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.

in Kagoshima has already been given in the Bulletin, Vol. VIII, No. 1. As illustrated in fig. 8, the course of the frequency variation of the large after-eruptions tended to be opposite to those of the small after-eruptions and the non-eruptive volcanic earthquakes.

The volcanic earthquakes not accompanied by explosions or by non-explosive outbursts were composed entirely of quick vibrations and were markedly different in nature from the slow shakings of the ground caused by the explosions.

31. ***Notes on the seismograms.*** In §§ 32 to 40 are given the results of the examination of the original tremor-recorder diagrams (magnification=200) of the following 9 well-recorded Sakura-jima earthquakes of volcanic nature :—

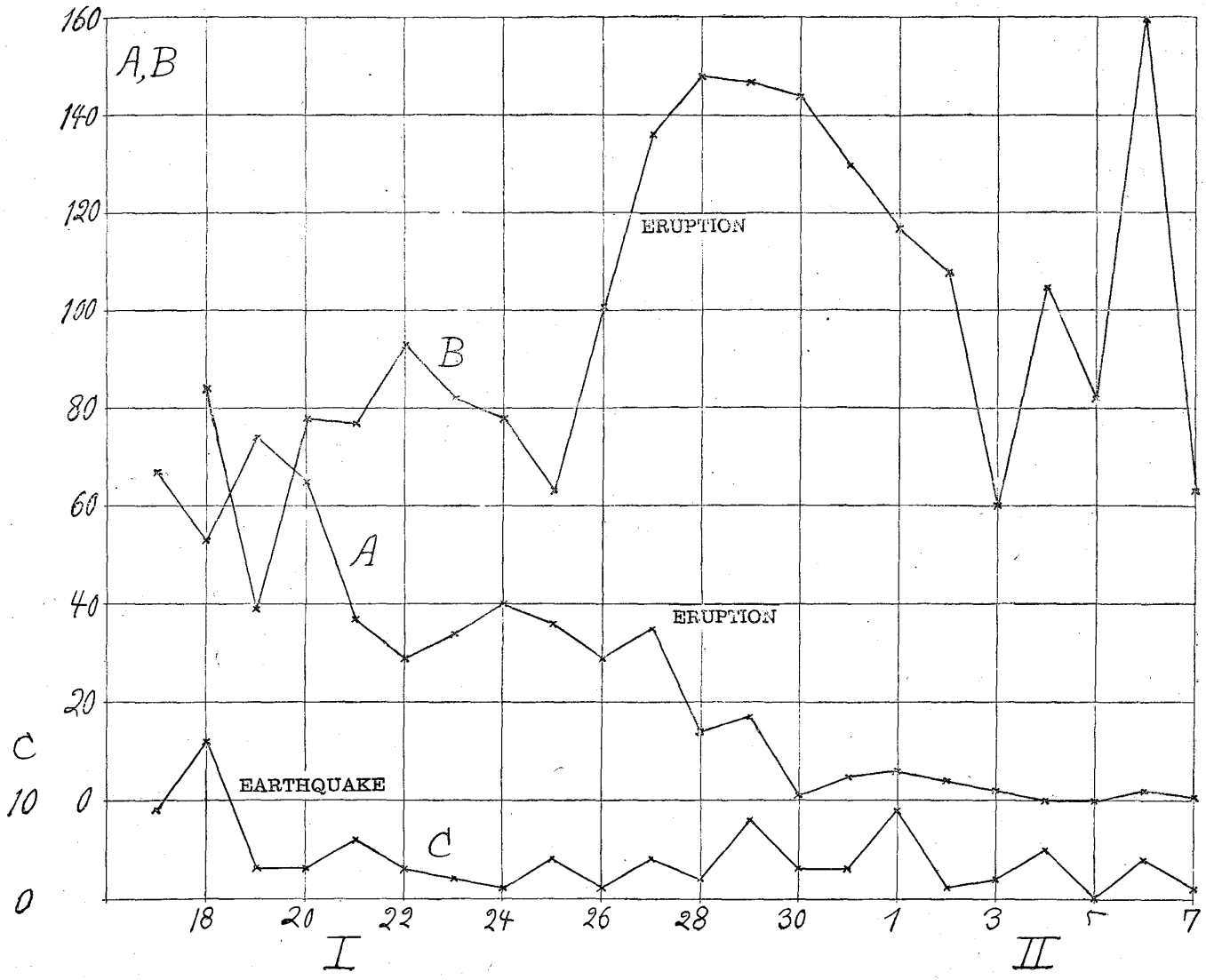
Jan. 23rd, 1914; 8.51.55 A.M.
„ 24th, „ ; 8.29.43 A.M.
„ 22nd, „ ; 1.13.17 P.M.
„ 28th, „ ; 5.20.41 A.M.
„ „ , „ ; 6.45.38 A.M.
Feb. 1st, „ ; 7.27.15 A.M.
„ 8th, „ ; 5.34.21 P.M.
Jan. 29th, „ ; 6.43.58 A.M.
„ 21st, „ ; 10.11.41 P.M.

