CHAPTER IV. FREQUENCY OF THE NON-ERUPTIVE EARTHQUAKES.

12. *Interval between successive non-eruptive Asama-yama earthquakes.* The seismographical observations during the 6 years 1911 to 1916 at Yuno-taira enabled us, owing to the proximity of the station to the crater, to register individually the Asama-yama seismic disturbances, which, in case of the non-eruptive character, often occurred in close series, with the maximum hourly frequency of 81 and with the successive time interval $(=\tau)$ varying mostly from a few seconds up to $\frac{1}{4}$ or $\frac{1}{3}$ of a minute. (See Tables VII—X.) Illustrative registers are reproduced in figs. 8 and 9.

Confining our attention to the cases in which the successive earthquakes took place at intervals less than 3 minutes, we may conclude from the results contained in Tables VII and VIII as follows. (i) Sensible and unfelt earthquakes taken together: the successive time interval $(=\tau)$ was included between 2 and 15 sec., with that of 12 sec. corresponding approximately to the maximum frequency. (ii) Sensible earthquakes only: the comparative majority of 32 out of the 100% were included between 6 and 20 sec. This displacement of the maximum frequency to the greater value of τ is quite natural, as the earthquakes of the class (ii) are on the whole larger than those of the class (i), and as strong seismic disturbances are the results of long continued stress increase in the earth's crust and occur of course at longer time intervals than the small ones.

The apparent small frequency for the time interval of $\tau = 1$ sec. must be due in a great measure to the difficulty of individu-

Pl. XXXVI.

Fig. 8. A Series of Non-eruptive Volcanic Earthquakes on Aug. 31, 1916, at 0½ A.M., observed at Yuno-taira (Asama-yama).

