1 or Q_1 is practically identical with the common difference of the successive periods in the principal portion of the earthquake motion; Q_1 being the period of the pulsatory oscillations most frequently occurring.

If the above considerations are correct, it appears that the fundamental or unit period of the earth vibration is t_1 $(= Q_1)$, the different longer periods being its multiples.

OCCURRENCE IN A DESCENDING ORDER OF THE PERIODS OF SUCCESSIVE VIBRATIONS IN THE PRINCIPAL PORTION.

76. From Table V it will be noted that in an earthquake, especially those of distant origin, the different periods of vibration in the principal portion generally occurred in a descending order, that is to say, the vibrations at the commencement of the initial phase had the longest period, those in the subsequent parts having periods which succes-

* See the *Publications*, No. 13, p. 85.

sively decreased. In the following table, the periods of the successive groups of vibrations in the different earthquakes are approximately expressed in terms of the periods t's.

TABLE XII. Periods of the Successive Groups of Vibrations in the different earthquakes.

No.	Origin.	Periods, in order of occurrence.
10	Izu.	t_7 ; t_3 ; t_2
22	Kyushyu.	t_9 ; t_6 ; t_4 ; t_2
23	,,	t_8 ; t_6 ; t_4
24	Ōshima.	t_6 ; t_3 ; t_2
25	,,	t_6 ; t_4 , t_3 , t_2 ; t_2
26	Ceram.	$t_9 - t_5$
27	New Guinea.	t_{11}; t_8 ; t_7 ; t_4 ; t_5 ; t_3
3′	Sumatra.	t_9 ; t_6 ; t_5 ; t_4 ; t_3
4′	Turkestan.	t_{13}; t_{10}; t_7 ; t_4 ; t_2 ; t_4
28	Alasca.	t_8 ; t_6 ; t_3
29	,,	t_{11}; t_9 ; t_8 ; t_5 ; t_3
30	,,	t_{11}; t_9 ; t_7 ; t_5 ; t_4 ; t_3
33	Aidin.	—; t_{10}; t_7 ; t_6 ; t_4 ; t_3
34	Saloniki.	t_{13}; t_9 ; t_7 ; t_4 ; t_3 ; t_2
31	Guatemala.	t_{10}; t_8 ; t_6 ; t_5 ; t_8 ; t_5 ; t_4
32	,,	t_{11}; t_9 ; t_6 ; t_5
5′	Mexico.	t_8 ; t_5 ; t_3
6′	Caracas.	t_{13}; t_{11}; t_6 ; t_8 ; t_6 ; t_5

In a few cases, namely, Eqkes Nos. 27, 4′, 31, and 6′, there occurred in the later part of the motion some slight inversions in the order of occurrence. In all the other cases, however, the series began with slow vibrations, whose periods were mostly t_8, t_9, t_{10}, t_{11}, or t_{13}, thence successively becoming shorter towards the end of the principal portion. Especially in Eqkes Nos. 3′, 29, 30, 33, 34, and 32, the succession of the different periods was in a perfect decreasing order.

In earthquakes of near origin, the occurrence of the different periods in a decreasing order is generally not well marked.

In the preliminary tremor of distant earthquakes there is no well marked order in which the different periods appear. There seems, however, in some cases, as in Eqkes Nos. 31 and 32, a tendency for an increasing order, that is to say, the motion begins with vibrations of periods of t_2 class, thence increasing up to periods of t_8 or t_9 class.

DURATION OF THE PART OF THE PRINCIPAL PORTION DURING WHICH CHANGES IN PERIOD TAKE PLACE.

77. The following list gives, for the different earthquakes, the period (T) and $2a$ in the successive parts of the *principal portion.*

Eqke No. 10.

(i) 27.6 sec.: 1 vib., $2a=12.2$ mm.

(ii) 51.6 „ : 4 vib., $T=12.9$ sec., max. $2a=17.6$ mm.

(During the next 1m 7s, the recording pointer was out of the smoked paper.)