Each of the first three earthquakes indicated some preliminary tremor, the direction of whose first displacement has been ascertained. On the contrary, the remaining 6 earthquakes began with principal vibrations at once and indicated no preliminary tremor, which either did not actually exist or was else obliterated by the slight motion more or less present at those days of the eruptive activity.

32. ***Eqke. of Jan. 23rd, 1914, at* 8.51.55 A.M.** (See fig. 9.) This was a sensible shock composed almost entirely of quick vibrations.

Fig. 8. Daily Frequency Variation of the Sakura-jima After-Eruptions and After-shocks tromometrically observed in Kagoshima. Jan. 17th.—Feb. 7th, 1914.

(A) Larger After-eruptions.
(B) Smaller „
(C) Non-eruptive Volc. Eqkes.



Total duration=40 sec. [Prel. tremor.] Duration=1.5 sec. Max. $2a$=0.027 mm. (N′. S′.), 0.024 mm. (E′. W′.).

1st Displacement.,.....0.0095 mm.,→S. 43°E.

[Princ. portion.] Duration=4.1 sec. The maximum vibration occurred at the commencement:—

1st Displt., ...0.087 mm.,→S. 45°E.
2nd (max.) Displt., ...0.15 mm. (N′. S′.), 0.15 mm. (E′. W′.).

T=0.25 sec. (N′. S′.), T=0.28 sec. (E′. W′.). During the next 12.7 sec., the motion was still active, but became much smaller than before: $2a$=0.18 mm., T=0.39 sec. (N′. S′.); $2a$=0.019 mm., T=0.31 sec. (E′. W′.). The subsequent motion was slow and very small.

33. *Eqke. of Jan. 24th*, 1914, *at* 8.29.43 A.M. A sensible shock, of total duration=66 sec. [Prel. tremor.] Duration=1.4 sec. During the first 0.69 sec., the motion was small and slow, but during the next 0.69 sec., it was larger and composed of quick vibrations.

1st Displt.,.....0.0046 mm.,→N. $37\frac{1}{2}$°E.
Max. $2a$ (2nd stage)=0.023 mm. (N′. S′.), 0.01 mm. (E′. W′.)

[Princ. portion.] Duration=14.3 sec. The motion was composed of quick movements which were most active at the commencement:

1st Displt.,.....0.074 mm.,→N. 44°E.;
4th „ ,..... 0.084 „ ,→S. 42°W.

The 2nd displt. was the maximum: $2a$=0.11 mm. in each component. After 26.0 sec. from the commencement, the motion became very small.

34. *Eqke. of Jan. 22nd*, 1914, *at* 1.13.17 P.M. Total duration=96 sec. Duration of the prel. tremor and the princ. portion=26.5 sec. [Prel. tremor.] Duration=2.5 sec. There was no prominent maximum

vibration in the princ. portion, the quick movements at the commencement of the prel. tremor being quite large and sharp:

1st well-defined Displt., ... 0.015 mm., → S. 45°W.,

this being preceded by a very small and slow displacement in the opposite direction. Max. $2a = 0.02$ mm. (N′. S′.), 0.012 mm. (E′. W′.). [Princ. portion.] The motion was composed of active quick movements for the 1st 7.9 sec. (E′. W′.) and 6.8 sec. (N′. S′.).

35. ***Eqke. of Jan. 28th*****, 1914, at 5.20.41** A.M. Total duration = 17 sec. There was apparently no prel. tremor, the 1st vibration being the greatest. Duration of the princ. portion, composed of quick vibrations, = 9.2 sec. (N′. S′.), 6.2 sec. (E′. W′.).

1st Displt., ... 0.026 mm., → N. 37°E.

The 2nd displacement was the maximum: $2a = 0.038$ mm. (N′. S′.), 0.033 mm. (E′. W′.).

36. ***Eqke. of Jan. 28th*****, 1914, at 6.45.38** A.M. This was a sensible shock, which indicated apparently no prel. tremor. Duration of the princ. portion, composed of quick movements, was = 4.0 sec. (N′. S′.), 1.7 sec. (E′. W′.), the motion ending therewith quite abruptly.

1st Displt., ... 0.023 mm., → N. 23°E.
2nd „ , (max.) = 0.038 mm. (N′. S′.), 0.032 mm. (E′. W′.).

37. ***Eqke. of Feb. 1st*****, 1914, at 7.27.15** A.M. The shock was sensible. Total duratien = 56 sec. Duration of the prel. tremor = 2.46 sec. [Princ. portion.] Duration = 6.1 sec. (N′. S′.), 5.2 sec. (E′. W′.). The motion was composed of quick vibrations.

1st Displt., ... 0.027 mm., → S. 50°W.
2nd „ , ... 0.033 „ , → N. 53°E.

$T = 0.38$ sec. (E′. W′.). After the princ. portion, there was practically no motion.

38. *Eqke. of Feb. 8th*, 1914; 5.34.21 P.M. A very small shock of the total duration=18 sec. The prel. tremor was not clearly indicated. [Princ. portion.] Duration=3.0 sec. The motion was composed of quick vibrations.

