CHAPTER III. NOTES ON THE DIAGRAMS OF THE EARTHQUAKES OBSERVED ON JAN. 11TH AND 12TH AT THE KAGOSHIMA METEOROLOGICAL OBSERVATORY.

8. ***Typical seismograms.*** In §§ 9 to 24 are given the elements of motion in the more prominent 24 among the numerous shocks observed at the Kagoshima meteorological observatory on Jan. 11th and 12th, 1914, prior to the commencement of the outburst of the Sakura-jima, as follows :—

						Intensity.	Character.
A,	Eqke.	No. 178,	Jan. 11th,	9.18 P.M. ;	Unfelt,	sharp.
	„	220,	„ „	11.09 P.M. ;	Slight,	sharp.
	„	405,	„ 12th,	9.26 A.M. ;	Unfelt.	
B,	„	10,	„ 11th,	4.45$\frac{2}{3}$ A.M. ;	Unfelt.	
	„	11,	„ „	4.54 A.M. ;	Unfelt.	
	„	25,	„ „	8.56 A.M. ;	Slight,	quick.
	„	49,	„ „	0.43 P.M. ;	Strong,	quick.
	„	118,	„ „	5.43 P.M. ;	Unfelt,	slow.
	„	125,	„ „	6.01$\frac{1}{2}$ P.M. ;	Slight,	slow.
	„	143,	„ „	7.51 P.M. ;	Moderate.	
	„	149,	„ „	8.11$\frac{1}{2}$ P.M. ;	Unfelt.	
	„	152,	„ „	8.18 P.M. ;	Unfelt.	
	„	159,	„ „	8.34 P.M. ;	Moderate.	
	„	159′,	„ „	8.37 P.M. ;	Unfelt,	slow.
	„	159″,	„ „	8.38 P.M. ;	Slight,	slow.
	„	176,	„ „	9.08 P.M. ;	Moderate,	sharp.
	„	177,	„ „	9.12 P.M. ;	Slight,	slow.
	„	199,	„ „	10.13 P.M. ;	Unfelt,	slow.
	„	222,	„ „	11.14 P.M. ;	Slight,	quick.
	„	307,	„ 12th,	4.10 A.M. ;	Unfelt,	slow.
	„	308,	„ „	4.23 A.M. ;	Unfelt.	

		Intensity,	Character.
Eqke. No. 314, Jan. 12th,	4.49 A.M.;	Slight.	
„ 322, „ „	5.19 A.M.;	Unfelt.	
„ 334, „ „	5.54 A.M.;	Slight,	quick.

The direction in the early part of the preliminary tremor, at the commencement of the diagram, has been ascertained in the three eqkes. of the (A) group. The duration of the preliminary tremor is given only for those cases in which an earthquake occurred while the recording drum of the seismograph, started by a previous shock, was still moving.

The earthquake motion is, as usual, divided into the *preliminary tremor*, the *principal portion*, and the *tail* or end portion. The range of motion, or double amplitude, is denoted by $2a$, and the complete vibration period by T.

9. *Eqke. No.* 178. The prel. tremor motion at the beginning of the diagram was

0.010 mm.,→S. 37° E.; 0.11 mm. upwards.

The princ. portion was composed of quick vibrations:—

	mm	mm
1st Displacement	0.44,→S. 66° E.;	0.14 upwards.
2nd „ „	0.55,→N. 28° W.;	0.18 downwards.

10. *Eqke. No.* 220. The prel. tremor displacement at the commencement of the diagram was

0.29 mm.,→S. 40° W.; 0.28 mm. upwards.

The princ. portion was active for 4.0 sec,, the quick and the slow vibrations at the commencement of the diagram being as follows:—

		mm	mm
Quick motion.	1st Displt., ...	1.14,→S. 36° W.;	0.28 upwards.
	2nd „ „	1.01,→N. 6° E.;	0.28 downwards.

		mm	
Slow motion.	1st Displt.,	1.60,	→S. 55° W.
	2nd „ „	2.20,	→N. 18° E.
	3rd „ „	1.36,	→S. 20° W.
	4th „ „	1.48,	→N. 42° E.

11. *Eqke. No. 405.* The prel. tremor displt. at commencement of the diagram was

0.60 mm.,→N. 51° E.; 0.19 mm. downwards.