Thereafter T remained constant as follows:—

(iii) 45.2 sec.: 6 vib., $T=7.9$ sec., max. $2a=17.0$ mm.

(iv) 49 „ : 6 „ , „ $=7.5$ „ , „ $=17.5$ „ .

(v) 43.8 „ : 6 „ , „ $=7.8$ „ , „ $=14.7$ „ .

(vi) 5m 32s: $T=8.4$ sec., max. $2a=5.65$ mm.

(vii) 4 12 : „ $=7.9$ „ , „ $=2.5$ „ .

Eqke No. 11.

(i) 2m 9s:
- 34 vib., $T=$ 3.8 sec., max. $2a=3.15$ mm.
- —— , „ $=$ 6.3 „ , „ $2a=4.3$ „
- —— , „ $=15.2$ „ , „ $2a=4.7$ „
- —— , „ $=$ 2.1 „ , „ $2a=2.3$ „

Thereafter T remained constant, as follows:—

(ii) 0m 25.8s: 3 vib., $T=$ 8.6 sec, max. $2a=4.35$ mm.

(iii) 3 15 : —— , „ $=6.1$ „ , „ $=3.6$ „

(iv) 5 5 : 43 vib., „ $=7.1$ „ , „ $=1.75$ „ .

(v) 6 14 : —— , „ $=7.1$ „ , „ $=0.75$ „ .

Eqke No. 12.

(i) 1m 15s: 8 vib., $T=$ 9.4 sec., max. $2a=1.75$ mm.

(ii) 3m 45s: { ——, „ T= 5.9 sec., max. $2a$=3.25 mm.
{ ——, „ =10.6 „ , T=3.5 sec.

(iii) 5 3 : { T= 6.8 sec, max. $2a$=1.3 mm.
{ „ = 9.3 „ , ——

(iv) 6 0 : { T=11.3 „ , max. $2a$=0.74 mm.
{ „ = 6.1 „ , ——

In this case the period thus remained nearly constant throughout the principal portion.

Eqke No. 1′.

The period remained constant throughout.

Eqke No. 24.

(i) 0m 25.7s: 1 vib., $2a$=3.3 mm.

(ii) 3 30 : { T=15.2 sec., max. $2a$=4.5 mm.
{ „ = 9.5 „ , ——

Thereafter the period became nearly constant, as follows:—

(iii) 2m 51s : T= 8.0 sec., max. $2a$=4.4 mm.

(iv) 7 45 : { „ = 8.3 „ , „ =2.15 „
{ „ =16.1 „ , ——

(v) 7 23 : 52 vib., T=8.5 sec., max. $2a$=1.56 mm.

Eqke No. 25.

(i) 0m 24.5s: 1 vib., $2a$=3.24 mm.

(ii) 3 21 : { T=10.4 sec., max. $2a$=4.7 mm.
{ „ =15.8 „ , ——
{ „ =18.5 „ , „ =4.65 „

Thereafter the T became constant, as follows:—

(iii) 3m 28s: T=9.1 sec., max. $2a$=7.6 mm.

(iv) 7 46 : 51 vib., T=9.2 sec., max. $2a$=4.2 mm.

(v) 7 40 : T=8.7 sec., max. $2a$=2.65 mm.

Eqke No. 27.

(i) 0m 46.8s: { 1 vib., $2a$=1.8 mm;
{ sup. by vib. of T=10.6 sec.

(ii) 0m 31.2s: 1 vib., $2a$=3.3 mm.

(iii) 1 57 : 4 vib., T=29.2 sec., max. $2a$=1.0 mm.

(iv) 2 19 : $T=18.5$ sec., max. $2a=1.0$ mm.

(v) 1 32 : 4 vib., $T=22.9$ sec., max. $2a=4.3$ mm.

Thereafter the period quickened and remained nearly constant (=14.3 sec.)

Eqke No. 28.

(i) 2m 35s : { 2 vib., $T=34.5$ sec., max. $2a=5.6$ mm ; $T=66$ sec.