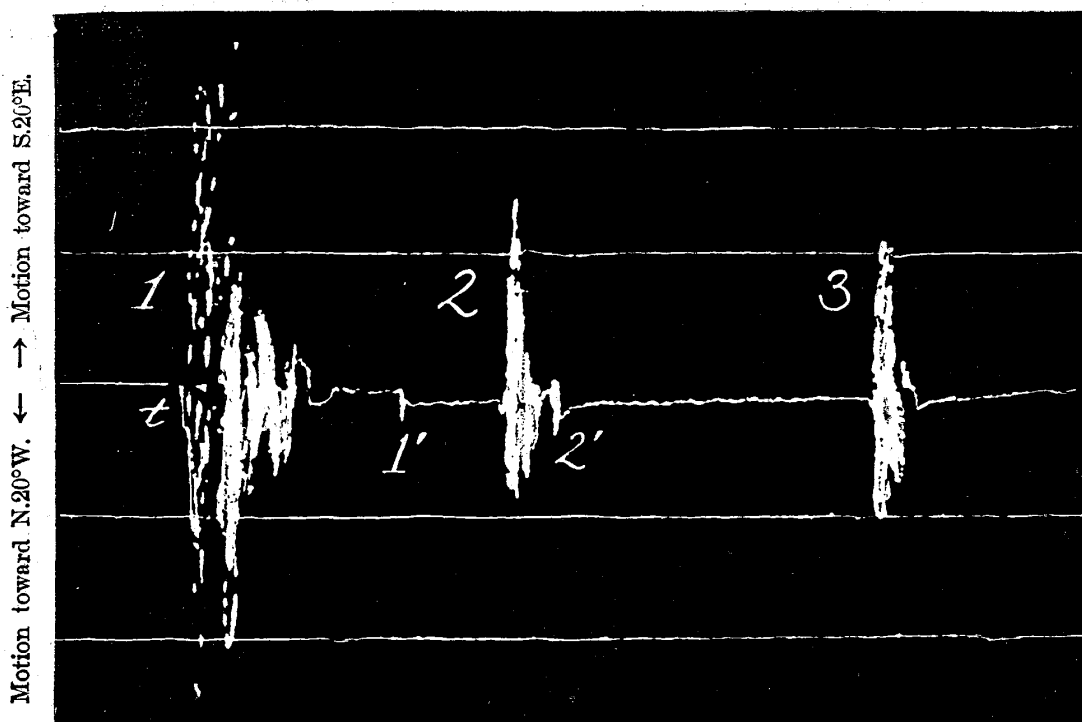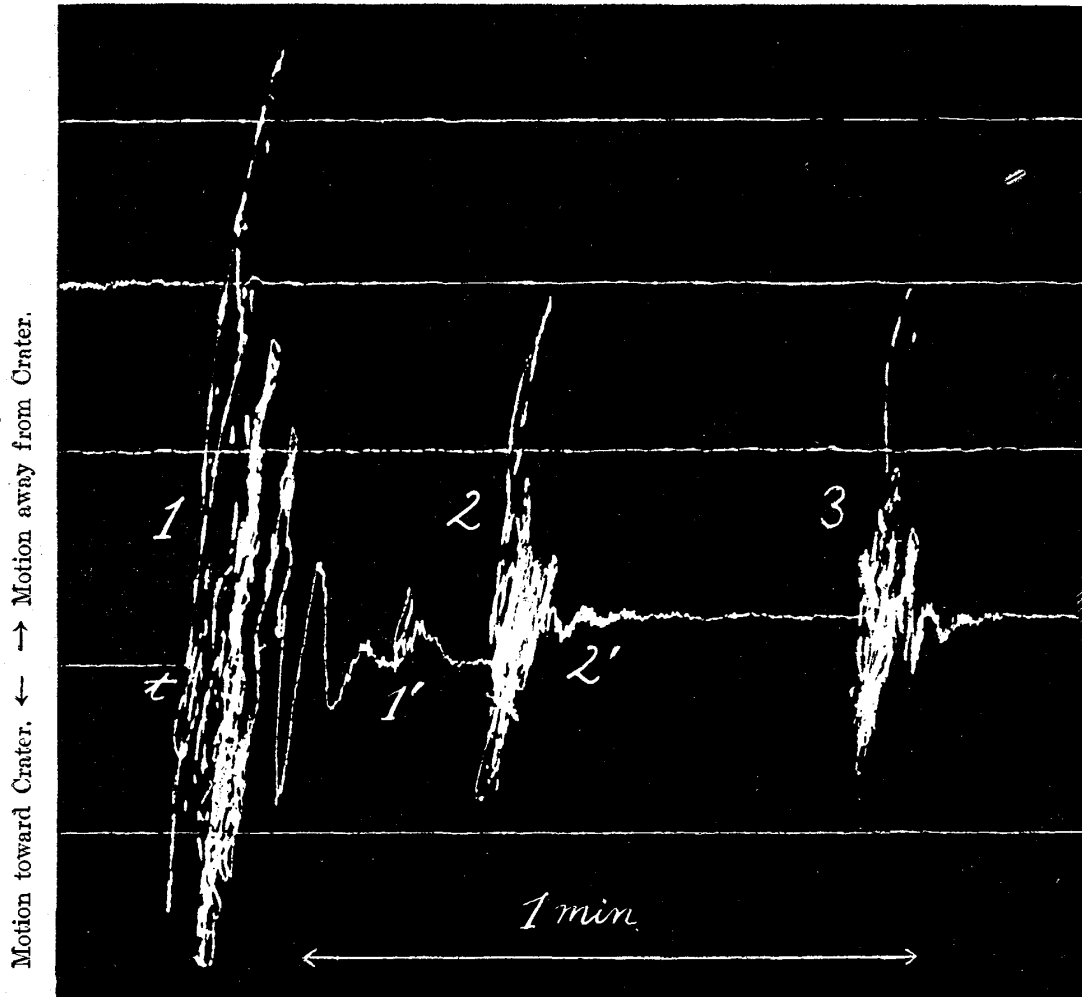Radial Component Tromometer