Slow vibration at the commencement of the princ. portion:—

	mm		mm	
1st Displt.,	1.16,	→S. 25° W.;	0.028	downwards.
2nd „ „	1.22,	→N. 14° E.;	0.44	upwards.

12. *Eqke. No. 25.* Max. vibration occurred at the commencement of the princ. portion:—

	mm		mm	
1st Displt.,	0.52,	→N. 23°W.;	0.14	upwards. (?)
2nd „ „	0.76,	→S. 37° E.		

13. *Eqke. No. 10.* Displt. at the commencement of the princ. portion: 0.41 mm.→N. 36° E.; 0.13 mm. upwards. Max. motion occurred 0.5 sec. later on: 0.42 mm. (N.S.), 0.38 mm. (E.W.), 0.2 mm. (vert.).

14. *Eqke. No. 11.* Total duration=60 sec. The prel. tremor lasted 2.15 sec. in each component and was composed of quick movements of T=0.11 sec. (N.S.). The princ. portion:—

		mm.	sec.	sec.
(N. S.)	Max.	$2a$=0.64,	T=0.125.	
(E. W.)	„	$2a$=0.32,	T=0.115.	
(Vert.)	„	$2a$=0.32,	T=0.115,	T=0.19.

There were also slower vibrations in the three components.

15. *Eqke. No. 49.* This was a strong shock whose prel. tremor lasted about 2 sec. The max. (slow) vibration occurred at

the commencement of the princ. portion: 1st displt., 1.6 mm.→S., 0.4 mm. upwards, corresponding to the two successive movements of 0.8 mm.→W. and 0.8 mm.→E.; 2nd displt., 4.4 mm.→N.; 0.97 mm. downwards, corresponding to the two movements of 1.64 mm. →W. and 1.72 mm.→E.

16. *Eqke. No.* 159. Princ. portion: 1st displt.=0.49 mm.→S. 38° W.; 2nd displt,=0.70 mm.→N. 29° E.

17. *Eqke. No.* 176. Princ. portion: 1st displt.=0.27 mm.→S. 42° W.; 2nd displt.=0.47 mm.→N. 27° E.

18. *Eqke. No.* 177. In the N.S. component, the prel. tremor lasted 1.65 sec.; the motion being slightly larger for the next 1.1 sec., with T=0.088 sec. In the E.W. compt., the prel. tremor lasted 2.0 sec. In the vert. compt., the motion was comparatively large from commencement. [Princ. portion.] T=0.10 sec., $2a$=0.2 mm. (N.S.). T=0.10 sec., $2a$=0.12 mm.; T=0.64 sec., $2a$=0.2 mm. (E.W.).

19. *Eqke. No.* 199. The prel. tremor lasted 2.25 sec., (N.S.). [Princ. portion.] 1st quick displt. =0.24 mm.→S. 25° E.

	sec.	sec.	mm.	sec.	mm.
(N.S.)	T=0.10;	T=0.24,	$2a$=0.24;	T=0.54,	$2a$=0.16.
(E.W.)	T=0.10;	T=0.25,	$2a$=0.2;	T=0.73,	$2a$=0.2.
(Vert.)		T=0.24,	$2a$=0.18.		

20. *Eqke. No.* 308. [Prel. tremor.] Duration=2.05 sec. (N.S.), 1.8 sec. (E.W.), 2.15 sec. (vert.). In the N.S. compt., T=0.086 sec. [Princ. portion.] T=0.09 sec., $2a$=0.48 mm. (N.S.); $2a$=0.32 mm.(E.W.). The quick vibrations predominated for 3.9 sec.

21. *Eqke. No.* 314. The displt. at the commencement of the diagram, which was very small, was upwards and directed toward the N.E. [Princ. portion.] The 1st eastward motion of 0.62 mm. corresponded to the two successive displacements of 0.24 mm.→S.

and of 0.24 mm.→N. The 2nd westward motion of 0.82 mm. corresponded to the 0.7 mm. southward motion: the resultant being 1.1 mm.→S. 50°W. In the later part, the motion was as follows:—

	sec.	mm.	sec.	mm.	sec.
(N.S.)	$T=0.5$,	$2a=0.9$;	$T=0.67$.		
(E.W.)	$T=0.89$,	$2a=0.9$;	$T=0.61$,	$2a=0.4$;	$T=0.73$.
(Vert.)	$T=0.48$,	$2a=0.16$;	$T=0.74$.		

