

# On the Fore-shocks of Earthquakes.

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With Pl. XXIII.

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**1. Introduction.** It often happens that precursory shakings, or "fore-shocks," of different intensities are felt at the epicentral district of a great earthquake. As the latter is generally due to the formation or enlargement of a fault or crack of considerable length along a seismic zone in the earth's crust, it is quite natural that some of the weakest secondary points at the strained region should first give way and produce the minor shocks, before the dislocation or fracture along the whole extension of the focus produces the final great disturbance. In many instances, the fore-shocks were quite numerous, some of them attaining the intensity

of a semi-destructive motion. I mention next the more typical cases of the destructive earthquakes in Japan, which were preceded by these small shocks.

**2. *Earthquake of Kagi (Formosa) of 1906.*** The destructive earthquake in the Kagi prefecture, Formosa, on March 17, 1906, caused by the formation of the Baishiko and Chinsekiryō Faults, (the *Bulletin*, Vol. I, No. 2), was preceded about 5 minutes before by two strong shocks accompanied by very loud *jinari*, or sounds, like that due to a continuous discharge of gun. As these disturbances were quite unlike ordinary earthquakes felt there, the people were alarmed and took precaution for an escape in case of emergency, many running out of doors. Thus it happened that a comparatively small proportion of the inhabitants remained within doors at the time of the final great shock, a circumstance which must have considerably reduced the amount of casualties.

The occurrence of the premonitory shocks and *jinari* was also very striking in the cases of the Ansei and Riku-U earthquakes (§§ 3 and 4).

**3. *Ansei earthquake in Central Japan.*** The great earthquake of the 1st year of Ansei (1854), which was violently felt in the provinces of Iga, Ise, Omi, Yamato, Yamashiro, and Settsu, took place on July 9, at about 2 am.\* The epifocus was a zone about 100 km. in length, which stretched from the vicinity of Yokkaichi (in Ise) to that of Nara (in Yamato), passing by the north of the town of Uyeno (in Iga), where considerable convul-

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\* This is different from the two great earthquakes of Dec. 23 and 24 in the same year, which originated off the Pacific coast of Japan. See also my note "On the earthquake zones in central Japan," the *Bulletin*, Vol. I, No. 3.

sions of the ground were produced. At the last named place, a moderate shock intense enough to drive people out of doors had been felt already two days before, namely, on the 7th, at 1 pm., succeeded by a stronger and unusually severe one at a little before 2 pm. These two shocks, which caused some cracks of the plastered walls, were followed by incessant *jinari*, or earth sounds, like thunders heard toward the north-west, the number of the minor shakings which occurred before the evening being 27. It is recorded that a traveller happening to arrive at Uye-no the same day was frightened by the *jinari*, so he went on and stayed at Kasagi, thereby escaping the risk of the disastrous earthquake. During the night of the 7th, the people were panic-stricken, no one going to bed. On the next day (the 8th), the weather was fine, and although the *jinari* did not cease, there was no specially severe shock, and the people began to be somewhat reassured. In the same evening, however, there were a few small shakings at about 8 pm., the final great earthquake having taken place the next morning at 2 am. The two shocks at 1 and 2 pm. on the 7th were also felt in Osaka.

**4. *Riku-U earthquake of Aug. 31, 1896, at 5h 6m pm.***

The Riku-U earthquake was most violent in the two counties of Senpoku and Hiraga, in the province of Ugo, and in the county of Nishi-Waga in the province of Rikuchu, producing the lines of dislocations known as the Senya and Kawafune Faults. In the epicentral district, there had occurred a shock of moderate intensity already 6 days before, namely, on Aug. 23rd, at 4 pm., followed daily by one or more small shakings. On the 31st, at 9 am., there was a strong shock, causing some damage to the dwelling

houses and throwing off the plastered walls of some old *dozo* (Japanese ware houses). Thereafter occurred nearly 30 shocks and *jinari*; amongst others the shock at 4h 42m pm. being the strongest. 24 minutes later on, at 5h 6m pm., the final great earthquake took place.

The epicentral district had, before August, 1896, been only rarely disturbed by earthquakes, and these latter had not been accompanied by *jinari*. But since the 23rd of August, the earthquakes were invariably accompanied by *jinari*, indicating their nature as fore-shocks and the proximity of their origins.