Diagram. Multiplication = 800.
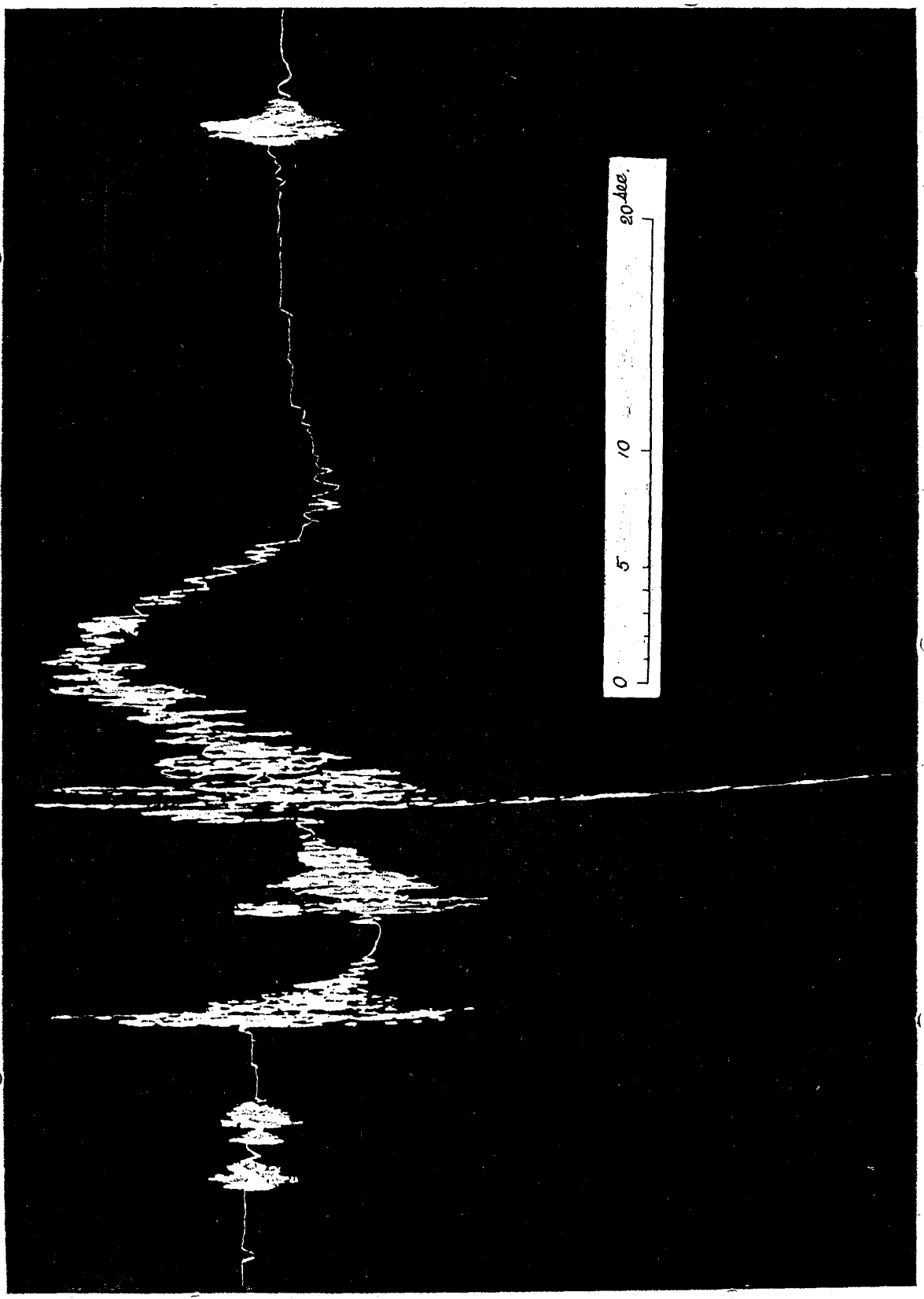
Motion away from Crater. ← → Motion toward Crater.