The quick vibrations were prominent for about 5 sec. This eqke. continued for 62 sec., when the next shock took place.

22. *Eqke. No.* 322. Duration of the prel. tremor=1.9 sec. (N.S.), 1.9 sec. (vert.). The princ. portion lasted 3.0 sec.: $T=0.10$ sec., $2a=0.1$ mm. (N.S.); $T=0.10$ sec., $2a=0.04$ mm. (vert.).

TABLE X. ELEMENTS OF MOTION IN EQKES. NOS. 118; 143; 149; 152; 222; AND 307.

No.	N.S. Compt.		E.W. Compt.		Vert. Compt.	
	Max. $2a$.	T	Max. $2a$.	T	Max. $2a$.	T
	mm.	sec.	mm.	sec.	mm.	sec.
118	1.9	0.52 0.11 0.22	0.60	0.53	0.45	0.55 0.11
143	0.64	—	0.56	0.50	0.20	—
149	0.70 0.40	0.55 0.82	0.44 1.00	0.45 0.40 0.85	0.40 0.13	0.35 1.05
152	0.90 0.46	0.45 0.095	1.08 0.22	0.59 0.095	0.30 0.31 0.25	0.095 0.42 0.24
222	0.14	0.10	0.10	—	0.05	0.16
307	0.60 0.94	0.42 0 86	0.80 —	0.64 0.96	0.25	0.19

23. ***Eqke. No. 334.*** The prel. tremor motion at the commencement of the diagram was 0.14 mm.→W., 0.1 mm.→N. (?), 0.28 mm. upwards. The 2nd (max.) displt. at the commencement of the princ. portion was 2.5 mm.→S., corresponding to the two successive movements of 0.68 mm.→E., and 0.74 mm.→W.

24. The max. $2a$ and the average period in the princ. portion of the eqkes. Nos. 118 ; 143 ; 149 ; 152 ; 222 ; and 307, are given in Table X, while the durations of the prel. tremor in the different earthquakes are collected in Table XII.

25. ***Period of vibration.*** The average periods of vibration existing in the principal portion of the different earthquakes, collected in Table XI, may be classified more or less definitely into 4 kinds, whose mean values are respectively

$$p_1 = \overset{\text{sec.}}{\mathbf{0.104}}\,;\quad p_2 = \overset{\text{sec.}}{0.22}\,;\quad p_3 = \overset{\text{sec.}}{\mathbf{0.52}}\,;\ \text{and}\ p_4 = \overset{\text{sec.}}{0.85}.$$

These 4 periods found in the horizontal and the vertical components, are approximately in the ratios of 1 : 2 : 4 : 8, with the mean unit length of about 0.11 sec. The vibrations of the p_1 and p_3 periods occurred most frequently, the $2a$ (single component) corresponding to p_3 having the maximum value of 1.9 mm. The p_1 class vibrations also occurred in the preliminary tremor.

The periods here considered are to be regarded as characterizing small earthquake movements on the hilly parts in and about the city of Kagoshima. The large destructive seismic motion as that of the earthquake at $6\frac{1}{2}$ p.m., on Jan. 12th, has probably a period equal to or larger than p_4.

26. ***Duration of preliminary tremor.*** The mean duration of the preliminary tremor in the different fore-shocks was 1.9 sec. (Table XII), corresponding to the central distance of 14.1 km. This duration is practically identical with that found from the

TABLE XI. SAKURA-JIMA FORE-SHOCKS OBSERVED AT THE KAGOSHIMA METEOROLOGICAL OBSERVATORY: PERIOD OF VIBRATION.

