11. *Notes on the Destructive Earthquake in Sagami Bay on the First of September, 1923.*[1]

By

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[With 10 text-figures and 1 Plate.]

(Contribution from the Geophysical Institute of the Tohoku Imp. University.
Read at the annual meeting of the Physico-Mathematical
Society of Japan, on April 3, 1923.
Received July 16, 1924.)

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1) It was on the first of Sept., 1923, that the memorable destructive earthquake in Sagami-Bay caused great damage everywhere around Tokyo Bay and Sagami Bay. It occurred 68 years after the so-called Ansei earthquake destroyed Edo (now Tôkyô).

In Sendai (about 380 km. distant from Sagami Bay) we felt this shock just at noon, the oscillation being very slow with large amplitude, so that we felt as if we were on board a rolling steamer at sea. There was no seismic sound, but a rattling due to the vibration of houses was heard. The intensity was of "a weak among strong shocks" and wall-clocks indoors were stopped, though no other damage was caused. Its amplitude was the largest ever recorded in our observatory which was established in 1913. This note is a report of the results of instrumental observations of it made in our Geophysical Institute. I wish to offer my hearty thanks to Prof. Dr. S. Kusakabe for his kind guidance during these investigations.

2) There are 8 sets of seismographs in the Geophysical Institute of Tohoku Imperial University, of which 7 sets are in Mukaiyama Observatory (N. 38° 14′ 38.″8, E. 140° 51′ 56.″3 and 88 metres above mean sea level) and another portable one (No. 3) in the Institute (N. 38° 15′ 5″, E. 140° 52′ 36″ and 33.5 metres high.) The earthlayer on which they are set is of the tertiary formation.

The instrumental constants are as follows:—

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(1) Communicated by Prof. Dr. S. Kusakabe.

No.	Type	Comp.	Period	Magnification	Damper
1.	Omori-microseismograph	NS	15	120	without
2, A.	Omori-tremometer	EW	30	10	"
" B.	" "	NS	30	10	"
" C.	" "	Z (Vertical)	10	10	"
3.	Portable-microseismograph	EW	5	20	"
		NS	5	20	"
4.	Imamura-strong-motion seismograph	EW	5	2	
		NS	5	2	
5, A.	Wiechert seismograph	EW	4	100	with air damper
		NS	6	100	
" B.	" "	Vertical	2	228	" " "

They are all of point-magnifications, and the registers are made on smoked papers.

3) Time is marked every minute on the seismogram by the Riefler clock which is corrected by the chronometer whose rate is determined both by time-signal from Funabashi radio-telegraph station and by astronomical observation in the Mukaiyama Observatory. The time of occurrence of the great earthquake according to our instruments was 11^h 59^m 21^s. (by Japanese central standard time at 135° E. longitude) and no difference of time was found in the records of the two places above named.

The seismogram of the strong motion seismograph is very finely registered in two-fold magnification; other instruments of high magnification were thrown out of scale, but they have recorded very distinctly the initial part of the earthquake. The result of each register is as follows:—

i) No. 1. Omori type horizontal NS-component micro-seismometer: The displacement of the first phase of the first motion was 3·2 mm. towards N. In the first motion when the needle had moved 3·2 mm. to N from zero point, it showed a small oscillation with amplitude 1·1 mm. and period 2^s; and then deflected farther northward up to 18 mm., to return thence back towards S. In 12^s, the needle was thrown out of the smoked paper.

ii) No. 2, A. Omori horizontal EW-comp. tremometer: The first displacement reached 1·4 mm. E-ward, showing, on its way, a small step at 0·4 mm. from zero. Showing one small short vibration at 1·4 mm., the needle deflected farther to the same side up to 3·2 mm., from zero, and then after two small oscillations (period 2^s) it turned back to W-ward about 53 mm., accompanied with small vibrations; it was thrown out of scale in 26^s.

No. 2, B. Omori NS-comp. tremometer: The first displacement was 4·1 mm. N., showing two steps at 0·3 mm. and 0·7 mm. respectively. This 4·1 mm. N-ward corresponds to 1·4 mm. of No. 2, A. EW-comp. at the corresponding time. After this first motion, the needle turned to S. up to 38·8 mm. from zero and went out of scale in 26^s.

No. 2, C. Omori vertical comp. tremometer: The first displacement was 0·6 mm. upward; the oscillation period of the first deflection $2{\cdot}2^s$; the average predominant period in the initial part of the preliminary tremor 7^s. At first the needle moved 0·6 mm. upward, then, after returning to zero position, it moved 2·1 mm. again in the same upward direction and was out of scale in 1^m 2^s.

iii) No. 3. Portable micro-seismograph: This instrument is set in the Geophysical Institute. In NS-comp. the first displacement of the preliminary tremor was 4·7 mm. N.; the average period of the first part of the preliminary tremor $3{\cdot}7^s$; it went out of scale in 18^s. After the first deflection, the needle oscillated 4 times and at the 5th. oscillation the needle went 90 mm. to N-side and was out of scale after turning back to S-side. In EW-component, the first displacement was 1·6 mm. E.; the mean period of the first part of the preliminary tremor $2{\cdot}^s2$. In 15^s, it moved 78 mm. to W-side and then 79 mm. to E-side, whence the needle turned back to W-side, to go out of scale in 24^s.

iv) No. 5, A. Wiechert horizontal seismograph: In NS-component the first displacement of the preliminary tremor was 2·7 mm. N.; the average period of the first part of the preliminary tremor $2{\cdot}^s6$; was out of scale in 50^s. When the needle returned to zero after the first deflection, it was displaced 5·8 mm. to the same N-side, again and then went 12 mm. to S. In EW-component the first displacement was 0·9 mm. E.; the average period of the first part of the preliminary tremor $\frac{5^s}{9}$; was out of scale in 17^s.

v) No. 4. Imamura strong motion seismograph: This instrument recorded this earthquake perfectly. The duration of the preliminary tremor was $47{\cdot}^s5$, which is clearly seen to be composed of two portions i.e. P-phase and S-phase, both the period and amplitude of the former being smaller than those of the latter. After these phases, the principal portion or L-phase followed. In NS-component the preliminary tremor duration was $47{\cdot}^s5$, the average period in P-phase $=4^s$, and the mean amplitude in P-phase $=0{\cdot}7$ mm. After

27^s from the commencement the S-phase was recorded, of which the average amplitude was 2·1 mm. and the average prominent period 6.2^s. This average prominent period was accompanied by small oscillations of an average period of 3^s. The first part of L-phase had an average period of 3·5^s. After 1^m from the tremor-commencement appeared M-phase, i.e. the phase of maximum motion, and became more prominent after 1^m 7^s·5. In M-Phase its average prominent period was 8^s, accompanied by small oscillation of an average period 3^s. The maximum displacement in NS-component, whose amount is $2a=58·1$ mm. was seen 1^m 27·^{s}5 after the beginning of the tremor. As its period was 8^s, it corresponds to an acceleration of 1·79 cm./sec.^{2} in the case of a simple harmonic motion, which is 0·18 % of that of gravity.