**5. *Tonan earthquake of Nov. 5, 1900, at 4h 41m pm.\****

This earthquake originated off the coast of Izu, and was strongly felt in Kozu-shima, Mikura-jima, and Miyake-jima. At the last-named island, the first fore-shock, which was moderate in intensity, occurred at 8 am., on the 4th, followed by many moderate and slight shakings. At Mikura-jima, there was a moderate shock at 6 am., on the 5th, followed every five or ten minutes by others, the two strongest among which took place at 2 and 3 pm. respectively. In Kozu-shima, there was at 8h 10m am., on the 5th, a slight shock, followed by about a dozen moderate and slight ones, the final and largest earthquake having occurred at 4h 41m pm. the same day. According to the instrumental observations in Tokyo, there were 7 shocks, which preceded the final earthquake, and the first of which occurred at 9h 16m am., on the 5th, the strongest among these being that at 2h 10m pm.

**6. *Mino-Owari earthquake.*** The great Mino-Owari earthquake of Oct. 28, 1891, at 6h 37m am., was preceded by a strong shock, which took place 58 hours earlier, namely, at

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\* "Tonan" islands are the islands off the coast of Izu belonging to the Fuji volcanic chain.

9h 14m pm., on the 25th of the same month. In the epicentral area, *jinari* were heard from time to time before the great earthquake.

**7. *Hokkaido earthquake of March 22, 1894.*** The earthquake of March 22, 1894, which caused damage in the two provinces of Nemuro and Kushiro, along the north-eastern coast of Hokkaido, occurred at 7h 20m pm., the origin being sub-oceanic and at about 140 km. to the south-east of the city of Nemuro. This earthquake was preceded by the four shocks, whose times of occurrence and the intensity of motion at Nemuro were as follows:—

(i)	3 <sup>h</sup>	49 <sup>m</sup>	14 <sup>s</sup>	am.	Slight.
(ii)	2	22	55	pm.	Moderate.
(iii)	2	33	25	pm.	Slight.
(iv)	2	37	10	pm.	„

Thus the first fore-shock and the 2nd, which was the strongest among the four, had occurred respectively 15h 30m and 4h 57m before the final great earthquake.

The above mentioned four fore-shocks were observed with the ordinary Gray-Milne-Ewing type seismographs. Had the observation been made with the modern sensitive tromometer adapted to a continuous recorder, probably there would have been registered many other small insensible shakings.

**8. *Remarks on the fore-shocks of the different earthquakes.*** The time distributions of the Riku-U and Tonan fore-shocks, which occurred on the same days as the principal earthquakes themselves, present some mutual resemblance, as will be seen from the following table.

TABLE I.—FORE-SHOCKS OF THE RIKU-U AND TONAN EARTHQUAKES.

Riku-U Earthquake.		Tonan Earthquake.	
Time of Occurrence.	Successive Interval.	Time of Occurrence.	Successive Interval.
9 <sup>h</sup> 58 <sup>m</sup> am.	<div> <div>..... 0<sup>h</sup> 15<sup>m</sup></div> <div>..... 4 54</div> <div>..... 0 11</div> </div> 5 <sup>h</sup> 20 <sup>m</sup>	9 <sup>h</sup> 16 <sup>m</sup> am.	<div> <div>..... 4<sup>h</sup> 55<sup>m</sup></div> <div>..... 0 37</div> <div>..... 0 06</div> </div> 5 <sup>h</sup> 38 <sup>m</sup>
10 13 am.		2 11 pm.	
3 07 pm.		2 48 pm.	
3 18 pm.		2 54 pm.	
4 42 pm.	1 24	3 07 pm.	<div> <div>..... 0 13</div> <div>..... 1 8</div> </div> 1 21
5 06 pm. (Great Eqke.)	0 24	4 15 pm.	
		4 42 pm.	0 27

Thus the successive intervals between the times of occurrence of the fore-shocks were on the whole identical for the Riku-U and the Tonan earthquakes; the last strong fore-shocks having also occurred in the two cases by a nearly equal time interval, namely, 24 and 27 minutes respectively before the final disturbances.