(ii) 3 48 : 7 vib., $T=32.6$ sec., max. $2a=15.2$ mm.

(iii) 4 42 : 10 vib., „ =24 „ , „ =11.1 „

Thereafter the period quickened and became nearly constant :—

(iv) 5m 28s : $T=14.9$ sec., max. $2a=5.0$ mm.

(v) 7 20 : „=13.8 „ , „ =3.0 „

(vi) 26 40 : { „=13.4 „ , „ =1.7 „ ; „=25.0 „ ———

Eqke No. 29.

(i) 1m 29s : 2 vib., $T=44.5$ sec., max. $2a=$ 2.3 mm.

(ii) 3 21 : { 6 vib., „ =37 „ , — , „ =32.5 „ , max. $2a=10.5$ „ .

(iii) 8 48 : $T=20.7$ sec., max. $2a=3.2$ mm.

Hereafter the period became quicker and nearly constant :—

(iv) 8m 42s : $T=14.9$ sec., max. $2a=2.1$ mm.

(v) 7 43 : „=13.4 „ , „ =0.9 „ .

(vi) 8 9 : „=14.4 „ , „ =0.8 „ .

Eqke No. 30.

(i) 0m 44.7s : { 1 vib., $2a=1.48$ mm ; $T=7.5$ sec.

(ii) 2 23 : 4 vib., $T=25.7$ sec., max. $2a=4.3$ mm.

(iii) 0 57 : 2 vib., „=28.6 „ , „ =0.8 „ .

(iv) 6 14 : $T=21.4$ sec., max. $2a=1.5$ mm.

(v) 6 40 : „=18.2 „ , „ =1.43 „ .

Hereafter the period became constant : –

(vi) 13m 15s : { $T=14.6$ sec., max. $2a=0.78$ mm ; „=25.0 „ , ———

The values of the duration ($=Y'$) of the part of the principal

portion during which the variation of period took place, for the different earthquakes noted above, are collected in the following table.

TABLE XIII. Comparison of Y' with the Duration of the Preliminary Tremor.

Earthquake. No.	Earthquake. Origin.	Duration of Total Prel. Tremor $= y$.	Y'
		m s	m s
10	Izu.	0 27	2 (approx.)
11	Off the NE coast of Main Island.	0 39	2 9
12	,,	1 31	(Remained constant throughout.)
1′	,,	0 58	(,, ,,)
24	Ōshima.	2 15	3 56
25	,,	2 17	3 46
27	New Guinea.	12 17	7 6
28	Alasca.	14 23	11 5
29	,,	14 13	13 38
30	,,	12 27	16 59

So far as the above table shows, the duration Y' seems to increase with the duration $(=y)$ of the total preliminary tremor; the two durations being of the same order of length.

XIII. REPETITION OF MAXIMUM MOVEMENTS IN THE EARTHQUAKE MOTION.

MACRO-SEISMIC MOTION.

78. I have noted, in the *Publications*, No. 13, pp. 127—130, that the macro-seismic motion observed at Hitotsubashi shows often a series

of maximum movements, which occurred at an average successive interval of about 5.0 sec. This has been explained by the supposition that the earthquake motion at Hitotsubashi is composed of the proper oscillations of the soft surface soil mixed up with the motion of the underlying harder ground.

In the next three §§, I give examples of the repetition of maxima in the case of the micro-seismic or unfelt earthquake motion observed with horizontal pendulum instruments.

EARTHQUAKES OBSERVED AT HONGO.

79. The following data relating to the repetition of maximum groups have been collected from the analysis of earthquakes observed at Hongo, between July 1898 and Dec., 1899; * the interval between two successive maximum groups being denoted by *J*.

[*Distant Earthquakes.*]

(i) *Eqke of July 15, 1898; 2h 6m 14s a.m.* (*NS Component.*)

The total preliminary tremor lasted 14m 15s.