In EW-component, the duration of the preliminary tremor was 47·^{s}5, the average period in P-phase 1·^{s}8, the average amplitude in P-phase 0·3 mm. After 27^s, S-phase appeared, of which the average period was 2·^{s}3, and the mean amplitude 1·8 mm. In the principal portion of the wave, the first part of the L-phase shows an average prominent period of 3·^{s}6, accompanied by small oscillations of a mean period 1·^{s}9, and the M-phase has an average predominant period of 8^s, with accompanying small oscillations of 3·2 period. The maximum motion in EW-component was seen after 1^m 16^s from the beginning of the tremor. Its displacement was $2a=64·2$ mm.; the period being 8 sec. Its acceleration is thus 1·98 cm./sec.^{2} or 0·2% of gravity. The mode of oscillation in the duration of the preliminary tremor is shown in Fig. 1, which was constructed by the combination of the two components, without considering free oscillation of the seismograph. The first part of the P-phase is clearly due to longitudinal wave. After about 7^s we find some small transversal waves, but within about 27^s of interval, the longitudinal waves are prominent. Thence afterwards, both longitudinal and transversal waves with larger amplitude are mixed together. This last interval is the S-phase above mentioned. From the sudden increase of amplitude it may be easily seen that after 47·^{s}5 the principal portion of the waves set in. The first displacement of M-phase was at 1^m after the tremor-commencement and 37·8 mm. toward N. 53·5 W. In 1^m 7·^{s}5 after the tremor-commencement, the maximum motion became more prominent, and at this instant the

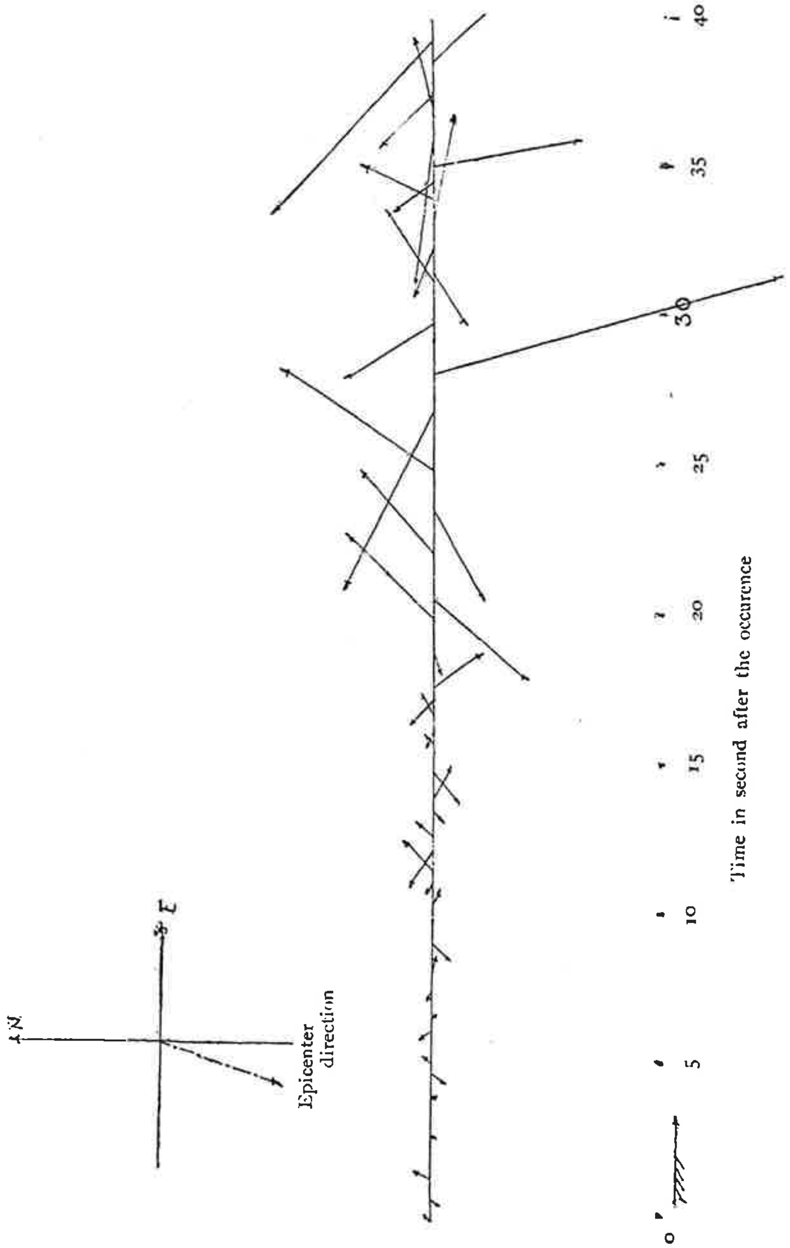


Fig. 1. Variation of Preliminary Tremors. (Magnification: 6)

displacement was 49·3 mm. toward S. 71° E. which is nearly normal to the direction of the first displacement of the preliminary tremor, whence we may conclude that this portion was due to the transversal wave. The average amplitude in the interval of maximum motion was $2a=62{\cdot}6$ mm. and, as its average period was 8^s the motion is equivalent to the simple harmonic motion whose acceleration is 1·93 cm./sec.² Thus the horizontal intensity of seismic force is 0·2 % of gravity at Sendai. Though we did not take into account the free oscillation of the instrument in the above examination, this factor must have a very great influence on the last part of the seismogram.

4) The seismic centre is known to be 383·5 km. distant from our Observatory, by the duration-time $47^s{\cdot}5$ of the preliminary tremor. The first horizontal displacement recorded by the Wiechert's instrument, Omori-tremometer, or the portable microseismograph, indicates the epicentre to lie in the direction S. 18°·5 W. The first displacement of the first motion, calculated from the record of the vertical component instrument, is directed 7°·9 upward from the horizontal plane. Thus the epicentre seems to be at a position N. 34° 52′, E. 139°36′, and the focal depth of the seismic centre to be 44·0 km. This depth is calculated under the assumption that the seismic ray is propagated along a straight line. But, in the actual case, the path may be curved on account of the difference of propagation-velocity from one layer of the crust to another. If the velocity in the lower layer is larger than that in the upper layer, the depth must become smaller.