N.S. Component.			E.W. Component.		Vert. Component.	
Prel. Tremor.	Princ. Portion.		Princ. Portion.		Princ. Portion.	
sec.	sec.	sec.	sec.	sec.	sec.	sec.
0.11	0.125	0.22	0.115	0.25	0.115	0.24
0.088	0.11	0.24	0.095		0.11	0.24
0.086	0.10		0.10		0.10	0.19
	0.10	0.23	0.10		0.095	0.16
0.095	0.10					0.19
	0.10	{max. 2a = 0.24 mm.	0.103		0.105	
	0.095		{max. 2a = 0.32 mm.		{max. 2a = 0.32 mm.	0.20
	0.09					{max. 2a = 0.32 mm.
	0.103		0.96			
	{max. 2a = 0.48 mm.		0.89			
			0.85			
			0.73			
	0.86		0.73			
	0.82				0.74	1.05
	0.84		0.83			
	{max. 2a = 0.94 mm.		{max. 2a = 1.0 mm.			
			0.64			
	0.67		0.64			
	0.55		0.61			
	0.54		0.59			
	0.52		0.53		0.55	
	0.50		0.50		0.48	
	0.45		0.45		0.42	
	0.42		0.40		0.35	
	0.52		0.55		0.45	
	{max. 2a = 1.9 mm.		{max. 2a = 1.1 mm.		{max. 2a = 0.45 mm.	

Mean Values.

Component.	Prel. Tremor.	Principal Portion.			
	sec.	sec.	sec.	sec.	sec.
N. S.	0.095	0.103	0.23	0.52	0.84
E. W.	—	0.103	0.25*	0.55	0.83
Vertical.	—	0.105	0.20	0.45	{1.05* 0.74*
Mean.	0.095	0.104	0.22	0.52	0.85

* The mean values of the most frequently occurring periods are given in thick figures. Asterisks indicate cases of single occurrence.

tromometer observations in Kagoshima of the volcanic earthquakes which happened subsequent to the commencement of the eruption. (See Chapter IV.)

TABLE XII. DURATION OF PRELIMINARY TREMOR OF THE FORE-SHOCKS OBSERVED AT THE KAGOSHIMA METEOROLOGICAL OBSERVATORY.

Eqke. No.	Duration of Preliminary Tremor in		
	N.S. Compt.	E.W. Compt.	Vert. Compt.
	sec.	sec.	sec.
159′	1.7?	1.7?	1.7?
159″	1.5?	1.5?	1.5?
125	2.1	2.1	2.1
143	1.8	1.8	1.8
152	1.8	1.8	2.4
222	1.7	1.6	1.9
307	1.8	1.7	1.5
308	2.05	1.8	2.15
322	1.9	—	1.9
11	2.15	2.15	—
177	1.65	2.0	—
199	2.25	—	—

27. *Direction of motion.* An ordinary Gray-Milne type seismograph proves very useful, amongst the others, in the investigation of the direction of motion of individual vibrations in the preliminary tremor of a strong earthquake.* In the case of a small shock, however, it fails to give satisfactory result in this connection, as the magnification ratios of the pointers are small and as the recording drum is started by the electric contact-maker necessarily

* See the Bulletin, Vol. VII, No. 3.

some time interval after the commencement, thereby the preliminary tremor being lost in the record partially or entirely. Thus, in the present instance, I was able to ascertain from the seismograms obtained at the Kagoshima meteorological observatory the direction of the preliminary tremor motion at the start of the machine only in the following three cases:—

Eqke.	Motion at Commt. of the Diagram.	Motion at Commt. of Princ. Portion. (1st Displt.)	(2nd Displt.)
	mm.	mm.	mm.
No. 405.	0.6→N. 51°E. Downwards.	1.16→S. 25°W. (Slow motion)	1.22→N. 14°E. (Slow motion)
No. 178.	0.1→S. 37°E. Upwards.	0.44→S. 66°E. (Quick motion.)	0.55→N. 28°W. (Quick motion.)
No. 220.	0.29→S. 40°W. Upwards.	1.14→S. 36°W. (Quick motion.) 1.58→S. 55°W. (Slow motion.)	1.01→N. 6°E. (Quick motion.) 2.2→N. 18°E. (Slow motion.)

The origins of the two disturbances Nos. 405 and 220 were thus situated to the N.E. of the Kagoshima met. observatory, at the distance of some 14 km., namely, under the sea off the Osaki-hana promontory. The origin of the eqke. No. 178 was probably inland, to the N.N.W. of Kagoshima.