Pl. XXXVII.

Fig. 9. Non-eruptive Volcanic Earthquakes on Sept. 19, 1915, observed at Yuno-taira (Asama-yama).

(1)	9.25.28 a.m.		1, 2, 3....Sensible shocks.
(2)	9.25.52 „		1′, 2′....Unfelt „
(3)	9.26.24 „		

t........Time (minute) mark cutting.
Magnification = 500.

ally recognizing in the tromometer diagrams the existence of earthquakes separated by the time difference less than 2 sec., as the rate of motion of the smoked-paper recorder was generally under 5 cm. per minute. The case of $\tau=0$ signifies the occurrence of two earthquakes at nearly simultaneous moments from different origins in or about the Asama-yama, and the corresponding frequency is in reality probably not much different from the values for $\tau=1$ or 2 sec. The following is the list of the 5 sec. frequency of the interval τ based on the figures given in Tables VII and VIII.

Time Interval.	Sensible and unfelt Earthquakes.	Sensible Earthquakes only.	Time Interval.	Sensible and unfelt Earthquakes.	Sensible Earthquakes only.
sec. sec.			sec. sec.		
1 — 5	69	6	51—55	18	2
6 —10	82	14	56—60	28	4
11—15	99	12	61—65	11	4
16—20	50	12	66—70	8	3
21—25	56	6	71—75	9	4
26—30	33	11	76—80	10	3
31—35	35	7	81—85	7	1
36—40	30	6	86—90	7	0
41—45	28	3	91—95	11	3
46—50	18	2	96—100	3	1

13. *Relation between the length of the interval and its frequency.* To consider theoretically the relation between the frequency ($=y$) and the length of the interval ($=\tau$), let us make the following assumptions:—

(i). Earthquakes take place at the successive time interval ($=\tau$) which is proportional to their magnitude ($=m$).

(ii). For a given observing place sufficiently near to the earth-
quake centres such that all the disturbances, even when
extremely minute, are registered on seismographs without
exception, the frequency ($=y_0$) corresponding to the in-
terval τ, decreases with the increase of the length of the
latter, attaining a limiting value ($=Y$) for the case of $\tau=0$.

(iii). For an observing place more or less distant from the
earthquake centres, such that the extremely minute distur-
bances are no longer there registered, the frequency ($=y$)
becomes evanescent for the case of $\tau=0$ and also for an
infinitely great value of τ.

These three assumptions can be represented by the following
equations in which h, a, b, and c are constants:

$$m = h\,\tau \quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(1)$$

$$y_0 = \frac{Y}{e^{cm}} = \frac{Y}{e^{a\tau}} \quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

$$y = \frac{Y}{e^{a\tau}}\left(1 - \frac{l}{e^{b\tau}}\right)\cdots\cdots\cdots\cdots\cdots\cdots(3)$$

The point of the maximum y is determined by the equation:—

$$\tau = \frac{1}{b}.\ \log_e\left(\frac{a+b}{a}\right).$$

The graphical representation (fig. 10) of the mean variation of
the frequency of the different time intervals between the successive
earthquakes observed at Yuno-taira in 1911–1916 seems to be
similar to that indicated by Equation (3).

The occurrence of earthquake shocks at close time intervals
must also be the case with the seismic region other than the
volcanic district of the Asama-yama. It is desirable that on future
occasions of marked display of seismic or volcanic activity, a

proper tromometrical registration should at once be made at a spot close to the disturbance centre.

Fig. 10. Variation in the Time Interval between the Successive Occurrence of the Non-eruptive Earthquakes. (Observed at Yuno-taira, Asama-yama, 1911—1916.)
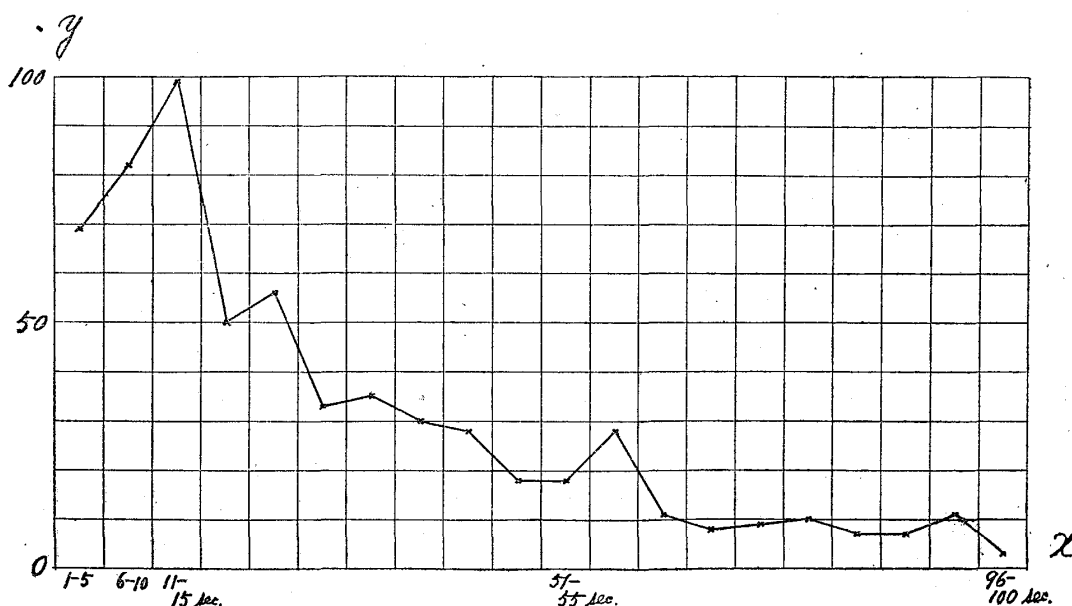
x = Successive Time Interval, in 5 seconds divisions.
y = Number of Cases corresponding to x.