Thus the epicentre is located in Sagami-Bay off the island Jôgashima at the edge of Miura peninsula. The seismic centre, however, would not have been a single point but had some spatial extension. We can therefore only conclude that the point above determined signifies the portion of the seismic centre whence the seismic wave was propagated to Sendai at the commencement.

5) On Sept. 1, the meteorological observations in our Observatory at 10^h and 14^h were as follows:—

Time	Atom. Press.	Wind Direction	Wind Press.	Atom. Temp.	Humid.
10^h	753·40	SE	2·5	24·5	87
14	748.85	S	5·92	23·4	100

Time	Cloud Quantity	Kind of Cloud	Cloud Direction	Cloud Vel.	Weather
10^h	10	N	SSE	7	Cloudy
14	10	N	SSE	9	Rainy

The maximum air temperature was 25·5° C. and the minimum 22·8°.; total wind path for 24 hours was 268 km. so that the mean wind velocity was 3·1 m/sec. The maximum wind pressure was 10·20 m. in SSE at $12^h{\cdot}5$, and the most frequent wind direction was S.

It rained moderately at $10^h\,1^m$, very heavily from $11^h\,5^m$ to $15^h\,55^m$, and afterwards slightly. At $16^h\,10^m$ the weather became fine and the sky was reddish-yellow with evening glow. The total rainfall in 24 hours was 62·1 mm.

The weather chart of the Central Meteorological Observatory of Japan shows that, though the typhoon located on the eastern sea of Ryukyû on Aug. 30 passed to the Japan Sea, crossing Honsyû Island, a secondary local depression passed over Kwantô provinces on the morning of Sept. 1, throwing Sagami-Bay under the influence of a remarkable pressure-gradient, and proceeded to Tôhoku province. Its centre did indeed reach Sendai at 17^h of that day. This local depression passing over Kwantô province might have had some influence on the pressure-distribution of the earth crust or on the height of the sea-level in Sagami Bay. Flood tide was at $8^h\,41^m$ on Sept. 1, which, combined with the accompanying light SE wind must have caused unusual variation of the water level. It is probable that these influences led to a sudden change of hydrostatic pressure on the sea-bottom when the high pressure took place soon after the centre of the low pressure had passed on and the flood tide turned into ebb. Also we must consider how the attraction of the moon would have acted upon the magma layer within the crust. These influences, taken together, acted probably as the proximate cause to induce this great earthquake along the weak line of earthcrust, which was at the critical state of stability.

6) We are not able to trace any fore-shocks of this earthquake with certainty, but we had some earthquakes which might be regarded as its foreshocks, for the reasons that the duration of their preliminary tremors, the positions of their epicentres, and the characteristic forms of vibrations were very like the great earthquake.

They are as follows:—

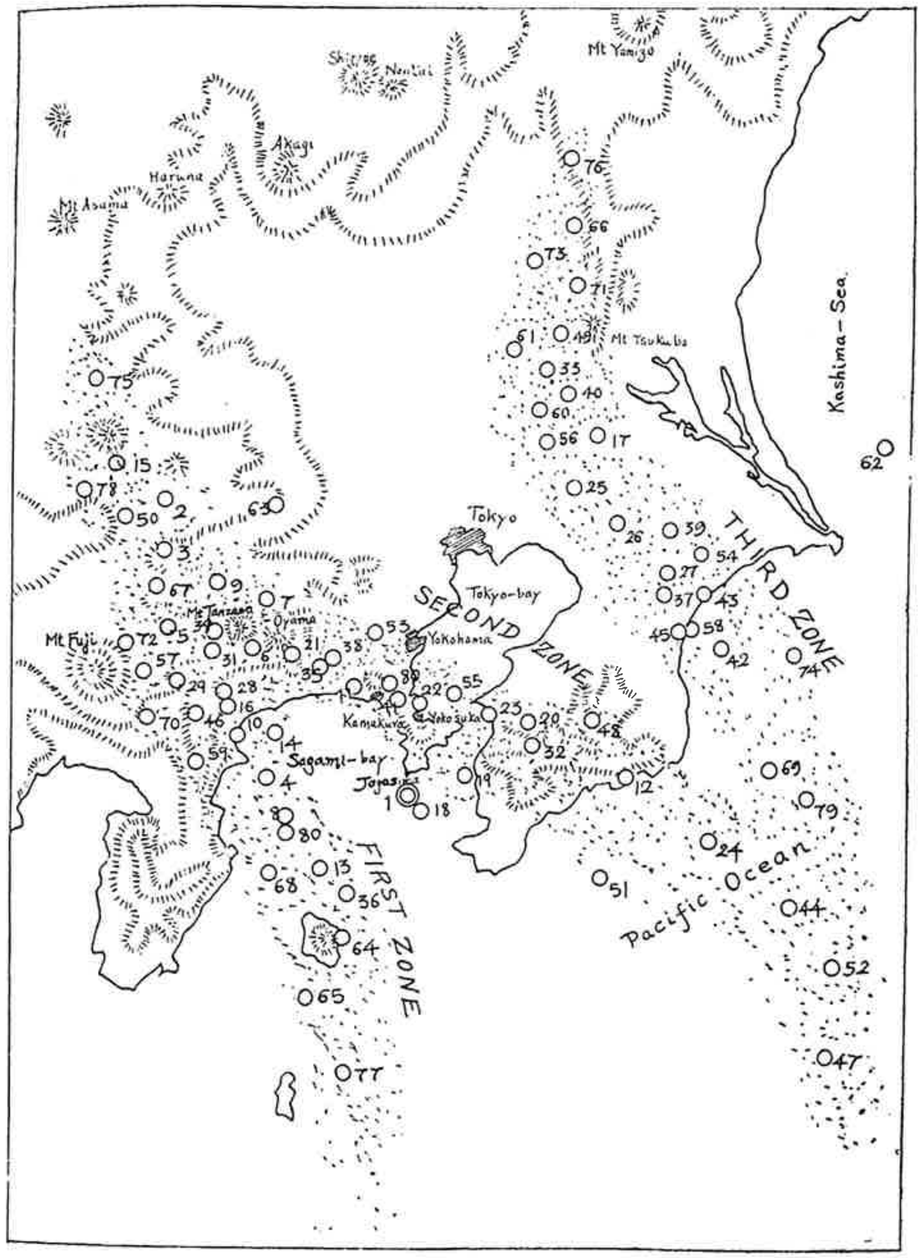
No.	Date	Time of Occurrence	Duration of Prel. Tremor	Max. Displ. to N.	Total Duration of Vibration	Direction of First Displacement
1	Aug. 18	10h 6m 51s	42s	2.2/120 mm.	2 m	NE Up
2	19	2 30 18	46	0.9/120	3	N Up
3	19	15 56 47	48	0.7/120	2.5	— —
4	20	4 0 53	42	1.5/120	3.5	N Up

Up till the end of December, 1923, we observed 652 aftershocks of the earthquake in our Institute. Among them there are 80 comparatively strong ones tabulated below whose epicentres are plotted in fig. 2.