1st Displt., ...0.013 mm.,→S.
2nd „ „ .....0.018 „ „,→N. 12°W.

After the princ. portion there was practically no motion.

39. *Eqke. of Jan. 29th*, 1914; 6.43.58 A.M. Total duration= 37 sec. There was apparently no prel. tremor. The princ. portion lasted 7.6 sec., the max. vibration occurring at the commencement:—

1st Displt., ...0.017 mm.,→S. 71°E.
Max. $2a$=0.045 mm. (N′. S′.), 0.038 mm. (E′. W′.).

After the princ. portion the motion was slow and very small.

40. *Eqke. of Jan. 21st*, 1914; 10.11.41 P.M. There was apparently no preliminary tremor, the duration of the princ. portion, composed entirely of quick movements, being 5.4 sec. (N′, S′.), and 3.2sec. (E′. W′.). Max. $2a$=0.036mm. (2nd displt., E′. W′.), 0.03mm. (3rd displt., N′. S′.). In the N′. S′. compt., the motion was most active for the first 1.2 sec., there occurring a second max. group ($2a$=0.012 mm.) 2.8 sec. after the commencement. In the E′. W′. compt., the most active part lasted 1.8 sec., there being no 2nd max. group. The 1st displacement was 0.0283 mm. toward the W′., which corresponded to the two successive movements of 0.0033 mm. toward the N′. and 0.021 mm. toward the S′.; the resultant being 0.034 mm.→S. 66°W. After the princ. portion, the motion became abruptly very small.

41. *Analysis of the seismograms photographically enlarged.* Several of the tromometer diagrams of the more prominent volcanic earthquakes have been enlarged photographically 6 or 7

times, with the resultant magnification of about 1,300 times, such that 1 minute time interval corresponded to the linear length of 336 to 500 mm. In §§ 42 to 48 are given the results of analysis of the photographically enlarged diagrams of the following eight seismic disturbances:—

Jan.	22nd,	1914;	9.38.45	A.M.
„	29th,	„ ;	11.41.11	A.M.
„	„	„ ;	11.41.52	A.M.
„	25th,	„ ;	10.49.31	A.M.
„	29th,	„ ;	6.56.37	A.M.
Feb.	1st,	„ ;	4.42.47	A.M.
„	8th,	„ ;	11.29.36	P.M.

In the diagrams of the first three earthquakes, the direction of the very first movement in the preliminary tremor has definitely been ascertained; while in those of the remaining four, the motion began at once with the maximum or large vibration, the preliminary tremor being not distinctly indicated.

42. ***Eqke. of Jan. 22nd*, 1914; 9.38.45** A.M. Total duration = 60 sec. [Prel. tremor.] The motion lasted 2.1 sec. in each component, and was composed of quick vibrations only, the very 1st displacement being 0.0104 mm. directed toward S. 29° E. Max. $2a=0.023$ mm. (E′. W′.), 0.017 mm. (N′. S′.), occurred 0.52 sec. after the commencement. [Princ. portion.] Duration = 2.1 sec. The maximum quick movements occurred at the commencement:—

1st	Displt.,	0.069 mm.,	→N. 35° E.
2nd	„ ,	0.136 „ ,	→S. $48\frac{1}{2}$° W.
3rd	„ ,	0.102 „ ,	→N. 55° E.

$T=0.375$ sec. (E′. W′.); $T=0.188$ sec. (N′. S′. compt.). During the next 10.6 sec., the vibrations were well-defined, but smaller: $T=0.34$ sec., $2a=0.018$ mm. (E′. W′. compt.). Thereafter the

motion, which continued for further 27.6 sec., became abruptly very small and slow.

43. ***Eqke. of Jan. 29th,*** **1914; 11.41.11** A.M. The duration of the prel. tremor was 1.77 sec. in the E′. W′. and 1.7 sec. in the N′. S′. compt. The 1st vibration was as follows:—

1st Displt.,.....0.0212 mm.,→S. 75° W.
2nd „ „.....0.0285 „ „,→N. 66° E.

The princ. portion, 5.4 sec. in duration, commenced with the following max. vibration:—

1st Displt.,.....0.12 mm.,→N. 36° E.
2nd „ „.....0.172 „ „,→S. 53° W.

44. ***Eqke. of Jan. 29th,*** **1914; 11.41.52.** A.M. This earthquake occurred 41 sec. after the commencement of the preceding. Total duration =16.7 sec. [Prel. tremor.] Duration =2.5 sec.:—

1st Displt.,.....0.0106 mm.,→N. 75° E.
2nd „ „.....0.022 „ „,→S. 81° W.

Max. $2a$=0.026 mm. (E′. W′. compt.); 0.024 mm. (N′. S′. compt.). [Princ. portion.] Duration=2.9 sec. Max. motion occurred at the commencement:—

1st Displt.,..... 0.03 mm.,→N. 87° E.
2nd „ „.....0.093 „ „,→S. 45° W.

The subsequent motion was slow and small.