14. Comparison with the Ō-shima (Izu) eruption in 1912.
The results stated in § 12 in connection with the successive intervals of the non-eruptive Asama-yama earthquakes are much similar to those relating to the Ō-shima eruption in April 1912, which was almost entirely *non-explosive* and consisted of frequent firework-like ejections of red-hot lava masses, there being also shakings of the ground distinctly sensible at the crater edge and at the base of the central cone. Thus, the mean intervals between these successive occurrences, which were practically identical for the two classes of disturbances, were, on the average, about 6.3 sec., 13.4 sec., and 29 sec., as follows :—

Date (1912).	Mean Successive Interval. (Ōshima Eruption.)					
	Outbursts.			Earth Shakings.		
	sec.	sec.	sec.	sec.	sec.	sec.
April 10th.	6.2	14.4	—	—	—	—
12th.	6.1	—	—	6.3	—	—
13th.	6.7	—	—			
14th.	6.5	13.3	25.3	5.1	12.7	34.0
16th.	6.1	—	—	7.6	—	29.0
,,				6.4	12.9	—
Mean.	6.3	13.9	25.3	6.4	12.8	32.0

It seems probable that the numerous non-eruptive Asama-yama earthquakes were the results of the underground eruptive efforts of the volcanic force.

TABLE VII. INTERVALS BETWEEN THE SUCCESSIVE TIMES OF OCCURRENCE OF THE ASAMA-YAMA NON-ERUPTIVE SENSIBLE AND UNFELT EARTHQUAKES. 1911 TO 1916, YUNO-TAIRA.

Time Interval	Number of Cases	Time Interval	Number of Cases	Time Interval	Number of Cases	Time Interval	Number of Cases	Time Interval	Number of Cases	Time Interval	Number of Cases
sec.		sec.		sec.		sec.		sec.		sec.	
1	1	31	11	61	1	91	3	121	—	151	—
2	17	32	4	62	3	92	1	122	1	152	—
3	22	33	10	63	0	93	5	123	—	153	1
4	14	34	3	64	2	94	—	124	—	154	—
5	15	35	7	65	5	95	2	125	1	155	1
6	16	36	7	66	1	96	1	126	—	156	—
7	20	37	6	67	6	97	2	127	1	157	1
8	19	38	6	68	—	98	—	128	2	158	—
9	12	39	7	69	1	99	—	129	—	159	—
10	15	40	4	70	—	100	—	130	1	160	—
11	20	41	9	71	3	101	2	131	—	161	—
12	23	42	5	72	1	102	—	132	—	162	—
13	19	43	1	73	2	103	—	133	3	163	—
14	18	44	4	74	1	104	2	134	2	164	—
15	19	45	9	75	2	105	2	135	3	165	—
16	11	46	1	76	1	106	1	136	—	166	—
17	11	47	6	77	2	107	—	137	1	167	—
18	11	48	2	78	3	108	—	138	—	168	1
19	7	49	4	79	2	109	1	139	—	169	1
20	10	50	5	80	2	110	1	140	—	170	—
21	10	51	3	81	1	111	4	141	1	171	—
22	9	52	1	82	1	112	1	142	—	172	—
23	10	53	8	83	2	113	1	143	—	173	—
24	13	54	1	84	1	114	1	144	2	174	—
25	14	55	5	85	2	115	—	145	—	175	—
26	6	56	7	86	1	116	—	146	1	176	—
27	4	57	7	87	2	117	—	147	—	177	—
28	8	58	5	88	1	118	1	148	—	178	—
29	7	59	4	89	2	119	—	149	—	179	—
30	8	60	5	90	1	120	—	150	—	180	—