Earthquake Nos.	Date	Time of Occurrence			Earthquake Nos.	Date	Time of Occurrence		
	Sept.	h	m	s		Sept.	h	m	s
1	1	11	59	21	26	,,	18	27	41
2	,,	12	19	26	27	,,	18	49	38
3	,,	12	25	12	28	,,	22	10	6
4	,,	12	30	48	29	,,	23	19	21
5	,,	12	40	54	30	3	10	47	54
6	,,	12	48	22	31	,,	23	31	27
7	,,	13	17	4	32	,,	23	52	57
8	,,	13	22	8	33	4	15	49	6
9	,,	13	59	53	34	5	0	25	43
10	,,	14	23	20	35	,,	3	13	20
11	,,	15	5	45	36	,,	7	23	50
12	,,	15	19	56	37	,,	20	13	47
13	,,	15	49	9	38	6	3	30	33
14	,,	15	57	17	39	,,	3	48	6
15	,,	16	25	19	40	7	12	59	50
16	,,	16	38	59	41	,,	23	31	13
17	,,	17	11	51	42	,,	23	47	26
18	,,	22	32	7	43	8	0	17	56
19	,,	22	53	1	44	,,	2	33	33
20	2	2	3	17	45	,,	8	40	21
21	,,	4	9	13	46	,,	18	9	40
22	,,	6	12	52	47	9	4	11	58
23	,,	6	49	21	48	,,	12	3	46
24	,,	11	47	37	49	,,	15	52	38
25	,,	14	11	4	50	,,	23	5	38

(*to be continued.*)

Fig. 2.
Distribution of Great After-Shocks



(*continued.*)

Earthquake Nos.	Date	Time of Occurrence h	m	s	Earthquake Nos.	Date	Time of Occurrence h	m	s
51	Sept. 10	3	11	55	66	Sept. 26	18	40	3
52	"	11	27	48	67	29	12	1	26
53	11	14	11	35	68	30	15	26	45
54	"	15	23	59	69	Oct. 4	0	54	56
55	"	23	8	56	70	"	22	6	21
56	14	15	33	56	71	8	8	41	53
57	15	2	42	30	72	17	3	4	43
58	16	17	19	45	73	Nov. 1	1	37	36
59	17	10	3	13	74	5	5	46	20
60	18	9	28	6	75	22	2	0	55
61	21	8	22	36	76	28	18	24	20
62	22	11	53	56	77	Dec. 19	22	49	36
63	26	13	4	24	78	24	12	41	48
64	"	17	24	39	79	31	11	22	29
65	"	17	28	0	80	"	14	52	13

From the figure we see that the epicentres are distrubuted in the form of the letter N, consisting of 3 zones. The first zone is parallel to the Fuji Volcanic Zone and goes along the Idzu Islands. The second zone, branching from the first zone at the vicinity of Tanzawa Mountain, runs along Miura peninsula and Bôsô Mountains, crossing the Uraga Canal, and meets the third zone in the Pacific Ocean, off the eartern coast of Bôsô peninsula while the third zone runs along the extended line of the Yamizo Mountains. We call this group of 3 zones by the name of "N seismic zones." These zones show such intimate relation to each other that, if one of them be active, then the other becomes active also. Such a group of zones may well be called "Conjugate Seismic Zones." In the Sagami Bay earthquakes, many of the after-shocks occurred in these conjugate zones. From the end of May to July, 1923, a great number of earthquakes were observed in Kwantô province, which were largely after-shocks of the earthquakes on May 26 in the first zone and on May 31 and June 2 in the third zone. The great majority of them occurred in these conjugate zones, which clearly shows the activeness of these zones. Fig. 3 and the following table show the frequency distribution of the durations of the preliminary tremors of aftershocks of the great earthquake. The duration is taken as abscissa which represents the distance from the seismic centre, and the

the number of occurrences of different durations as ordinates. Here we see some points of maximum frequency as marked by *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, in the figure. The great Sagami Bay earthquake has a duration corresponding to the point *e*.

Duration of PS-phase in sec.	No. of Frequency of Earthquakes Sept.	Oct.	Nov.	Dec.	Sum (4 Months)	May 24 to July
* 30	0	0	0	0	0	4
31	1	0	3	0	4	3
32	5	0	2	2	9	25
33	6	2	3	1	12	30
34	9	1	4	1	15	20
35	11	1	0	1	13	5
36	7	0	2	0	9	3
37	27	2	4	2	35	11
38	33	2	1	1	37	6
39	14	0	1	0	15	2
40	34	0	3	0	37	7
41	16	2	1	1	20	1
42	44	1	2	3	50	3
43	52	3	2	1	58	3
44	25	3	2	1	31	4
45	20	4	1	1	26	2
46	29	2	0	2	33	0
47	47	2	0	1	50	1
48	59	2	1	1	63	3
49	7	1	0	0	8	0
50	10	5	0	0	15	0
51	8	2	2	0	12	0
52	16	3	2	0	21	1
53	16	0	1	1	18	5
54	6	0	0	0	6	0
55	10	1	0	0	11	3
56	2	1	0	0	3	0
57	4	1	1	1	7	0
58	4	0	0	0	4	1
59	0	0	0	0	0	0
60	0	0	0	0	0	0
61	0	1	0	0	1	0
62	1	0	0	0	1	0
63	2	0	0	1	3	0
64	2	0	0	0	2	0
65	0	1	0	0	1	0