45. ***Eqke. of Jan. 25th,*** **1914; 10.49.31** A.M. An unfelt shock, whose max. vibration occurred at the commencement:—

1st displt., ...0.034 mm.,→N. $43\frac{1}{2}$° E.
2nd „ „.....0.060 „ „,→S. 58° W.
3rd „ „.....0.048 „ „,→N. 60° E.

Duration of the princ. portion, composed of quick vibrations, =7.7

sec. (N′. S′.), 6.4 sec. (E′. W′.). The subsequent motion was very small.

46. ***Eqke. of Jan. 29th*, 1914; 6.56.37** A.M. The motion was maximum at the commencement:—

1st Displt.,.....0.034 mm.,→N. $37\frac{1}{2}°$ E.
2nd „ ,.....0.0605 „ ,→S. 50° W.

The princ. portion, 7.4 sec. in duration, consisted of quick vibrations of $T=0.132$ sec. (N′. S′. compt.). The subsequent motion was small and slow.

47. ***Eqke. of Feb. 1st*, 1914; 4.42.47** A.M. Total duration = 31 sec. Maximum movements occurred at the commencement:—

1st Displt.,.....0.0169 mm.,→S. 45° W.
2nd „ ,.....0.0335 „ ,→N. 55° E.
3rd „ , ...0.0355 „ ,→S. 55° W.

The subsequent motion was much smaller:—

$T=0.39$ sec., $2a=0.0106$ mm., (E′. W′. compt.).
$T=0.27$ sec., $T=0.34$ sec., $2a=0.018$ mm., (N′. S′. compt.).

48. ***Eqke. of Feb. 8th*, 1914; 11.29.36** P.M. Total duration = 8.3 sec. Duration of the prel. tremor=2.1 sec. [Princ. portion.] Maximum movements occurred at the commencement:—

1st Displt.,..... 0.035 mm.,→S. $66\frac{1}{2}°$ W.
2nd „ ,.....0.059 „ ,→N. 60° E.
3rd „ , ...0.036 „ ,→S. 47° W.

The princ. portion was composed of quick vibrations and lasted 3.4 sec., the subsequent motion being much smaller and slower.

49. ***Duration of Motion.*** The mean duration of the preliminary tremor in the different volcanic after-shocks mentioned in the preceding §§ was 1.94 sec., as follows:—

Duration of Prel. Tremor.	1st displt. of prel. tremor directed
1.50 sec.	toward S.E.
1.72	,,
2.04	,,
2.11	,,
1.40	toward N.E.
1.74	,,
2.50	,,
2.00	
2.46	
1.94 (mean)	

The corresponding focal distance is 14.4 km., which is exactly the distance from the observing place (Kagoshima prefectural office) from the main centre of the seismic disturbances assumed in § 51. It follows that the focal depth was very small. Consequently, the thickness of the surface layer of the earth's crust over the lava "reservoir" under the inner Kagoshima bay, must be also small.

The duration of the principal portion, generally not much different in the N′. S′. and the E′. W′. components, was most frequently included between 3 and 9 sec., as follows:—

	sec.	sec.	sec.
Duration of Princ. Portion (N′. S′. Compt.)	=2.1	4.1	7.7
	2.9	5.4	9.2
	3.0	5.4	14.3
	3.3	6.1	20.0
	3.4	7.4	26.5
	4.0	7.6	

The total earthquake duration was mostly under 60 sec., with the mean of about 40 sec., as follows:—

	sec.	sec.	sec.
Total Duration.	=8.3	31	60
	16.7	37	66
	17.	40	96
	18.	56	

50. ***Period of vibration.*** The mean values of the periods of vibration occurring in the different earthquakes were (i) 0.33 sec., and (ii) 0.16 sec., as follows:—

sec.		sec.
0.254		0.132
0.267		0.188
0.280		0.16 sec.
0.305	mean,	
0.340	**0.33** sec.	
0.335		
0.375		
0.387		
0.392		