TABLE VIII. INTERVALS BETWEEN THE SUCCESSIVE TIMES OF OCCURRENCE OF THE ASAMA-YAMA NON-ERUPTIVE SENSIBLE EARTHQUAKES.
1911 TO 1916, YUNO-TAIRA.

Time Interval	Number of Cases.	Time Interval	Number of Cases.	Time Interval	Number of Cases.	Time Interval	Number of Cases.	Time Interval	Number of Cases.	Time Interval	Number of Cases.
sec.		sec.		sec.		sec.		sec.		sec.	
1	—	31	2	61	—	91	2	121	—	151	—
2	1	32	1	62	1	92	—	122	—	152	—
3	3	33	2	63	—	93	—	123	1	153	—
4	1	34	—	64	1	94	1	124	—	154	—
5	1	35	2	65	2	95	—	125	—	155	—
6	2	36	1	66	—	96	1	126	—	156	—
7	3	37	1	67	1	97	—	127	—	157	—
8	5	38	1	68	1	98	—	128	—	158	—
9	3	39	1	69	1	99	—	129	—	159	—
10	1	40	2	70	—	100	—	130	—	160	—
11	3	41	1	71	—	101	—	131	—	161	—
12	4	42	1	72	—	102	—	132	—	162	1
13	1	43	—	73	1	103	1	133	—	163	—
14	2	44	—	74	2	104	1	134	1	164	—
15	2	45	1	75	1	105	—	135	—	165	—
16	3	46	—	76	—	106	—	136	—	166	—
17	3	47	1	77	—	107	—	137	—	167	—
18	3	48	1	78	1	108	—	138	—	168	—
19	—	49	—	79	—	109	—	139	—	169	—
20	3	50	—	80	2	110	1	140	—	170	—
21	1	51	—	81	—	111	1	141	—	171	—
22	—	52	—	82	—	112	2	142	—	172	—
23	—	53	1	83	1	113	1	143	—	173	—
24	3	54	1	84	—	114	1	144	—	174	—
25	2	55	—	85	—	115	—	145	—	175	—
26	—	56	1	86	—	116	—	146	—	176	1
27	2	57	2	87	—	117	1	147	—	177	—
28	3	58	—	88	—	118	1	148	—	178	—
29	4	59	—	89	—	119	—	149	—	179	—
30	2	60	1	90	—	120	—	150	—	180	—

TABLE IX.   INTERVALS BETWEEN THE SUCCESSIVE TIMES OF
OCCURRENCE OF THE NON-ERUPTIVE EARTHQUAKES,
OBSERVED IN 1912 AT YUNO-TAIRA
(ASAMA-YAMA).

Successive Interval.	Number of Cases.	Successive Interval.	Number of Cases.
2 sec. 3 4 5	7 7 *Mean.* 8 7.5 8	31 sec. 32 33 34 35	6 2 *Mean.* 3 4.4 1 10
6 7 8 9 10	8 10 12 8.0 2 8	36 37 38 39 40	5 4 2 3.4 5 1
11 12 13 14 15	10 16 11 11.2 10 9	41 42 43 44 45	5 1 0 2.6 3 4
16 17 18 19 20	8 4 7 6.6 6 8	46 47 48 49 50	0 3 1 1.6 3 1
21 22 23 24 25	4 4 6 6.4 8 10	51 52 53 54 55	3 0 3 1.6 0 2
26 27 28 29 30	4 2 7 4.6 6 4	56 57 58 59 60	1 3 5 2.8 4 1

TABLE X. OCCURRENCE IN CLOSE SUCCESSION OF THE NON-ERUPTIVE VOLCANIC EARTHQUAKES. (OBSERVATION AT YUNO-TAIRA, ASAMA-YAMA.)