As will be seen from fig. 5, the directions of the 1st and 2nd displacements of the vibration occurring at the commencement of the principal portion were, in each case, more or less near to that about the commencement of the preliminary tremor. This relation was found also to be true of the volcanic earthquakes tromometrically observed in Kagoshima subsequent to the opening of the eruption. The direction of the initial vibrations of the principal portion may, therefore, be taken as a rough substitute for those of the preliminary tremor, in the indication of the position of the origin of disturbance.

Taking together the directions relating to the preliminary tremor and the commencement of the principal portion in the different earthquakes, the mean values are found to be, (i), S. 33°W.–N. 33°E.; (ii), S. 36°E.–N. 36°W. (See Table XIII and fig. 6.) The majority of the cases belonged to the (1) class and seems to point to the location of the principal submarine origin of the seismic activity to the north of Sakura-jima. (See Chapter IV.) The (ii) class shocks probably originated mostly under the sea to the south of the same "island."

28. *Amplitude of motion at commencement of principal portion.* The 2nd displacement of the vibration occurring at the commencement of the principal portion was greater than the 1st displacement in the average ratio of 1.63 : 1. (See Table XIV.) In the earthquakes of the (i) class the 1st displacement was directed almost always toward the S.W., and the 2nd displacement towards the N., E., or N.E.

29. *Destructive shock of Jan. 12th*, (1914), *at* 6.29 P.M. This was a large earthquake of non-local character, felt most strongly in the low sea-coast districts of Kagoshima. In the city, 39 buildings were totally destroyed, 130 half-demolished, and 977 partially damaged; the casualty consisting of 96 persons wounded, and 13 killed. In the provincial parts, there were altogether 16 dead, besides 2 killed by the eruption and 27 missing, in the island of Sakura-jima.

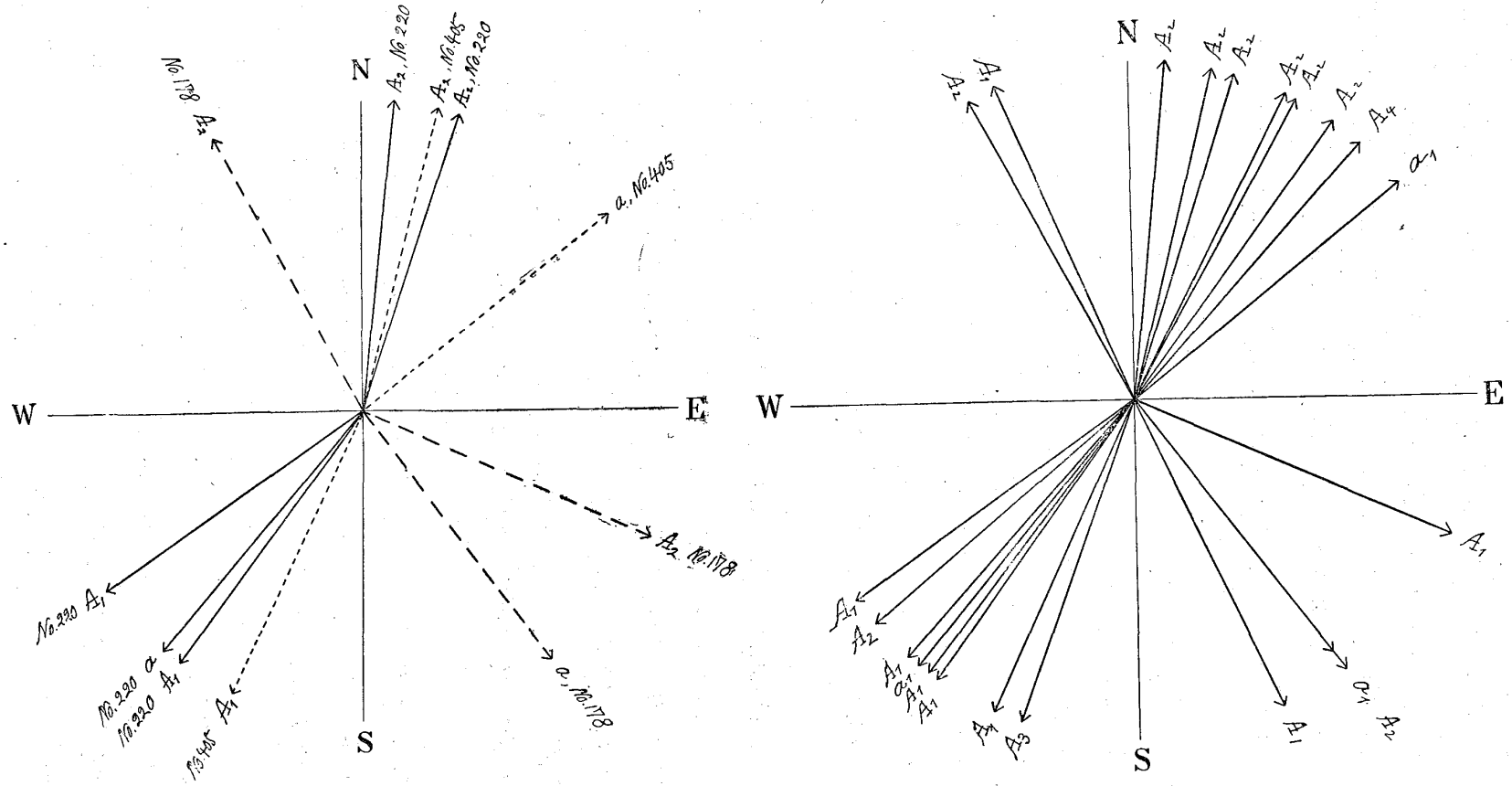
From the record furnished by the ordinary Gray-Milne seismograph at the Kagoshima meteorological observatory (fig. 7), it will be seen that the very first displacement was directed toward the N.W., accompanied by an upward motion. Hence the earthquake origin must have been situated to the S.E. of the observatory. Taking into consideration also the direction of motion in different