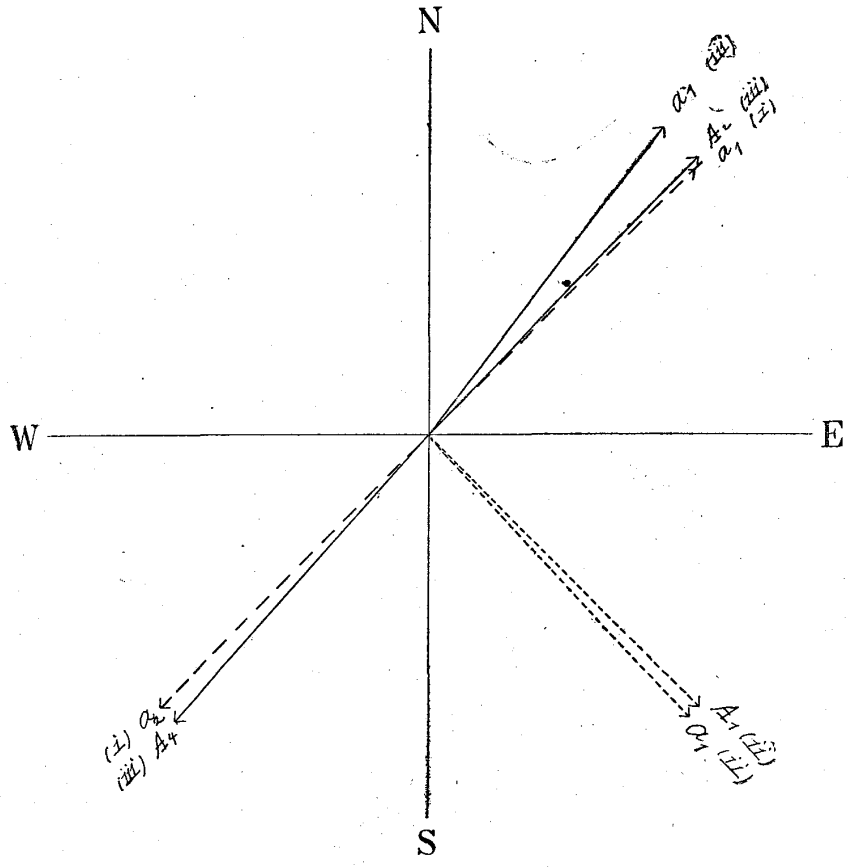
The (ii) period is half of the (i) period.

These periods may be regarded as characterizing the place of observation, in the prefectural compound, where the soil is low and soft, and are different from those at the Kagoshima meteorological observatory (old site) standing on the top of a hill (§ 1).

51. ***Direction of motion.*** (See figs. 10, 11, and 12.) The direction of motion of the vibrations at the commencement of the preliminary tremor and the principal portion have been ascertained in 6 cases, as in Table XV.

Fig. 10. Tromometer Observation of the Sakura-jima After-shocks in Kagoshima: Vibration Direction at the Commencement of the Preliminary Tremor compared with that at the Commencement of the Principal Portion. (From original diagrams.)

3 Earthquakes: (i) Jan. 22nd, 1914; 1. 13. 17 P.M.
(ii) „ „ „ ; 8. 51. 55 A.M.
(iii) „ „ „ ; 8. 29. 43 A.M.



Direction of the

a_1..... 1st Displacement, Preliminary Tremor.
A_1.....1st „ , Principal Portion.
A_2.....2nd „ , „ „
A_4.....4th „ , „ „

Tromometer Observation of the Sakura-jima After-shocks in Kagoshima: Vibration Direction at the Commencement of the Preliminary Tremor compared with that at the Commencement of the Principal Portion.

(From photographic enlargements.)

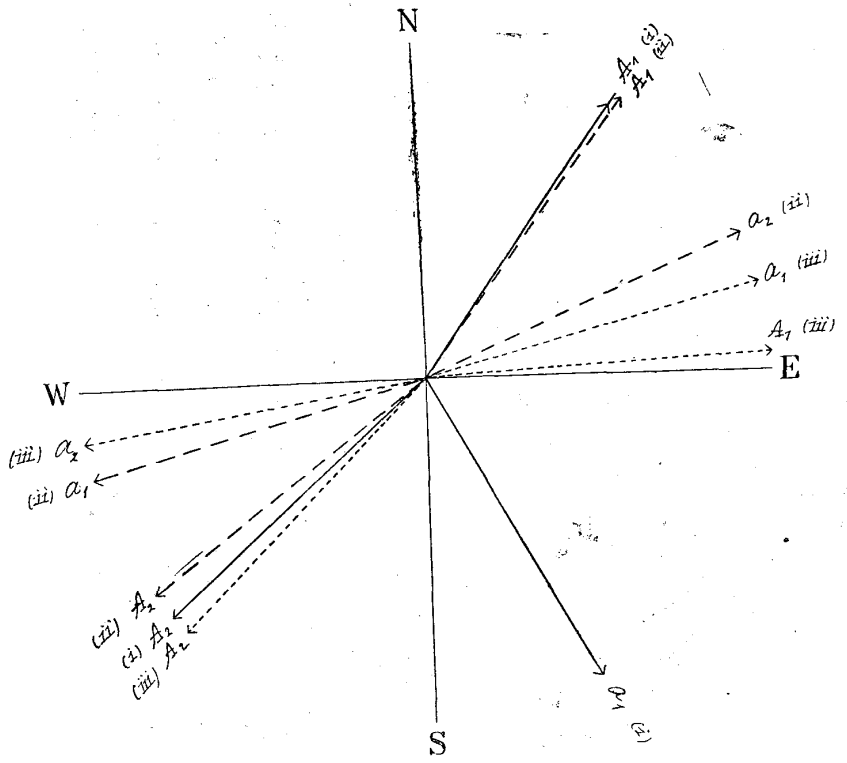


Fig. 11. 3 Eqkes.: (Jan. 1914) { (i) 22nd; 9.38.45 A.M. (ii) 29th; 11.41.11 „ (iii) „ ; 11.41.52 „