Fig. 3.
Distribution of Duration of Preliminary Tremor in Aftershocks

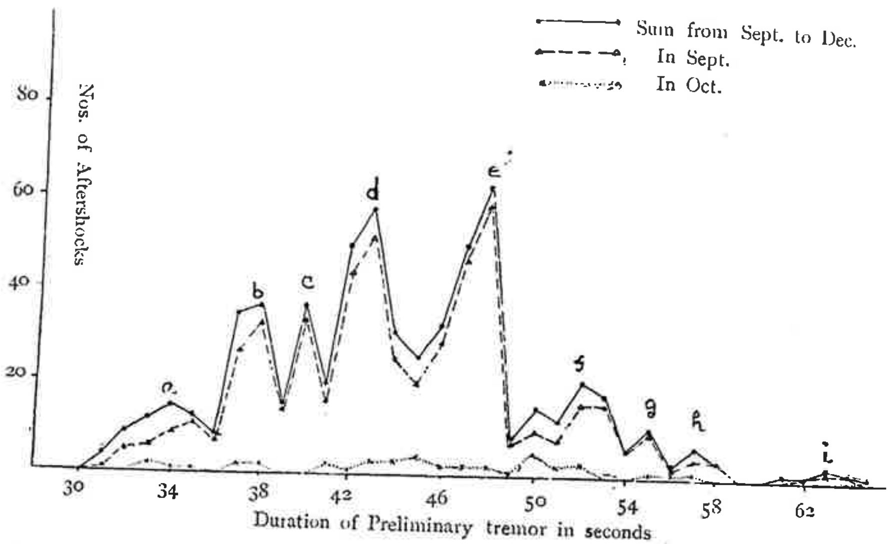
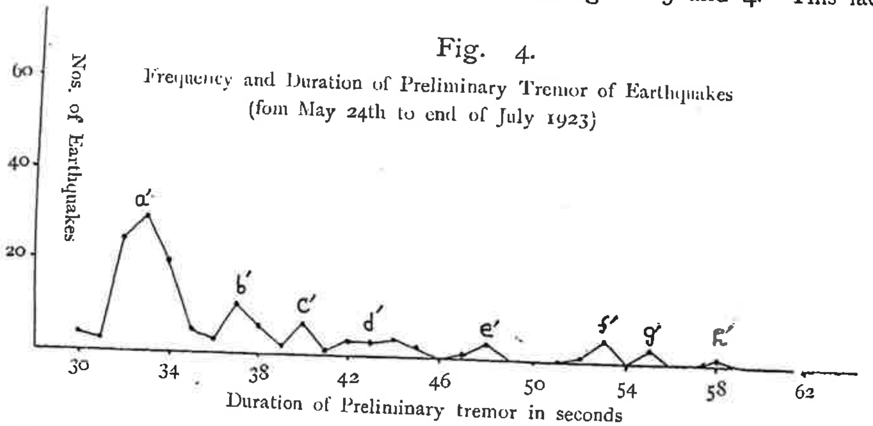


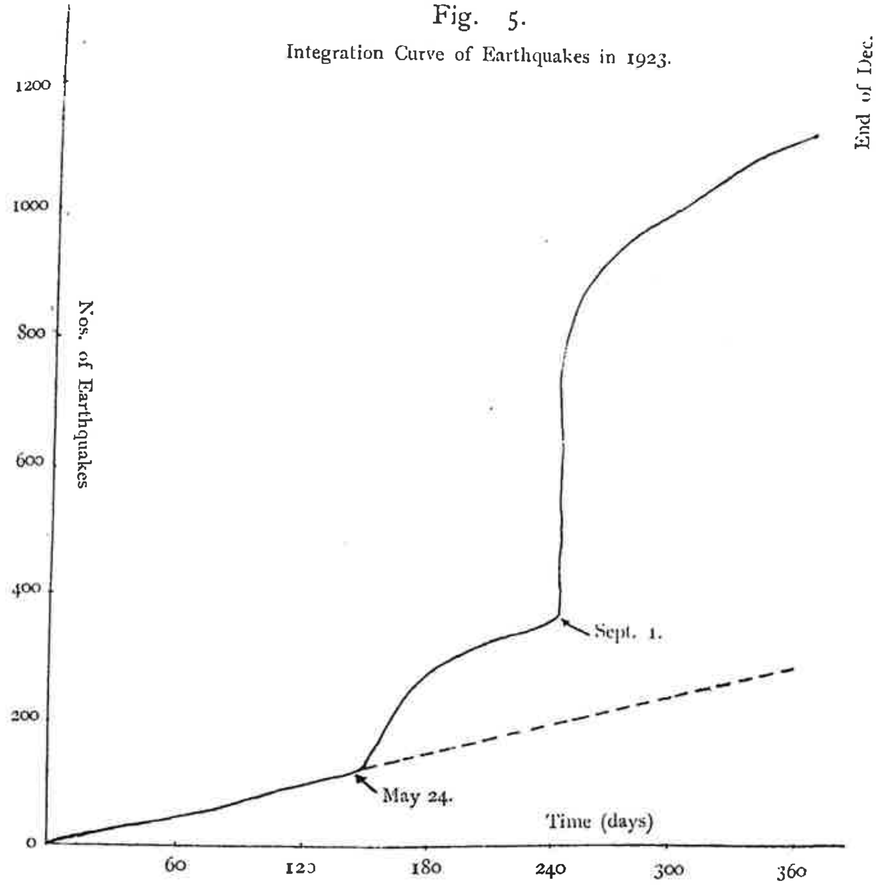
Fig. 4 (last column of the above table) shows the distribution-diagram, similarly constructed for the earthquakes from May 24 to the end of July in Kwantô province above mentioned. In this curve, there are also some points of maximum frequency, a' b' c' d' e' f' g' h' i'. These series of points are distributed at nearly the same values of abscissa in both figures 3 and 4. This fact

Fig. 4.
Frequency and Duration of Preliminary Tremor of Earthquakes
(fom May 24th to end of July 1923)



is very interesting as it suggests an intimate relation between the earthquake in June, 1923 and that on Sept. 1. Fig. 5 is the integral frequency curve of earthquakes, in which we take the integrated number of earth-

Fig. 5.
Integration Curve of Earthquakes in 1923.



quakes as ordinate and the time as abscissa. The dotted line is the extension of the nearly straight part which is the normal seismic state at ordinary times. If the curve becomes parallel to the dotted line, we may believe that the aftershocks of an earthquake have ended. In September there were 544 aftershocks as shown in Fig. 6. The curve may be represented by $F=\frac{81.681}{t-0.895}$ where F is the numbers of frequency of aftershocks in 24 hours from noon to noon and t is the time in units of a day.

7) It is said that, in the case of some earthquakes, telegraph operators often feel electric shocks, which is considered as the result of the change in the contact resistance of the electric earth-plate caused by the