There were three maximum groups of vibration, with two minimum groups between them, as follows:—

Vibration.	Duration	Average *T* of vibration	Max. 2*a*.	Time of occurrence of the max. 2*a*.
	m s	sec.	mm.	
1st max. group.	2 53	10.8	0.55	2h 22m 27s a.m.
2nd „ „	2 0	11.6	0.45	
3rd „ „	1 36	9.2	0.35	
Mean.	—	**10.5**	—	
1st min. group.	0 49	8.1		
2nd „ „	0 36	7.2		
Mean.	—	**7.7**	—	

* The *Publications*, No 6. Unless otherwise stated the analysis refers to the EW component seismogram.

Thus the vibrations in the max. groups had a mean T of 10.5 sec., which is longer than that of the vibrations in the min. groups, namely, 7.7 sec. This relation of the periods in the two series of groups, which sometimes happens in distant earthquakes, is the reverse of what took place in the Echigo Eqke, No. 7.

(ii) ***Eqke of Aug. 8, 1898; 4h 57m 35s p.m.*** (***NS Component.***)

The total duration of the prcliminary tremor was 7m 7s.

1st max. group: T=13.2 sec., max. $2a$=0.5 mm.

2nd „ „ : „ =13.6 „ , „ =0.35 „

The two max. $2a$'s occurred respectively at 5.17.55 and 5.23.23 p.m.

(iii) ***Eqke of April 16, 1899; 11h 1m 34s p.m.***

Total duration of the preliminary tremor=17m 35s.

The maximum groups, in the principal portion, occurred in the NS and EW components at average intervals of 1m 12s (average T =8.7 sec.) and 1m 36s (average T=9.2 sec.) respectively.

(iv) ***Eqke of April 17, 1899; 10h 46m 50s a.m.***

Total duration of the preliminary tremor=18m 55s.

There were, in the EW component, 4 max. and 4 min. groups, as follows:—

Group.	Duration.		Average T of vibration.	Max. $2a$.	Number of vib. in each max. group.
	m	s	sec.	mm	
1st max. group.	7	43	26.0	0.14	—
2nd „ „	2	31	16.8	0.10	9
3rd „ „	2	14	16.8	0.08	8
4th „ „	4	35	16.2	0.08	17
1st min. „	5	5	9.2	0.05	—
2nd „ „	2	48	—	Small.	—
3rd „ „	2	25	—	„	—
4th „ „	2	5	—	„	—

(v) ***Eqke of May 2, 1899; 11h 36m 47s p.m.*** (***EW Component.***)

Total duration of the preliminary tremor = 5m 31s.

The average J was 1m 30s, the T being 8.8 sec.

(vi) ***Eqke of June 14, 1899; 8h 27m 46s p.m.***

Total duration of the preliminary tremor = 16m 7s.

In the NS component, the average J was about 4 min.; the T's deduced from two series each of 50 vibrations being 18.4 and 16.4 sec. respectively. In the EW component, the corresponding periods were 18.8 and 17.0 sec. respectively.

(vii) ***Eqke of June 16, 1899; 2h 49m 10s p.m.*** (***EW Component.***)

Total duration of the preliminary tremor = 6m 28s.

The average J was 1m 54s, the T being 12.4 sec.

(viii) ***Eqke of June 25, 1899; 1h 12m 28s a.m.*** (***NS Component.***)

Total duration of the preliminary tremor = 17m 24s.

The average J was 1m 30s, the T being 15.7 sec.

(ix) ***Eqke of Aug. 18, 1899; 5h 46m 31s a.m.*** (***NS Component.***)

Total duration of the preliminary tremor = 25m 0s.

There were 5 conspicuous max. movements, which occurred respectively at 6.11.46; 6.14.18; 6.16.53; 6.19.13; and 6.21.23 a.m. The 4th was the absolutely greatest one, ($2a = 0.35$ mm), the T being 13.5 sec.

(x) ***Eqke of Aug. 26, 1899; 7h 7m 11s a.m.*** (***EW Component.***)

Total duration of the principal portion = 2m 16s.

Three max. $2a$'s occurred respectively 2m 19s, 3m 33s, and 4m 59s after the commencement of the earthquake; the average T being 9.0 sec.