The interval between the times of occurrence of the first strong fore-shock and the final great earthquake was, for the different cases, as follows:—

Ansei Eqke. ....	1 day	13 hours
Riku-U ,, ....	6	1
Tonan ,, ....	1	9
Mino-Owari Eqke. ....	2	10
Hokkaido ,, ....	0	15½

Again, the interval between the time of occurrence of the principal disturbance and the commencement of the last epoch of increased activity or frequency of the fore-shocks, was as follows :—

Ansei	Eqke.	.....	6 <sup>h</sup>	0 <sup>m</sup>
Riku-U	„	.....	8	34
Tonan	„	.....	7	26
Hokkaido	„	.....	4	57

The occurrence of fore-shocks is of course not limited to the few cases of the great earthquakes considered in §§ 2 to 7. The same phenomena are shown by the large as well as the semi-destructive or strong earthquakes originating off the north-eastern coasts of Japan, along the Fuji volcanic chain, or off the eastern coast of Formosa. A few illustrative cases are given next.

**9. Hokkaido earthquake of June 4, 1893.** The earthquake of June 4, 1893, at 2h 27m am., shook the southern islands of the Kuriles. Thus, in Shikitan island, the shock was felt strongly, being followed by the *tsunami* along the coast, which reached a height of about 8 feet over the ordinary sea level. Again, in the Shibetori county (northern part of the Etrup island), the *tsunami* came on about 20 minutes after the shock, and caused an increase of water of 5 feet, forcing the river waters to flow upwards. The *tsunami* continued till 9 am., and the large waves were repeated five times, rocks having been thrown down at many places along the coast. Prior to this earthquake, there had occurred between the 1st and 3rd (June), five moderate and slight earthquakes, which shook the Kuriles or the eastern part of Hokkaido; there being one or more shocks each day between the 4th and the 13th, except the 10th and the 12th.

**10. *Karenko (Formosa) earthquake of 1905.\**** The earthquake of Aug. 28, 1905, at 1h 24m pm., which was a local earthquake and which was semi-destructive at Karenko (Formosa), was preceded by several fore-shocks. Thus, at the latter town, there was a shock on the fore-noon of Aug. 8, several on the 13th, one each on the 18th, 19th, 20th, and 21st. A moderately strong shock occurred on the 26th, at 4h 50m pm., followed by a few slight ones, the final strong earthquake having taken place on the 28th. The after-shocks were also numerous, there being 20 or 30 of these on the same day and on the 29th.

**11. *Oshima (Izu) earthquakes of June 6 and 7, 1905.*** These two earthquakes, which caused some damage in the island of Oshima (Izu), were preceded by numerous small shocks. According to the report of the Governor of the island, there were more than 30 shakings between 1 am. and 10h 15m am., on the 5th, and a strong earthquake took place at 0h 35m am., on the 6th, causing several landslips in the island. The subsequent shocks were very frequent, more than 100 having happened before 11 am. the same day. On the 7th, at 2h 39m pm., there took place the principal earthquake, which were followed by more than 50 after-shocks in the course of the next 12 hours.

According to the tromometer observation in Tokyo, the first shock occurred on the 5th, at 10h 23m 26s am., between which time and the midnight of the 7th there were 28 others. Of these the 22nd one, which gave the greatest diagram, took place on the 7th at 2h 39m 30s pm. The following table gives a list of the earthquakes observed on the 5th to 7th in Tokyo.

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\* See my note on the Bokusekikaku and Basshisho earthquake of Jan. 11, 1908, given elsewhere in this Number.



TABLE II.—OSHIMA (IZU) EARTHQUAKES OBSERVED IN TOKYO.