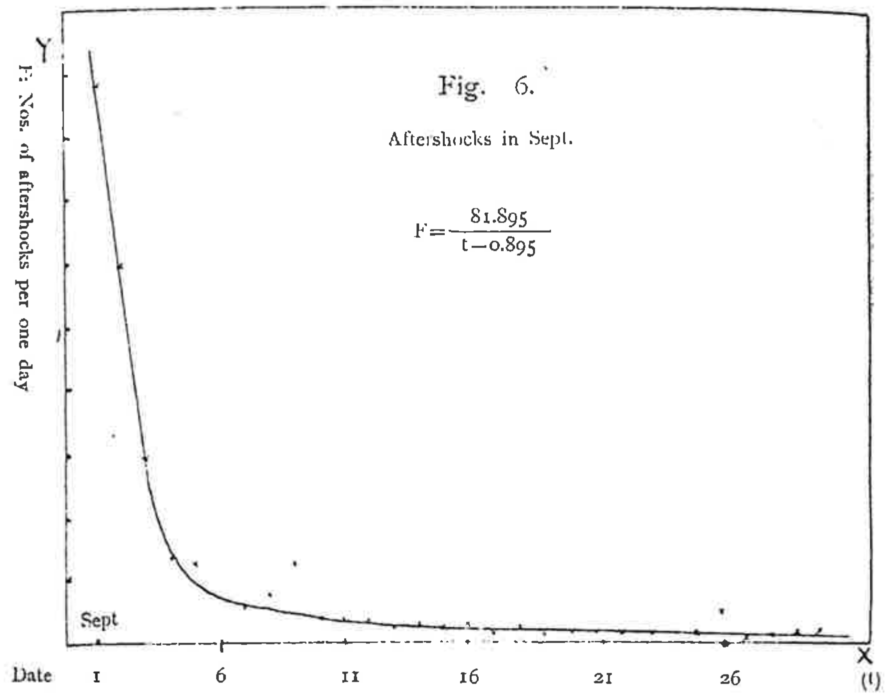


Fig. 6.
Aftershocks in Sept.

earthquake. Fortunately, we have for some time been observing the variation of earth-potential, by a zero method, using a potentiometer.

Three electrodes (dia. 2 cm.) of copper, galvanized with zinc, were arranged as shown in Fig. 7. The depth of the electrode is 1 metre under ground and the distance between E and W, or E and N is 10 metres; the direction of E to W is E-W and that E to N N-S. If the magnetic flux varies in some way in the loops of the leading wires from the electrodes to the potentiometer, corresponding electromotive force must be induced; but, though we have examined this effect by making other loops parallel to those, it was too small to be observed by the potentiometer. In fact, however, it

Fig. 7.
Positions of Electrodes

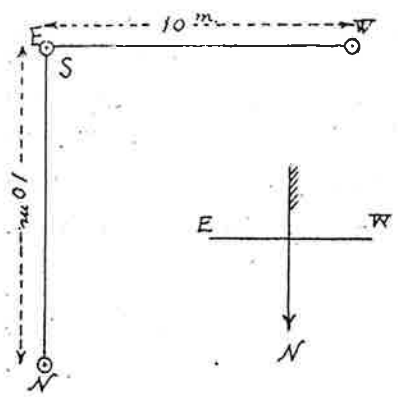


Fig. 8.

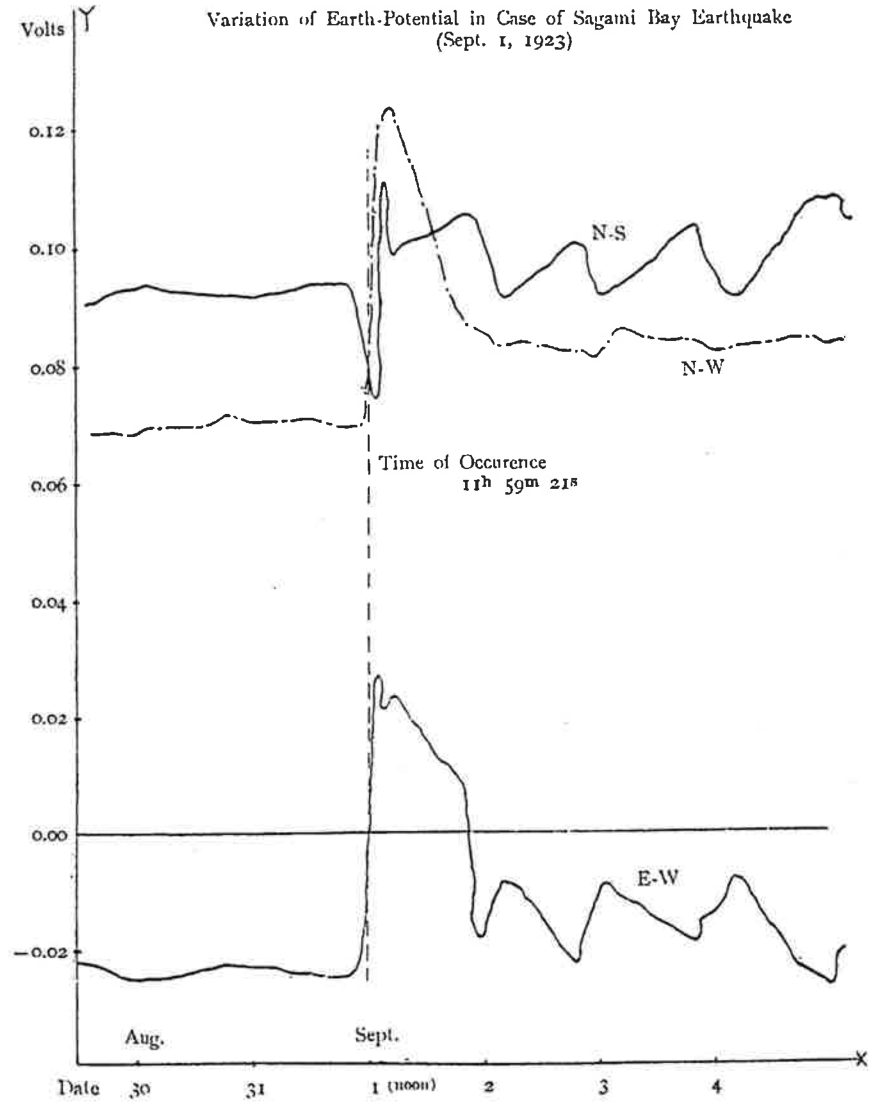


Fig. 9.

In Case of Tono Earthquake (Oct. 9, 1923)