(xi) ***Eqke of Aug. 26, 1899; 1h 58m 29s p.m.*** (***EW Component.***)

Total duration of the preliminary tremor=2m 13s.

Three max. $2a$'s occurred respectively 2m 49s, 4m 2s, and 5m 33s after the commencement of the earthquake; the average T in the 1st group being 10.1 sec., and that in the 2nd group 9.2 sec.

[*Earthquake which originated off the North-eastern Coast of the Main Island.*]

(xii) ***Eqke of Sept. 13, 1899; 11h 6m 56s p.m.*** (***NS Component.***)

Total duration of the preliminary tremor=0m 30s.

Six max. $2a$'s occurred respectively 2m 3s, 3m 58s, 5m 14s, 6m 10s, 7m 7s, and 8m 6s, after the commencement of the earthquake. In the 1st max. group, the average T was 5.1 sec.

[*Kyushyu Earthquake.*]

(xiii) ***Eqke of March 24, 1899; 1h 2m 35s p.m.***

Total duration of the preliminary tremor=1m 51s.

The average J was 1 min.

EARTHQUAKES OBSERVED AT HITOTSUBASHI.
EW COMPONENT.

80. The following data relating to the repetition of max. groups are taken from the analysis of the seismograms obtained from the *D*-instrument in 1900 at Hitotsubashi.*

[*Distant Earthquakes.*]

(i) ***Eqke of Dec. 25, 1900; 2h 7m 44s p.m.***

Total duration of the preliminary tremor=2m 30s.

The 1st three max. groups were as follows:—

1st group: max. $2a$=12.3 mm, T=31.4 sec.;
2nd „ : „ = 6.0 „ , „ =14.3 „ ;
3rd „ : „ = 3.8 „ , „ =13.8 „ .

The interval between the 1st and 2nd maxima was 1m 56s, and that between the 2nd and 3rd was 1m 3s. In the minimum epoch

* The measurements, reduced in a tabular form, are given in the *Publications*, No. 13.

between the two latter maxima there were some vibrations of $T=9.0$ sec., and also those of $T=4.3$ sec.

Later on there were 6 max. groups which occurred at an average interval of 1m 54s, the T being 9.8 sec.

(ii) ***Eqke of Nov. 10th, 1900; 2h 20m 59s a.m.***

In the earlier part of the principal portion, 11 max. groups occurred at an average interval of 1m 11s, the T being 8.3 sec. Each of these groups consisted of about 5 vibrations.

In the end portion, 11 max. groups occurred at an average interval of 1m 7s, the T being 9.2 sec.

[*Earthquake which originated off the North-eastern Coast of the Main Island.*]

(iii) ***Eqke of March 12, 1900; 10h 35m 1s a.m.***

The preliminary tremor lasted 46 sec.

The earlier quick vibrations of macro-seismic nature indicated 3 max. groups, as follows.—

1st group: max.	$2a=1.56$	mm	$T=0.91$ sec.
2nd „ : „	$=1.63$	„	
3rd „ : „	$=1.75$	„	

These 3 maxima occurred respectively 56s, 1m 6s, and 1m 18s after the commencement of the earthquake; there being also some vibrations of $T=8.6$ sec.

In the principal portion, there were 10 distinct max. groups, as follows.—

Max. group.	Max. $2a$.	Average T.	Time of occurrence (after the commencement of princ. portion.)		Interval between successive maxima $= J$.	
	mm	sec.	m	s	m	s
1	2.75	7.0 (Also vib. of $T=2.9$ sec.)	0	0		
2	2.94		0	33	0	33
3	2.00		1	13	0	40
4	3.05		1	46	0	33
Mean.	....	....	.....		**0**	**35**
5	1.7	4.7	3	3		
6	1.7		3	44	0	41
7	1.48		4	29	0	45
8	1.5		5	11	0	42
9	1.4		5	58	0	47
10	1.4		6	48	0	50
Mean.	....	....	.....		**0**	**45**

The average J of the 1st 4 max. groups was 35 sec., and that of the last 6 was 45 sec.