Fig. 5. Earthquakes Nos. 178; 220; and 405.

Fig. 6. Different Earthquakes taken together.

a.....Direction of the preliminary tremor motion at the commencement of the seismogram.

A_1 and A_2.... Respectively the directions of the 1st and 2nd displacements at the commencement of the principal portion.



Ordinary Seismograph Observation of the Sakura-jima Fore-shocks at the Kagoshima Meteorological Observatory: Direction of the Preliminary Tremor Motion compared with the Directions of the 1st and 2nd Displacements at the Commencement of the Principal Portion.

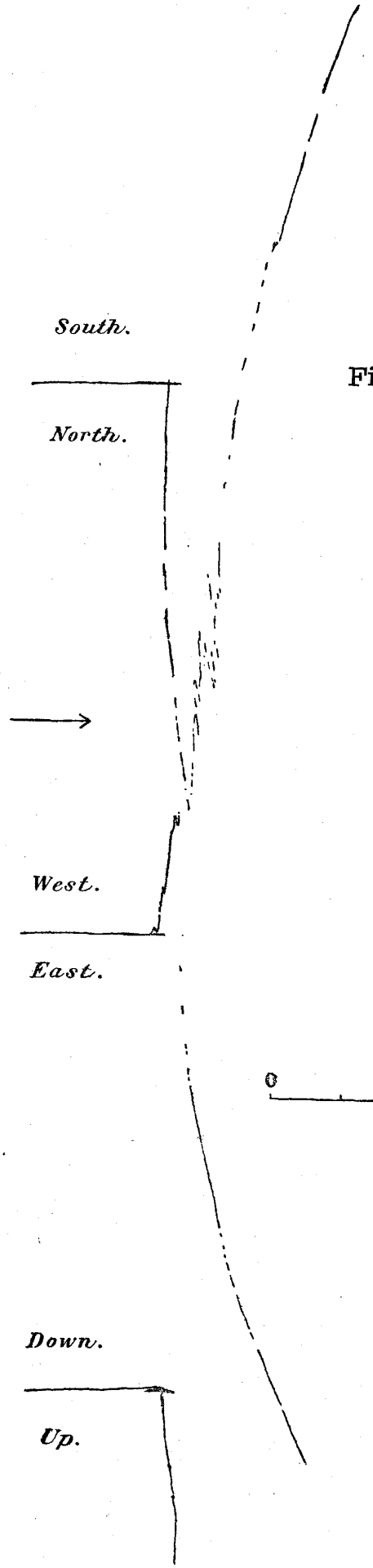


Fig. 7. Violent Kagoshima and Sakura-jima Earthquake on Jan. 12th, 1914, at 6½ P.M.: the commencement registered on an ordinary Gray-Milne Seismograph at the Kagoshima Meteorological Observatory.