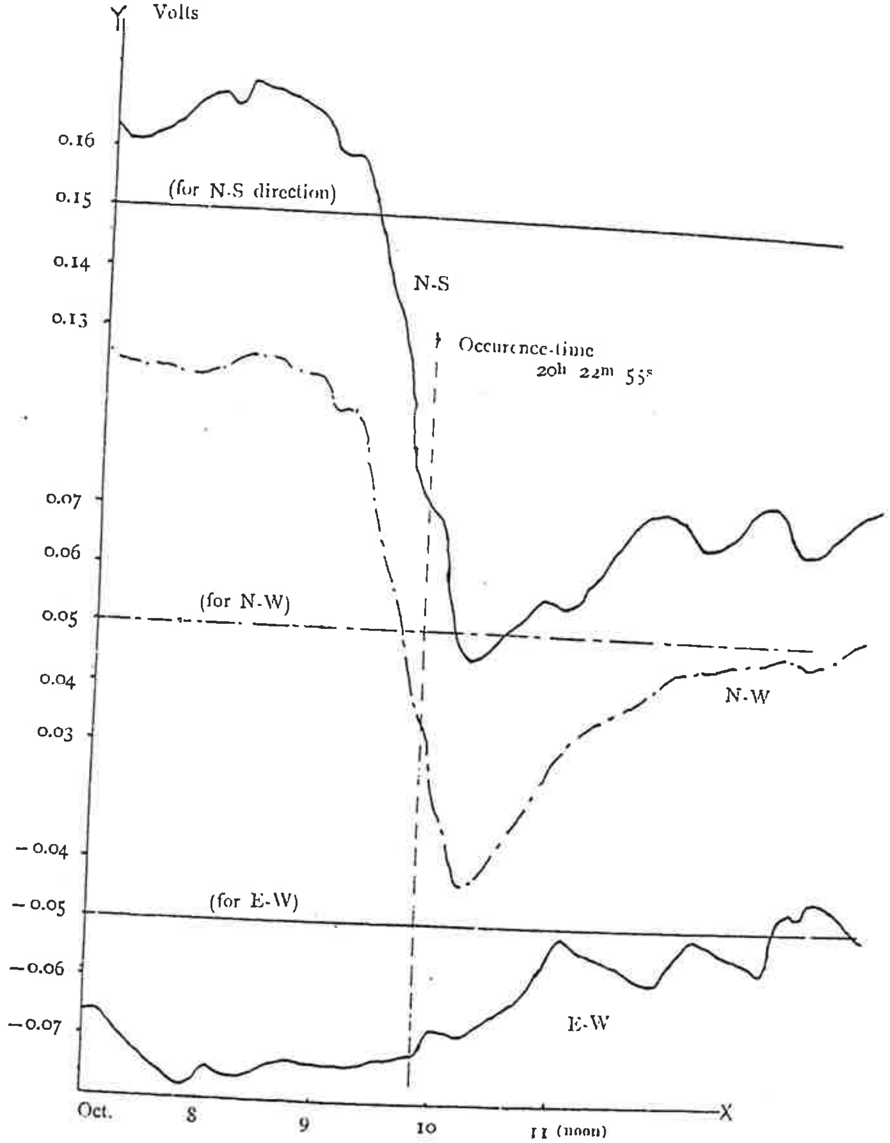
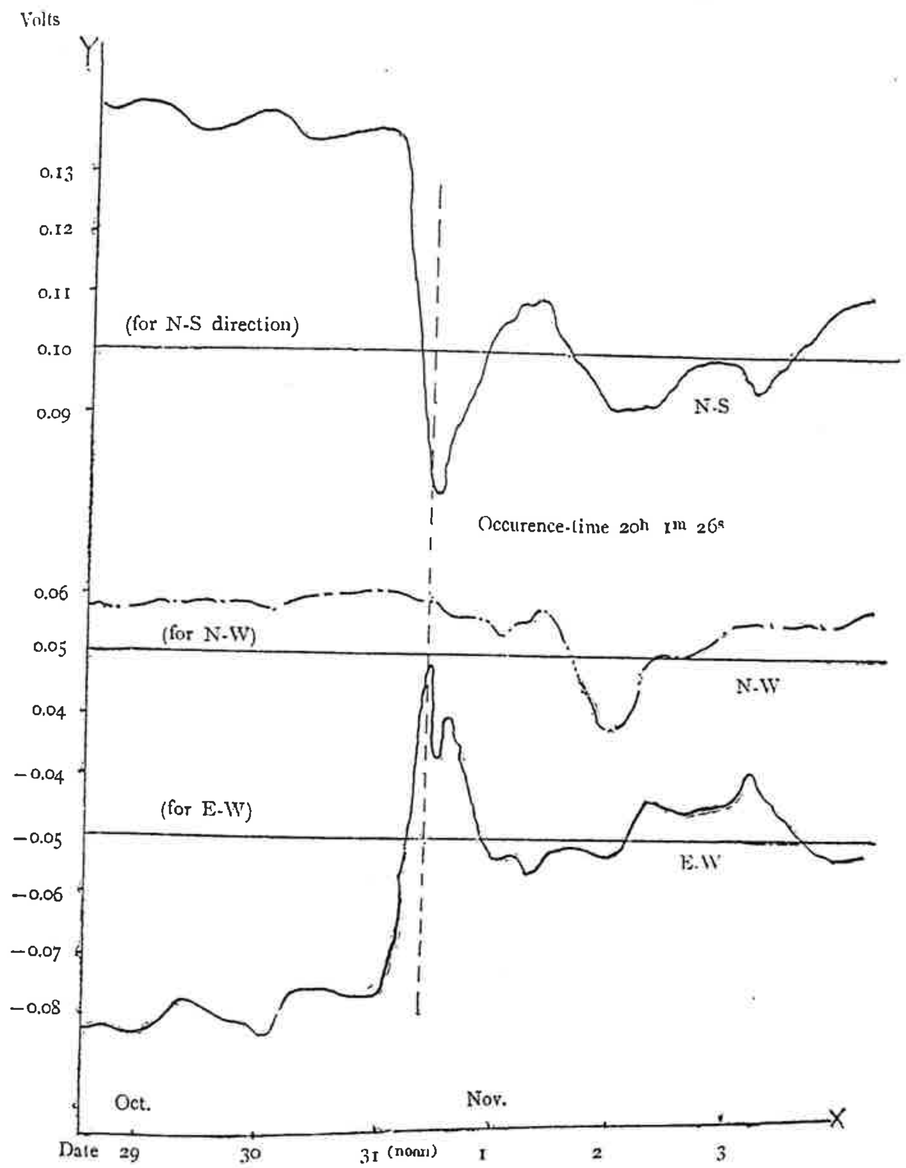


Fig. 10.

In Case of Nakamura Sea Earthquake (Oct. 31, 1923)



is observed that the earth-potential shows abnormally large variation during earthquakes, especially in case of near earthquakes. Its variation during the great Sagami Bay earthquake is shown in Fig. 8, in which the courses of the potential difference in the three directions NS, NW, and EW are given. On Oct. 9, 1923, ($20^h 22^m 55^s$) a comparatively strong near earthquake occurred at Tono, Iwate Prefecture (about 120 km. distant from Sendai), in which case the potential difference in NS and NW was affected while that in EW was not, as shown in Fig. 9. There was another near earthquake with sudden shocks in the sea off Nakamura, Fukushima Prefecture (about 60 km. distant from Sendai) at $20^h 1^m 26^s$ of Oct. 31, 1923, in which case NS and EW were influenced, but NW-component remained constant, as we see in Fig. 10. The values of potentials are given in the following tables.

Variation of Earth Potential, Accompanying Earthquakes.

i) Sagami Bay Earthquake (Sept. 1, 1923.)