Direction of the
a_1.....1st Displacement, Preliminary Tremor.
a_2.....2nd „ , „ „

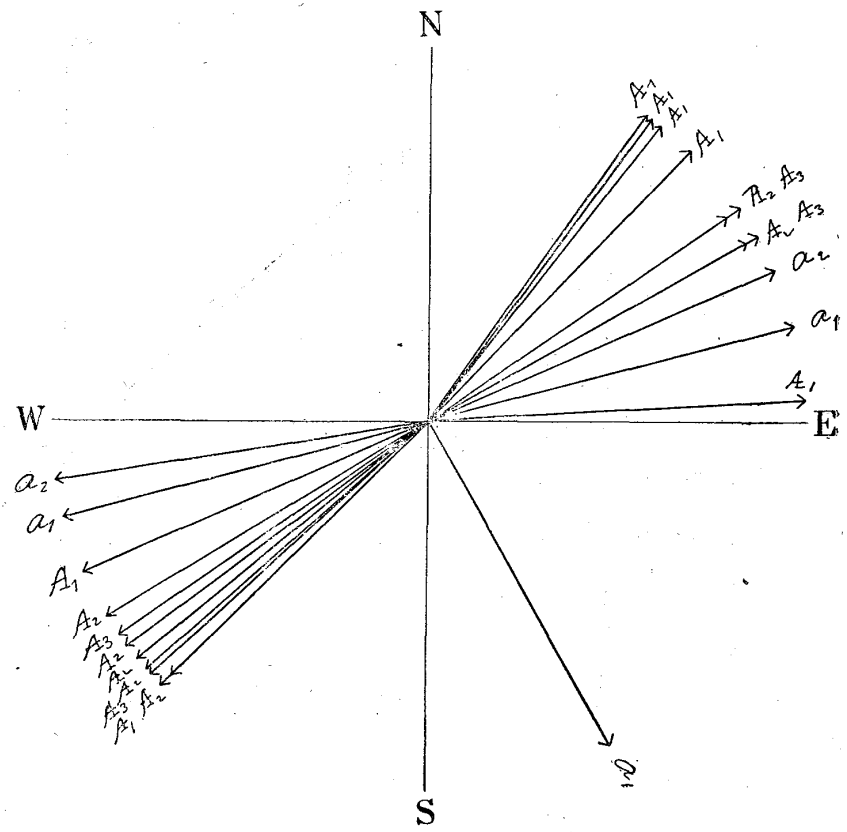


Fig. 12. Different Earthquakes taken together.

Direction of the
A_1.....1st Displacement, Principal Portion.
A_2..... 2nd „ , „ „
A_3.....3rd „ , „ „

In the 3 eqkes. Nos. vi, iv, and ii, the direction of the 1st displacement in the preliminary tremor coincided nearly with that in the principal portion, while in the eqke. No. v, the two directions were roughly opposite. Again, in the 4 eqkes. of the (A) group, the 1st displacement of the preliminary tremor was directed toward the N.E. (in one case, toward the S.W.), and in the two eqkes. of the (B) group, it was directed towards the S.E.; while the direction of the 1st displacement in the principal portion was all directed toward the N.E., except in the one case of (ii), in which it was

TABLE XV. DIRECTION OF THE 1ST VIBRATION IN THE PRELIMINARY TREMOR COMPARED TO THAT IN THE PRINCIPAL PORTION.

Earthquake No.		Date (1914) and Time of Occurrence.	Preliminary Tremor.		Principal Portion.	
			1st Displt.	2nd Displt.	1st Displt.	2nd Displt.
A	v	Jan. 29th; 11.41 11 A.M.	mm. 0.0212→ S.75°W.	mm 0.0285→ N. 06°E.	mm. 0.12→ N. 36°E.	mm. 0.172→ S.53°W.
A	vi	Jan. 29th; 11.41.52 A.M.	0.0106→ N. 75°E.	0.022→ S.81°W.	0.03→ N 87°E.	0.093→ S 45°W.
A	iv	Jan. 24th; 8.29.43 A.M.	0.0046→ N.37°½E.	——	0.074→ N. 44°E.	(4th displt.) 0.084→ S.42°W.
A	iii	Jan. 22nd; 1.13.17 P.M.	(Small)→ N. E.	0.015→ S 45°W.	——	——
B	i	Jan. 22nd; 9.38.45 A.M.	0.0104→ S. 29°E.	——	0.069→ N. 35°E.	0.136→ S.48°½W.
B	ii	Jan. 23rd; 8.51.55 A.M.	0.0095→ S. 43°E.	——	0.087→ S. 45°E.	——

directed toward the opposite side. I conclude:—*firstly*, that the 1st vibrations in the preliminary tremor and the principal portion were executed mostly in approximately similar directions; and, *secondly*, that the 1st displacement in the principal portion tended to be directed generally toward the N.E. This latter fact is seen also from Table XVI, which gives, for the different earthquakes, the direction and amplitude of the 1st and 2nd displacements of the

vibration at the commencement of the principal portion. Thus the 1st displacement in question was directed toward the N.E., in the 8 eqkes. of the (I) group, and directed toward the opposite side, or the S.W., in the 4 eqkes. of the group (I′). In the 3 eqkes. of the (II) group, the initial direction was toward the S. or S.E.