Magnification :—

N. S. and E. W. Components, ... 3.6 times.

Vertical Component, ... 7.1 „

Time Scale: 0 — 5 sec.

TABLE XIII. SAKURA-JIMA FORE-SHOCKS OBSERVED AT THE KAGOSHIMA METEOROLOGICAL OBSERVATORY: DIRECTION OF THE PRELIMINARY TREMOR MOTION AND THE VIBRATIONS AT THE COMMENCEMENT OF THE PRINCIPAL PORTION.

(i)		(ii)
S. 36° W.	N. 6° E.	S. 25° E.
S. 55° W.	N. 18° E.	S. 66° E.
S. 20° W.	N. 42° E.	S. 37° E.
S. 40° W.	N. 14° E.	S. 37° E.
S. 25° W.	N. 51° E.	N. 28° W.
S. 42° W.	N. 27° E.	N. 23° W.
S. 38° W.	N. 29° E.	S. 36°E.–N. 36°W.
S. 50° W.	N. 36° E.	
S. 33°W.–N. 33°E.		

TABLE XIV. KAGOSHIMA OBSERVATION OF SAKURA-JIMA FORE-SHOCKS: COMPARISON OF 1ST AND 2ND DISPLACEMENTS OF THE VIBRATION AT THE COMMENCEMENT OF THE PRINCIPAL PORTION.

	Eqke. No.	1st Displacement $=p_1$	2nd Displacement $=p_2$	Ratio: p_2/p_1
		mm.	mm.	
(i)	10	0.18→W.	0.42→N. 36°E.	2.31
	49*	1.6 →S.	4.4 →N.	2.75
	159	0.49→S. 38°W.	0.7 →N. 29°E.	1.44
	220	1.14→S. 36°W. (Quick motion.)	1.01→N. 6° E. (Quick motion.)	0.89
		1.58→S. 55°W. (Slow motion.)	2.20→N. 18°E. (Slow motion.)	1.39
	314	0.62→E.	1.1 →S. 50 W.	1.78
	334*	1.4 →S.	2.48→N.	1.77
	405	1.16→S. 25°W.	1.22→N. 14°E.	1.05
(ii)	25	0.52→N. 23°W.	0.76→S. 37°E.	1.46
	176	0.27→S. 42°W.	0.59→N. 27°E.	1.83
	178	0.44→S 66°E.	0.55→N. 28°W.	1.24
	199	0.21→S. 25°E.	——	—
			Mean.....	1.63

* Only the N.S. component movements taken into comparison, the corresponding E.W. compt. motion being composed of half-period small movements.

parts of the city of Kagoshima and the position of the strong motion area, the centre of disturbance was probably located at the distance of some 5 km. to the S.E. of the observatory, in the Kagoshima strait and between the former Karasu-jima island and the coast of Kagoshima.

CHAPTER IV. TROMOMETER OBSERVATIONS IN KAGOSHIMA OF THE SAKURA-JIMA AFTER-SHOCKS, OR THE VOLCANIC EARTHQUAKES NOT DIRECTLY ACCOMPANIED BY EXPLOSIONS.

30. ***Tromometer observations.*** A 200-times magnification Omori horizontal tromometer of portable form, which the present author took with him at his first visit to Sakura-jima immediately after the commencement of the eruption in January (1914), was temporarily set up on the solid stone foundation in a room of the Weight and Measure Department, in the compound of the Kagoshima prefectural office, and the observation was started, under the care of my assistant, Mr. H. Krosaka, on the 16th of the same month and continued till Feb. 8th, when the instrument was removed to the village of Frusato in Sakura-jima. The two horizontal pointers of the tromometer were so oriented as to record the movements respectively radial and transverse with regards to the centre of Sakura-jima, namely, parallel to the directions of E. 8°S.-W. 8°N. and N. 8°E.–S. 8°W. These two sets of motion will be styled in the following pages as the E′.–W′. and N′.–S′. components. The natural oscillation period of each of the horizontal pendulums was 4.5 sec.

The list of the daily numbers of the small and large after-eruptions* and of the volcanic earthquakes recorded continuously

* See the Bulletin, Vol. VIII, No. 1.