Time	Potential Difference in Volts.		
	N-W	N-S	E-W
Aug. 31, 8h	0.070525	0.091275	−0.020850
11	0.070150	0.091150	−0.021215
13	0.070155	0.091865	−0.021470
16	0.070100	0.092045	−0.021880
19	0.069990	0.092875	−0.022455
Sept. 1, 8	0.069545	0.093550	−0.023920
9	0.069550	0.092985	−0.023675
11	0.069570	0.085025	−0.015700
13	0.098275	0.073650	+0.026750
14	0.117910	0.101710	+0.021340
16	0.122900	0.098075	+0.024830
19	0.109960	0.099840	+0.024365
2, 8	0.092315	0.105245	+0.008860
9	0.085700	0.105580	+0.008835

ii) Tono Earthquake (Oct. 9, 1923.)

Time	Potential Difference in Volts.		
	N-W	N-S	E-W
Oct. 8, 15h	0.094040	0.168450	−0.074560
17	0.095540	0.171655	−0.076170
9, 9	0.091250	0.164510	−0.073825
11	0.087390	0.160825	−0.073855
13	0.085830	0.159560	−0.074030
15	0.087110	0.160560	−0.073680
17	0.086215	0.160355	−0.074275
19	0.051760	0.121860	−0.073145
10, 8	0.026770	0.098750	−0.071925
11	0.019850	0.087590	−0.067710
13	0.014520	0.081520	−0.067185
17	0.006070	0.074820	−0.068575

iii) Nakamura Sea Earthquake (Oct. 31, 1923.)

Time	Potential Difference in Volts.		
	N-W	N-S	E-W
Oct. 30, 17h	0.060050	0.134335	−0.075150
21	0.060080	0.133580	−0.073660
31, 9	0.060345	0.133265	−0.074825
11	0.060790	0.137540	−0.076990
13	0.061065	0.136895	−0.076110
16	0.060985	0.119780	−0.073245
19.5	0.059140	0.077970	−0.020920
20.5	0.059405	0.076750	−0.017595
23.5	0.057075	0.084435	−0.027260
Nov. 1, 9	0.056255	0.105020	−0.049100

From these results it may be safely concluded that such potential variations depend on the direction of the epicentres of earthquakes. Sagami Bay is in the direction of SSW from Sendai, Tono, in NNE and sea off Nakamura, in ESE.

In conclusion I wish to express my sincere thanks to Mr. Seiki Ito, assistant in our Observatory who has examined with me such a number of records of earthquakes, and also to Mr. Y. Ueno.

Feb. 2, 1924.

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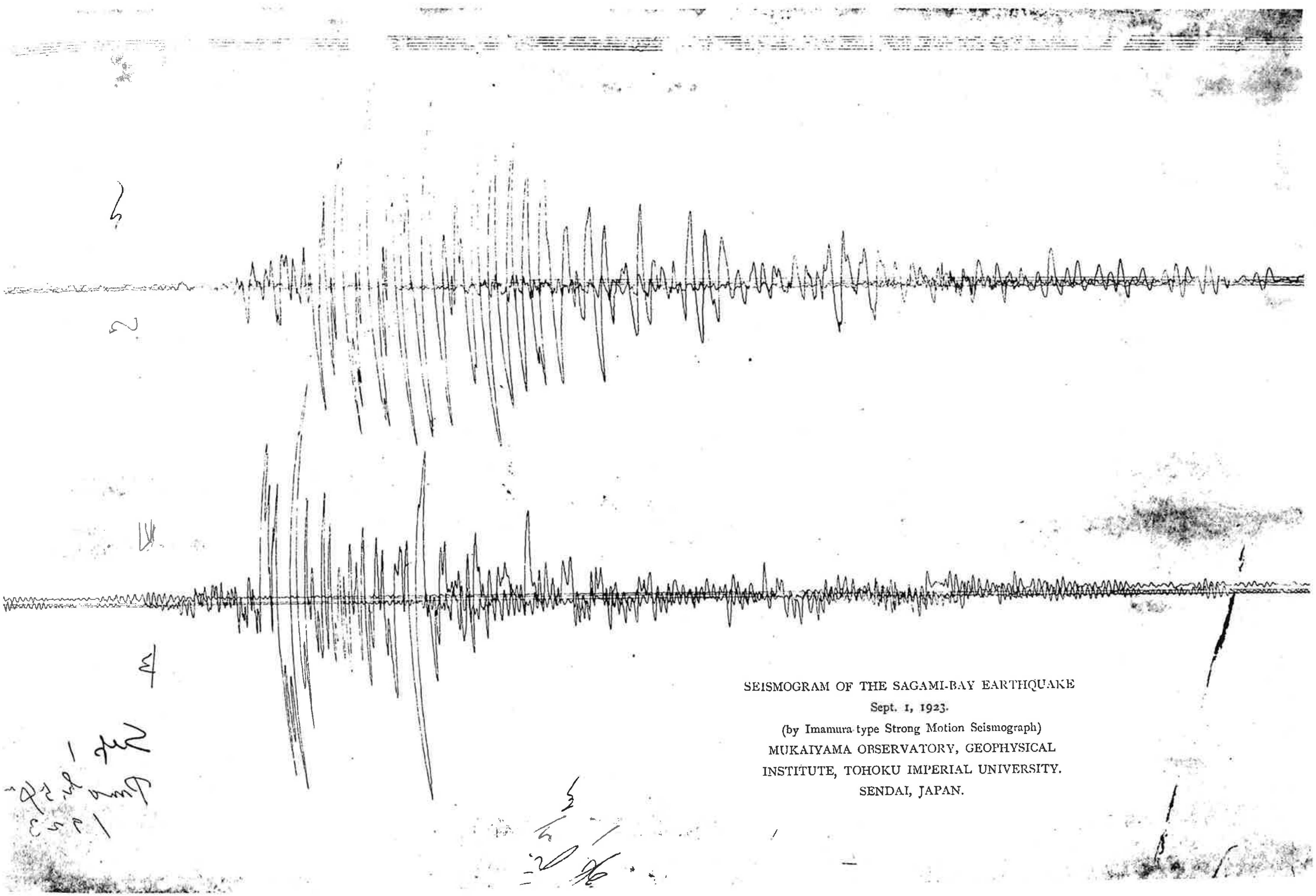

SEISMOGRAM OF THE SAGAMI-BAY EARTHQUAKE
Sept. 1, 1923.
(by Imamura type Strong Motion Seismograph)
MUKAIYAMA OBSERVATORY, GEOPHYSICAL INSTITUTE, TOHOKU IMPERIAL UNIVERSITY.
SENDAI, JAPAN.

K. SHIRATORI: Notes on the Destructive Earthquake in Sagami-Bay on the First of September, 1923.