$2a$ = Max. range of motion in the direction radial to the crater centre.

Date.	$2a$	Time of Occurrence.	Successive Time Difference m	s	Date.	$2a$	Time of Occurrence.	Successive Time Difference m	s
IX 29, 1911.	252$^\mu$	1.14.14 P.M.	0	24	VI 25, 1912.	365$^\mu$	2.39.57 A.M.	1	11
	1110	14.38		31		12*	41.08		59
	18*	15.09	1	22		3*	42.07		23
	17*	16.31		13		10*	42.33		13
	150	16.44		13		5*	42.46		12
	8*	16.57		12		50*	42.58		12
	21*	17.09	2	57		5*	43.10		4
	269	20.06		18		Large.	43.14	1	53
	123	20.24	12	46		44*	45.07		38
	54	33.10	9	23		22*	45.45		8
	43	42.33		22		110	45.53		12
	10*	42.55		17		580	46.05		29
	96	43.12		26		26*	46.34		9
	6*	43.38		41		95	46.43		15
	80	44.19		8		17*	46.58		11
	24*	44.27		9		18*	47.09		3
	6*	44.36		55		90	47.12		12
	10*	45.31	10	16		65*	47.24		12
	40	55.47		9		16*	47.36		36
	25*	55.56		22		116	48.12	2	33
	18*	56.18		11		15*	50.45	4	21
	80	56.29	13	54		6*	55.06	17	6
	47	2.10.23	8	20		3*	3.12.12 A.M.		3
	12*	18.43	1	30		260	12.15		14
	37*	20.13		11		20*	12.39		13
	8*	20.24		13		7*	12.52		2
	31	20.27		9		100	12.54		10
	15*	20.36				32*	13.04	2	56
						5*	16.00	1	7
X 5, 1191.	46	2.40.38 A.M.				730	17.07		26
	263	40.46		12		14*	17.33		28
	26*	41.11		25		40*	18.01		12
	7*	42.01		50		260	18.13		42
	105	42.54		53		5*	18.55		
	110	43.00		6					
	142	43.03		3	VII 16, 1912.	2*	7.50.09 A.M.	0	13
	27*	43.23		20		Large.	50.22	2	13
	15*	45.44	2	21		30*	52.35		6
	14*	45.47		3		10*	52.41		14

Date.	2a	Time of Occurrence.	Successive Time Difference.	
	μ		m	s
VII 16, 1912.	92	52.55 A.M.		
	10*	53.07		12
	23*	53.28		21
	42*	53.48		20
	11*	54.03		15
	60	55.01		58
	50*	55.09		8
	13	55.59		49
	43	56.14		16
	Large.	56.21		7
	30*	57.14		53
	18*	57.27		13
	60	58.19		52
	30*	58.32		13
	20*	58.39		7
	48*	58.45		6
	10*	59.26		41
	210	59.59		33
	15*	8.01.06	1	7
	28*	01.51		45
	255	02.05		14
	10*	02.46		41
	3*	03.35		49
	158	03.59		24
	3*	05.04	1	5
	4*	05.08		4
	23*	05.49		41
	118	06.00		11
	70*	06.37		37
	500	07.06		29
	170	07.53		47
	90	09.07	1	14
	5*	10.04		57
	⋮	⋮		
	6*	8.16.15 A.M.	0	33
	45	16.48		20
	2*	17.08		20
	5*	17.28		7
	5*	17.35	1	28
	30	19.03		25
	48	19.28		37
	8*	20.05		36

Date.	2a	Time of Occurrence.	Successive Time Difference.	
	μ		m	s
VII 16, 1912.	8*	20.41 A.M.		
	2*	21.05		24
	125	21.44		39
	2*	22.19		35
	⋮	⋮		
	2*	25.17		
	53	25.28		11
	3*	26.50	1	22
	⋮	⋮		
	1*	32.15		
	20	33.14		59
	11*	34.10		56
	⋮	⋮		
	2*	38.19		
	90	39.03		44
	23*	39.38		35
	⋮	⋮		
	10*	49.36		
	100	52.57	3	21
	31*	53.42		43
	370	55.57	2	15
	2*	57.48	1	51
	⋮	⋮		
	5*	9.01.00		
	120	01.17		17
	268	01.45		28
	158	02.03		18
	9*	02.39		36
	⋮	⋮		
	2*	9.10.19 A.M.		
	Large.	10.46	0	27
	10*	12.37	1	51
	40	13.07		30
	2*	13.52		45
	⋮	⋮		
	20*	20.32	1	9