In the subsequent portion of the principal portion, the average T was 5.9 sec.

In the end portion, the average T was 9.7 sec.

EQKES NOS. 7, 8, 10, 24, 25, 1', 11, 12 and 20.

81. The following table gives the data relating to the repetition of the max. movements, in some of the different earthquakes, whose seismogroms have been described in §§5—55; in general the duration J may be taken as being equal to the interval between successive max. $2a$'s.

TABLE XIV. REPETITION OF MAX. MOVEMENTS.*

Eqke No.	Max. Group.	Max. $2a$.	Average T.	Time of occurrence of max. $2a$ (after commencement of princ. portion.)		Interval between successive max. $2a$.'s	
		mm.	sec.	m	s	m	s
7 (NS)	1	11.9	5.5	0	44	‡0	46
	2	12.5	4.5	1	15	‡0	56
	3	5.15	4.1	2	28		
8 (NS)	1	8.8	6.8	0	46	0	32
	2	7.15		1	25		
	3	3.75		1	50		
	4	2.4		2	23		
8 (EW)	1	7.5	6.2	0	39	0	35
	2	8.25		1	16		
	3	3.9		1	48		
10	1	17.6	17.6	0	45	1	0
	2	—	—	—			
	3	17.0	7.9	3	4		
	4	17.5	7.5	3	56		
	5	14.7	7.8	4	45		
	6	5.65	8.4	5	46	1	6
	7			6	55		
	8			8	10		
	9			8	50		
	10			10	10		
24	1	3.3	25.7	—			
	2	4.5	15.2	—			
	3	4.4	8.0	3	59	1	14
	4	3.6		5	16		
	5	4.4		6	26		
25	1	3.24	24.5	—			
	2	4.7	10.4	—			
		4.65	18.5				
	3	7.4	9.1	4	12	1	19
	4	6.9		5	19		
	5	7.6		6	49		

* Unless otherwise mentioned, the figures refer to the EW component seismograms.

‡ The two intervals are those between the successive max. groups.

TABLE XIV. (*Continued.*)

Eqke No.	Max. Group.	Max. $2a$.	Average T.	Time of occurrence of max. $2a$. (after commencement of princ. portion.)		Interval between successive max. $2a$'s.	
		mm	sec.	m	s	m	s
1′	1	3.7	6.7	0	2		
	2	4.2	6.8	0	49	0	35
	3	3.7	6.4	1	7		
	4	2.7		1	48		
11	1	4.3		0	22		
	2	3.6	6.3	1	7	0	37
	3	3.8		1	38		
	4	3.15	3.8	1	50	0	43
	5	4.35	8.6	2	33	1	17
	6	3.6	6.1	3	50	1	56
	7	2.7		5	46		
12	1	1.75	9.4	0	56		
	2	3.2	5.9 (also sup. by vib. of T=10.6s, and T=3.5s.)	3	16	0	58
	3	3.25		3	58		
	4	2.45		5	0		
	5	2.7		6	11		
20	1	2.7					
	2	2.9	9.5			0	45
	3	2.7					
	4	3.3	6.0				

In the Echigo Eqke, No. 8, (EW comp.), the 3 max. $2a$'s were respectively the 1st, 2nd, and 1st vibrations of the three max. groups.

Again in the Izu Eqke, No. 10, the 1st 5 max. $2a$'s were respectively the 2nd, —, 4th, 4th, and 4th vibrations of the 5 max. groups, which comprised respectively 4, —, 6, 6, and 6 vibrations.

82. ***The mean interval J in the different earthquakes.***

In the following table are collected the mean values of the

interval ($=J$) between successive maximum groups* in the different earthquakes, arranged according to an ascending order.

TABLE XV. Mean Interval between Successive Maximum Groups $=J$.