No.	Group.	Intensity in Tokyo. (*....Unfelt)	Time of Occurrence in Tokyo.	Mean Time of Occurrence in Tokyo.
1		*	5th 10 <sup>h</sup> 23 <sup>m</sup> 26 <sup>s</sup> am.	
2	A	*( <i>Strong</i> in Oshima)	6th 0 40 34 „	<b>2 08 44</b> am.
3		*	0 43 37 „	
4		*	0 59 16 „	
5		*	1 13 43 „	
6		*( <i>Moderate</i> at Yokohama)	1 19 21 „	
7		*	1 38 56 „	
8		Slight ( <i>Moderate</i> at Mera)	1 50 50 „	
9		*( <i>Moderate</i> at Yokohama)	2 05 09 „	
10		Slight ( <i>Moderate</i> at Mera)	2 22 53 „	
11		*	2 50 45 „	
12		*	4 42 27 „	
13		*( <i>Moderate</i> at Yokohama)	5 17 13 „	
14	B	*	9 19 57 „	<b>10 53 14</b> am.
15		*	9 23 08 „	
16		*	10 23 30 „	
17		*	0 30 14 pm.	
18		*	0 49 22 „	
19	C	*	5 28 22 „	<b>7 28 39</b> pm.
20		*	9 28 55 „	
21	D	*	7th 6 12 05 am.	<b>6 12 05</b> am.
22	E	Slight ( <i>Strong</i> in Oshima, rather <i>strong</i> at Yokohama.)	2 29 30 pm.	<b>2 39 30</b> pm.
23	After- shocks.	*	3 30 41 „	
24		*	3 44 18 „	
25		*	4 13 58 „	
26		*	8 43 54 „	
27		*	10 06 51 „	
28		*	11 09 18 „	

From the above table it will be seen that the 12 shocks, Nos. 2 to 13, occurred one closely after the other. Similarly the 5 shocks, Nos. 14 to 18, occurred together, being, however, separated from the preceding ones by a long interval. Thus the 21 shocks, Nos. 2 to 22, the last of which was the principal earthquake, may be divided more or less definitely into the five groups, A, B, C, D, and E, whose mean times of occurrence are found to be as follows :—

A ( 12 shocks ).....6th: 2 <sup>h</sup> 8 <sup>m</sup> 44 <sup>s</sup> am.	Time Interval.
B ( 5 „ )..... 10 53 14 „	..... 8 <sup>h</sup> 45 <sup>m</sup>
C ( 2 „ )..... 7 28 39 pm.	..... 8 35
D ( 1 „ ).....7th: 6 12 05 am.	.....10 43
E ( 1 „ )..... 2 39 30 pm.	..... 8 27

The successive intervals between the mean times of occurrence, which may be regarded as indicating the most active epoch of the different groups, were approximately equal to one another, varying from 8h 27m to 10h 43m. Further, the numbers of the shocks in the first four groups were respectively 12, 5, 2, and 1. That is to say, the fore-shocks of the earthquake, No. 22, occurred periodically in groups at a mean interval of about  $8\frac{1}{2}$  to  $10\frac{1}{2}$  hours, the activity or frequency being successively lessened, till the principal disturbance finally took place. This time relation of the fore-shocks is somewhat similar to that in the case of the Ansei earthquake of July 9, 1854.

The shocks, Nos. 23 to 28, were the after-shocks. It seems that on the occasion under consideration the fore-shocks were more numerous than the after-shocks.

**12. Hachijo-jima earthquakes of May 13, 1908.** The two principal earthquakes on May 13, 1908, at 5h 23m and 5h

37m am., originated under the ocean nearly midway between the Cape Omae-zaki of Totomi and the island of Hachijo-jima, at a distance of about 100 km. to the north-west of the latter.\* There were 5 fore-shocks, which were registered at the meteorological observatory of Hachijo-jima on the Omori horizontal pendulum tromometer of 150 times in the EW direction, the results of the observation being shown in Table III. (See the diagram reproduced in Pl. XXIII.)

TABLE III.—EARTHQUAKE OBSERVATION AT HACHIJO-JIMA.

(Nos. 1-5 are fore-shocks).

No.	Time of occurrence at Hachijo-jima. (May 13)	Intensity.	Duration of		Max. 2a.	Difference between the successive times of occurrence.
			Total Eqke.	Preliminary Tremor.		
1	4 <sup>h</sup> 44 <sup>m</sup> 13 <sup>s</sup> am.	Insensible.	1 <sup>m</sup> 15 <sup>s</sup>	16.0 <sup>sec</sup>	0.043 <sup>mm</sup>	22 <sup>m</sup> 37 <sup>s</sup>
2	5 06 50	„	2 25	16.3	0.16	8 43
3	5 15 33	„	0 35	—	0.017	3 57
4	5 19 30	„	0 30	—	0.024	2 13
5	5 21 43	„	0 30	16.8	0.027	1 26
6	5 23 09	Strong.	{ Longer than 10 <sup>m</sup>	15.2	Large.	
7	5 37 55	„	Do.	—	Do.	