Date.	2a	Time of Occurrence.	Successive Time Difference.		Date.	2a	Time of Occurrence.	Successive Time Difference.	
			m	s				m	s
VII 16, 1912.	40 μ	9.21.41 A.M.			X 5, 1916.	44 μ	6.20.01 A.M.		
	2*	22.39		58		40	20.13		12
	2*	23.00		21		7*	20.28		15
	38	27.27	4	27		2*	20.58		30
	2*	28.39	1	12		2*	21.12		14
	2*	28.44		5		44	21.33		21
	40	29.19		35		2*	22.06		33
	2*	32.19	3	0		3*	22.43		37
	13*	32.33		14		5*	22.58		15
	41	33.09		36		2*	23.30		32
	3*	34.06		57		13*	24.27		57
	⋮	⋮				5*	24.50		37
	2*	36.14				2*	25.04		14
	35	36.24		10		13*	25.57		53
	20*	37.55	1	31		995	26.07		10
	8*	10.07.33	29	38		18*	26.48		41
	73	07.40		7		26	27.50	1	2
	25*	17.14	9	34		6	27.57		7
	38	18.37	1	23		27	28.21		31
	—	33.11	14	34		6*	28.44		23
	84	34.16	1	5		3*	29.29		45
	13*	36.50	2	34		5*	30.03		34
	70	44.30	8	20		7*	30.12		9
	21*	49.04	4	34		40	30.24		12
	27*	51.39	2	35		5*	6.32.54		30
	19*	51.45		14		23	33.32	0	38
	—	53.14	1	29		423	34.32	1	0
						14*	35.13		41
						19*	35.50		37
IX 4, 1916.	4*	5.38.39 P.M.				43	36.06		16
	7*	41.54	3	15		15*	36.21		15
	4*	42.03		9		⋮	⋮		
	7*	42.41		38		10*	38.45		
	19*	43.12		31		60	38.48		3
	7*	44.05		53		24*	39.03		15
	7*	44.11		6		⋮	⋮		
	213	44.23		12		10*	47.49		
	39*	44.59		36		25	48.19		30
	3*	46.26	1	27		2*	48.55		36
	6*	46.51		25		325	51.29	2	34
	75	46.57		6		114	53.00	1	31
	7*	47.11		14				2	16

Date.	$2a$	Time of Occurrence.	Successive Time Difference.		Date.	$2a$	Time of Occurrence.	Successive Time Difference.
	μ		m s			μ		m s
X 5, 1916.	2*	15.16 A.M.	17		X 6, 1916.			
	4*	55.33	2 45					
	7*	58.18	10 6			7*	9.25.59 A.M.	13
	45	7.08.21	1 24			209	26.12	17
	5*	C9.48				45*	26.29	17
						95	26.46	
	⋮	⋮				⋮	⋮	
	8*	36.48	2 12					
	21	39.C0	2 14			4*	10.40.24	
	3*	41.14						

* indicates an unfelt shock.

CHAPTER V.   FREQUENCY OF THE ERUPTIONS.

15. *Occurrence of stronger explosion.* The dates of the stronger Asama-yama explosions during the 24 years, 1894–1917, are shown in Table XI; the outbursts which occurred in quick succession and evidently formed a group being indicated by a bracket. The intervals between the successive eruptions, or the commencements of the different eruption groups, are shown in Table XII. With the exception of July 1894 to Feb. 1899, and Sept. 1902 to Dec. 1907, when the eruptions were very few, the intervals in question varied between 4 and 179 days, being, as shown in Table XIII, most frequently 4 to 11 days, with the mean of 7 days. This is nearly similar to the result mentioned in § 16 with respect to the recurrence of the maximum frequency of the small outbursts in 1913. Further, the stronger eruptions indicates amongst the others an interval of 167 to 179, with the mean of 170 days.