Eqke No.	J		Average T.	Duration of Prel. Tremor.	
	m	s	sec.	m	s
8 (NS)	0	32	6.8	0	20
,, (EW)	0	35	6.2	0	20
1′	0	35	6.6	0	58
iii, § 80.	0	35	7.0	0	46
11	0	37	6.3	0	39
,,	0	43	3.8	,,	,,
12	0	45	9.5 ; 6.0	1	31
iii, § 80.	0	45	4.7	0	46
7	0	51	4.7	0	17
12	0	58	5.9	1	31
10	1	00	7.7	1	39
xiii, § 79.	1	00	—	1	51
10	1	6	8.4	1	39
ii, § 80.	1	7	9.2	—	
,,	1	11	8.3	—	
xii, § 79.	1	11	5.1	0	30
iii, § 79. (NS)	1	12	8.7	17	35
24	1	14	8.0	2	15
x, § 79.	1	15	9.0	2	16
25	1	19	9.1	2	17
11	1	17	8.6	0	39
xi, § 79.	1	22	10.1 ; 9.2	2	13
v, § 79.	1	30	8.8	5	31
viii, § 79.	1	30	15.7	17	24
i, § 80.	1	30	31.4 ; 14.1	2	30
iii, § 79. (EW)	1	36	9.2	17	35
vii, § 79.	1	54	12.4	6	28
i, § 80.	1	54	9.8	2	30
11	1	56	6.1	0	39
ix, § 79.	2	24	13.5	25	0
vi, § 79.	About	4m.	18.6 ; 16.7	16	7

Thus it will be seen that the values of I most frequently occurring were included between $\frac{1}{2}$ and $1\frac{1}{2}$ min; the distribution of the 31

* Assumed to be equal to that between the successive max. $2a$'s.

cases contained in the above table into half minute intervals being as follows:—

Between	0m	0s	and	$\frac{1}{2}$m,	 0	cases.
„	0	31	„	1 ,	12	„
„	1	1	„	$1\frac{1}{2}$,	13	„
„	1	31	„	2 ,	 4	„
„	2	1	„	$2\frac{1}{2}$,	 1	„
„	3	31	„	4 ,	 1	„

From the above table it may be concluded that the length of the interval J does not depend on the duration of the preliminary tremor, nor on the period of vibration in each maximum group alone. In different earthquakes with approximately equal periods of vibration, however, the values of J seem to be in many cases also approximately equal to one another. (Compare with the next §.)

The results contained in table XV relate to the vibrations in the principal portion of the earthquake motion. In the *end portion* there are also often well defined series of the alternation of maximum and minimum groups. Thus, for instance, in the end portion of the Caracas earthquake, No. 6′, the maximum groups occurred at an average interval of 1m 55s, the T being 17.9 sec. It is hereby to be noted that the *pulsatory oscillations* also show always alternations of max. and min. groups.

CAUSE OF THE OCCURRENCE OF THE MAXIMUM GROUPS.

83. The occurrence of max. and min. groups in the earthquake motion is evidently the result of the coexistence of a series of vibrations with different periods. Thus let τ_1 and τ_2 denote two periods of vibration. If, *firstly*, τ_1 be slightly greater than τ_2, then the two series of vibrations will, by their superposition, produce maximum groups at an interval of

$$J=\frac{60 \text{ sec.}}{\text{Frequency of } \tau_2 \text{ vib.—Frequency of } \tau_1 \text{ vib.}}=\frac{\tau_1 \tau_2}{\tau_1-\tau_2} \quad \ldots . (1)$$

If, *secondly*, τ_1 differs from $2\tau_2$ by a small quantity, we get the following relation:—

$$J=\frac{2\tau_1\,\tau_2}{\tau_1\sim 2\tau_2} \quad \ldots\ldots\ldots\ldots (2)$$

The following are some of the instances, in which the occurrence of maximum movements may *approximately* be explained by one or other of the two above equations, under the supposition that the vibrations (of period τ_1) in a given max. group are the result of superposition of a series of movements of $T=\tau_1$ with another series of movements of $T=\tau_2$, which characterizes the vibrations in the part either preceding or following the group under consideration.