Taking together all the determinations relating to the 1st and 2nd displacements of the preliminary tremor and the principal portion, as shown in Table XVII, we obtain the following two mean directions:—

(I) N. 52°.6. E.–S. 52°.6 W. (II) S. 42° E.–N. 42°W.

(I) represented the most frequently occurring direction of motion, and may be taken as indicating the existence of the principal source of seismic disturbance to the N. 52.°6 E. from the site of observation (the prefectural compound, Kagoshima) at the focal distance of 14.4 km. (§ 49). The position thus defined corresponds to a place off the Osaki-hana promontory, and naturally we are led to identify it with the *centre of elevation* of the sea-bottom* to the north of the Sakura-jima, at $\varphi=31°40'$N., $\lambda=130°40'$E., which is situated at the distance of exactly 14.4 km. to the N.54°E. from the observing station. In this connection it may be added that the fore-shocks were felt with a very high frequency at the village of Saido on the north-western coast of Sakura-jima. (See the Bulletin, Vol. VIII, No. 1, p. 11.) (II) may be taken as indicating the existence of a secondary source of submarine seismic disturbance to the south of the "island."

52. *Range of motion.* From Table XVI it is seen that the 2nd displacement of the initial vibration of the principal portion was greater than the 1st in the average ratio of 1.8:1. Confining our attention to the cases of the group (I), the ratio in question

* See the Bulletin, Vol. VIII, No. 4.

TABLE XVI. SAKURA-JIMA VOLCANIC EARTHQUAKES OBSERVED TROMOMETRICALLY IN KAGOSHIMA, JAN. 16TH—FEB. 8TH, 1914: THE VIBRATION AT THE COMMENCEMENT OF THE PRINCIPAL PORTION.

	1st Displacement.	2nd Displacement.
	mm.	mm.
(I)	0.069→N. 35° E.	0.136→S. 48°½ W.
	0.074→N. 44° E.	—
	0.034→N. 43°½ E.	0.060→S. 58° W.
	0.026→N. 37° E.	—
	0.023→N. 23° E.	—
	0.034→N. 37°½ E.	0.061→S. 50° W.
	0.120→N. 36° E.	0.172→S. 53° W.
	0.030→N. 87° E.	0.093→S. 45° W.
(I′)	0.017→S. 45° W.	0.034→N. 55° E.
	0.027→S. 50° W.	0.033→N. 53° E.
	0.035→S. 66°½ W.	0.059→N. 60° E.
	0.034→S. 66° W.	
(II)	0.017→S. 71° E.	
	0.087→S. 45° E.	
	0.013→S.	0.018→N. 12° W.

TABLE XVII. TROMOMETER OBSERVATION OF SAKURA-JIMA VOLCANIC EARTHQUAKES, JAN. 16TH—FEB. 8TH, 1914: DIRECTIONS OF THE 1ST AND 2ND DISPLACEMENTS AT THE COMMENCEMENT OF THE PRELIMINARY TREMOR AND THE PRINCIPAL PORTION.

N. 23° E.	N. 53° E.	S. 42° W.	S. 53° W.	S. 43° E.
N. 35° E	N. 55° E.	S. 45° W.	S. 55° W.	S. 45° E.
N. 36° E.	N. 55° E.	S. 45° W.	S. 58° W.	S. 71° E.
N. 37° E.	N. 60° E.	S. 45° W.	S. 66° W.	S. 29° E.
N. 37° E.	N. 60° E.	S. 48°½ W.	S. 66°½ W.	S.
N. 37°½ E.	N. 66° E.	S. 50° W.	S. 75° W.	N. 12° W.
N. 43°½ E.	N. 75° E.	S. 50° W.	S. 81° W.	N. 51° W.
N. 44° E.	N. 87° E.	S. 47° W.		

(I) **N. 52.°6 E.—S. 52.°6 W.**

(II) **S. 42°E.—N. 42°W.**

comes out to be 2.0:1. These results are what may be expected, as the 1st displacement is of the nature of a simple amplitude and the 2nd of that of the double amplitude.

53. *Comparison with the fore-shocks.* The ordinary seismograph diagrams of the Sakura-jima fore-shocks obtained at the Kagoshima meteorological observatory (Chapter III) was inferior to the continuous tromometer registers of the volcanic after-shocks in the accuracy of the determination respecting the directions of motion. Still the results furnished by the former series of observation was approximately similar to those by the latter; the most active centres of the volcanic fore-and after-shocks being probably identical, and situated under the sea, coincident with the elevation part of the bottom of the inner bay. A feature of special interest is that the maximum displacements at the commencement of the principal portion tended to take place toward, or away from, the centre here assumed, even in some cases in which the 1st movements in the preliminary tremor pointed toward the S.E., with the origin of disturbance in the latter direction. This may be considered as indicating a habit of the Sakura-jima earthquakes, due probably to the facility of the production of prominent movements radially to the sensitive seismic focal area, irrespective of the location of disturbance origins at other points in the vicinity.