The time difference between the 1st and 2nd shocks was 22m 37s, while that between the 2nd and 3rd shocks was shorter and 8m 43s. The succeeding three intervals again decreased and were respectively 3m 57s, 2m 13s, and 1m 26s. Thus in the present case, the fore-shocks, the first of which had occurred 39m before the principal earthquake, quickly increased in fre-

\* These two earthquakes are discussed more in detail elsewhere in this Number.

quency till the latter was finally produced, indicating a rapid progress of disturbance at the focus.

**13. *Distinction between local and large earthquakes.***

A local shock, which may be regarded as originating from a centre or point and is sometimes destructive at the epicentre, is characterized by the smallness of its total energy. Such a disturbance seems generally to be unaccompanied by the fore-shocks. On the other hand, large earthquakes, whose focus has a considerable extension and may be regarded as being equivalent to a collection of a great number of local centres of disturbance arranged along a zone, seem to be preceded on many occasions by minor shocks. The fore-shocks of a great earthquake may first occur several days or several hours before the latter, and their time distribution may be sometimes more or less periodical.

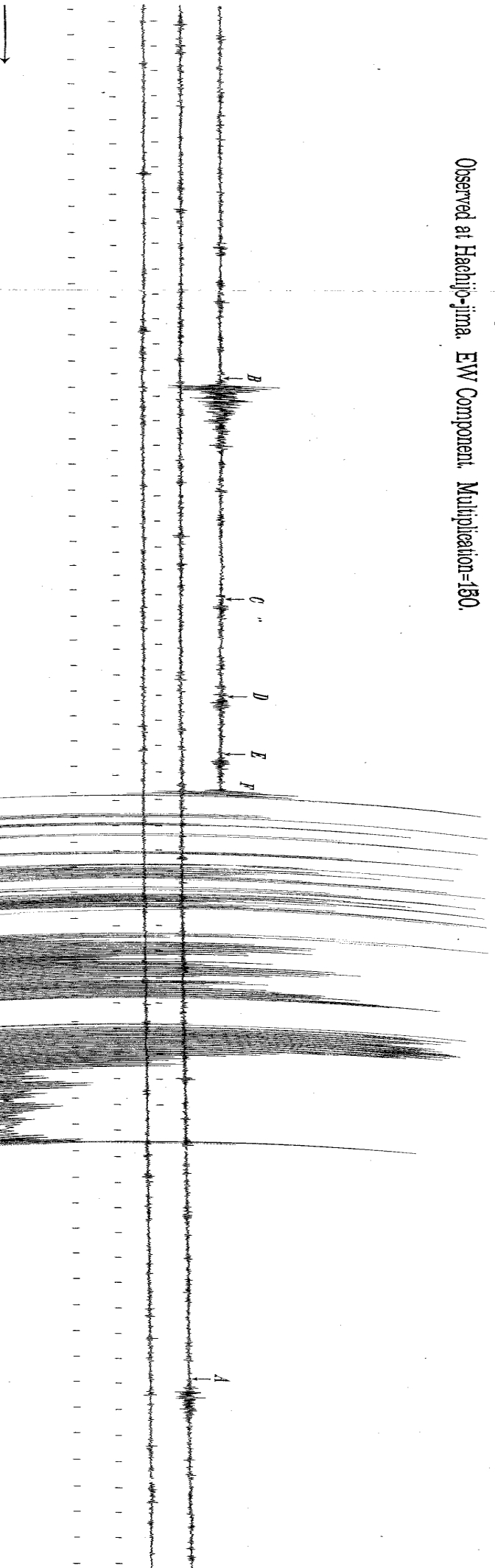
The phenomena of fore-shocks furnish a very interesting subject of study, and give a practical importance to the tromometrical observation in earthquake countries. My belief is that a large destructive earthquake will be foretold in its epicentral region by some fore-shocks.

Tokyo.      May, 1908.

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# Omori Tromometer Diagram of the Earthquakes of May 13, 1908.

Observed at Hachijo-jima. EW Component. Multiplication=150.



A..... 4 44' 13 AM  
 B..... 5 00 00 "  
 C..... 5 15 30 "  
 D..... 5 19 30 "  
 E..... 5 21 45 "  
 F..... 5 23 00 "

The first earthquakes A, B, C, D, and E are the first shocks of the large or principal disturbance F. (The motion of the F earthquake was too great and often threw the pen from the marked paper.)