(*a*) ***Eqke No. xi, § 79.*** The periods in the 1st and 2nd max. groups were respectively $\tau_1=10.1$ sec., and $\tau_2=9.2$ sec. We have:

$$J=\frac{\tau_1\,\tau_2}{\tau_1-\tau_2}=\frac{10.1\times 9.2}{10.1-9.2}=1\text{m }43\text{s}.$$

The actual mean interval between 3 successive max. groups was 1m 22s.

(*b*) ***Eqke No. iii, § 80.*** The first 4 max. groups in the principal portion had an average period of vibration, $\tau_2=7.0$ sec.; while the superposed vibrations in the "preliminary tremor" had an average period of $\tau_1=8.6$ sec. We have, therefore,

$$J=\frac{8.6\times 7.0}{8.6-7.0}=37.7 \text{ sec.}$$

The actual mean interval between the 4 max. groups was 35 sec. Again, the vibrations in the next 6 max. groups (in the principal portion) had an average T of 4.7 sec., while those in the subsequent part of motion had an average T of 5.9 sec. If we double both of these periods, and put $\tau_1=5.9\times 2=11.8$ sec., $\tau_2=4.7\times 2=9.4$ sec., we obtain

$$J=\frac{11.8\times 9.4}{11.8-9.4}=46 \text{ sec.}$$

The actual mean interval between the 6 groups under consideration was 45 sec.

(*c*) ***Eqke No. 7 : NS Component.*** (Table XIV.)

There were 3 well defined max. groups, the average T's in the 1st and 2nd being respectively 5.5 and 4.5 sec. If we double both of these periods and put $\tau_1=5.5\times2=11$ sec., and $\tau_2=4.5\times2=9$ sec., we obtain

$$J=\frac{9\times11}{11-9}=49.5 \text{ sec.}$$

The actual interval between the 2 max. groups was 46 sec.

Again, let us compare the 2nd with the 3rd max. group, the average T in the latter being 4.1 sec. Putting $\tau_1=4.5$ sec., and $\tau_2=4.1$ sec., we obtain

$$J=\frac{4.5\times4.1}{4.5-4.1}=46 \text{ sec.}$$

The actual interval between the 2 groups under consideration was 56 sec.

(*d*) ***Eqke No. 11.*** (Table XIV.)

The average period of vibration in the first 3 max. groups was $\tau_1=6.3$ sec., while the average period of the vibrations in the succeeding part was 3.8 sec. $=\tau_2$.

In this case we have

$$J=\frac{2\tau_1\tau_2}{2\tau_2-\tau_1}=\frac{2\times6.3\times3.8}{7.6-6.3}=37 \text{ sec. ;}$$

the corresponding actual mean interval was 38 sec.

(*e*) ***Eqke No. 12.*** (Table XIV.)

The average period in the 1st max. group was $\tau_1=9.4$ sec., while that in the 4 succeeding groups was $\tau_2=5.9$. We have

$$J=\frac{2\times9.4\times5.9}{11.8-9.4}=46 \text{ sec. ;}$$

the mean interval between the last 4 groups was 58 sec.

XIV. CONCLUSION.

84. The different results contained in the preceding pages are to

be regarded only as rough approximations, which may serve as preliminaries for future investigations. They show, however, that the earthquake motion is subject to several simple laws: one of the consequences being that the disturbances proceeding from neighbouring localities are usually similar to each other.

It is extremely desirable to make a comparative study of the earthquake motion observed at different places all over the earth; this being one of the principal seismological problems, the working out of which ought to be undertaken by the International Seismological Association.

It must here be remarked that for getting a trustworthy record of the motion of the ground the period of the so-called *steady mass* of the seismograph must be made as long as possible. If the period of free oscillation be under 30 sec. the *steady mass* is very often thrown into its proper movements, thereby much confusing the record of the real motion of the ground. An instrument with a free oscillation period of about 1 minute gives usually satisfactory results, in so far as the observation of distant earthquakes is concerned.

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