The great eruption of Sakura-jima of 1914 may be regarded as the culmination of the powerful volcanic tension which had existed under the volcano and the bottom of the Inner Kagoshima Bay, and the principal eruptive energy has been spent during the first two days of the outburst, Jan. 12th and 13th, when the emission of an immense quantity of smoke, ashes, and pumice, was followed by the outflows of an exceptionally large amount of lava. The eruption took place from the Sakura-jima, but the lava

Diagrams illustrating the Origin of the Fore-shocks and After-shocks of the Sakura-jima Eruption.

LL.....Underground Lava Reservoir. *P* .....Pressure of the Surface Earth-crust.
T ..... Underground Volcanic Tension. *K* .....Observing Station.

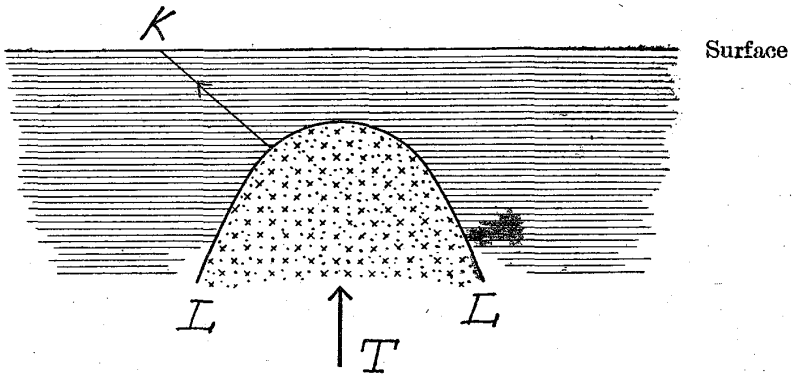


Fig. 13. Origin of a Volcanic *Fore-shock*.

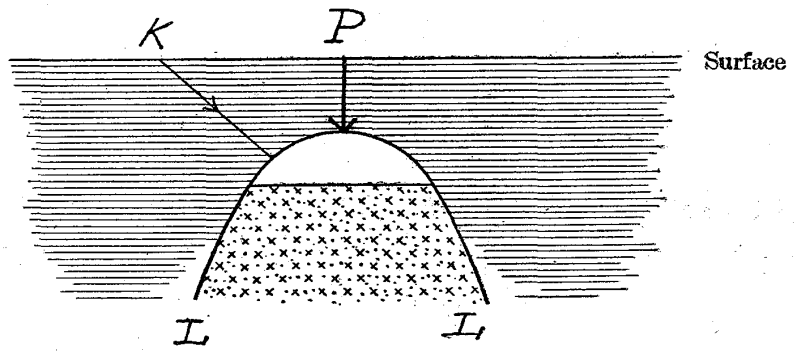


Fig. 14. Origin of a Volcanic *After-shock*.

"reservoir" existed under the inner bay,* where the principal seismic centre was also located. The volcanic fore-shocks on the 11th and 12th of Jan. 1914, were doubtless the result of the upward underground tension, contending to burst open the superincumbent portion of the earth's crust. After the principal eruptive stages, there set in the subsidence of the disturbed region, which tended to push down the superficial portion of the earth's

* The Bulletin, Vol. VIII, Nos. 2 and 4.

crust spanning over the more or less vacant lava "reservoir," this being probably the main cause of the volcanic after-shocks. Hence, the 1st displacement of the principal or maximum vibration of a volcanic fore-shock ought most naturally to be directed outwards, and that of volcanic after-shocks to be directed origin-wards, as illustrated diagrammatically in figs. 13 and 14. This directional difference is in harmony with the results of the instrumental observations in Kagoshima (§ 51), where the 1st displacement of the principal portion of the fore-shocks was mostly directed towards the S.W., and that of the after-shocks mostly toward the N.E.

In the above considerations respecting the direction of motion, it is assumed that the application of the volcanic tension from below did not result in a marked upheaval of a small central area, in which case the 1st displacement ought to be directed inwards, being virtually the first stage in a volcanic explosion.

CHAPTER V. TROMOMETER OBSERVATION IN KAGOSHIMA OF THE SAKURA-JIMA AFTER-ERUPTIONS, JAN. 16TH—FEB. 8TH, 1914.

54. *Observation in Kagoshima.* The compound of the Kagoshima prefectural office, where the tromometer observation has been carried on (§ 30), is situated 10 km. nearly westwards from the centre of Sakura-jima. Its position relative to the craterlets on the two sides of the volcano, which were active at the time concerned, was as follows :—

5.9 km.	to the W.	5° N.	from the	Lowest Craterlet on the W. flank ;
8.5 km.	„ W.	8° N.	„	Highest „ „ ;
11.8 km.	„ W.	10° N.	„	No. 2. Craterlet on the S.E. flank ;
14.3 km.	„ W.	11° N.	„	Lowest „ „ .