A, B, C.

PUBLICATIONS

OF THE

Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

No. 22.

TOKYO. 1906-8.

PREFACE.

For the sake of quick publication and also for the convenience of reference, future numbers of the "Publications of the Earthquake Investigation Committee" will, when composed of several articles on different subjects, be issued in separate sections, and include one or more of the following :—

Section **A** ......*Seismological.*

Section **B** ......*Physical.*

Section **C** ......*Geological and Vulcanological.*

Section **D** ......*Technical*

The letters **A, B, C, D** printed on the title page of a number of the "Publications" will be used to indicate the sections of the articles contained in it.

B. Mano, *President.*

F. Omori, *General Secretary.*

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PUBLICATIONS

OF THE

Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

NO. 22 A.

TOKYO, 1908.

PUBLICATIONS OF THE EARTHQUAKE INVESTIGATION COMMITTEE. NO. 22. SECTION A.

Observation of Local Earthquakes on Mount Tsukuba, in 1905.

By

F. Omori, Sc. D.,

Member of the Imperial Earthquake Investigation Committee.

With Pls. I—VI.

Place of observation. The present paper is a preliminary report on the seismometrical measurements made in 1905 at H.I.H. Prince Yamashina's meteorological station at Tsukuba, a small town at mid-height of the southern slope of the Tsukuba-san. The latter is a mountain of granite and diorite formations, which is situated in the south-western part of the province of Hitachi, and which rises, almost as a solitary mass, to an elevation of 870 metres, directly out from the low plain bordering the lower course of the river Tone and the Kasumiga-ura. The geographical position of the meteorological station in question, which is 240 metres above the sea level, is $\varphi=36° 12' 22''$ N., $\lambda=140° 5' 56''$ E. A full account of these earthquake observations as well as those made at His Highness' Meteorological Observatory, established in 1901, at the top of one of the double peaks of the Tsukuba-san, will be given as an appendix to the "Ergebnisse der meteorologischen Beobachtungen auf dem Tsukubasan."

Instrument. The observations, whose object was the study of the near earthquakes, were made with an EW component horizontal tremor-recorder*, (shown in the accompanying figure), whose instrumental constants were as follows :

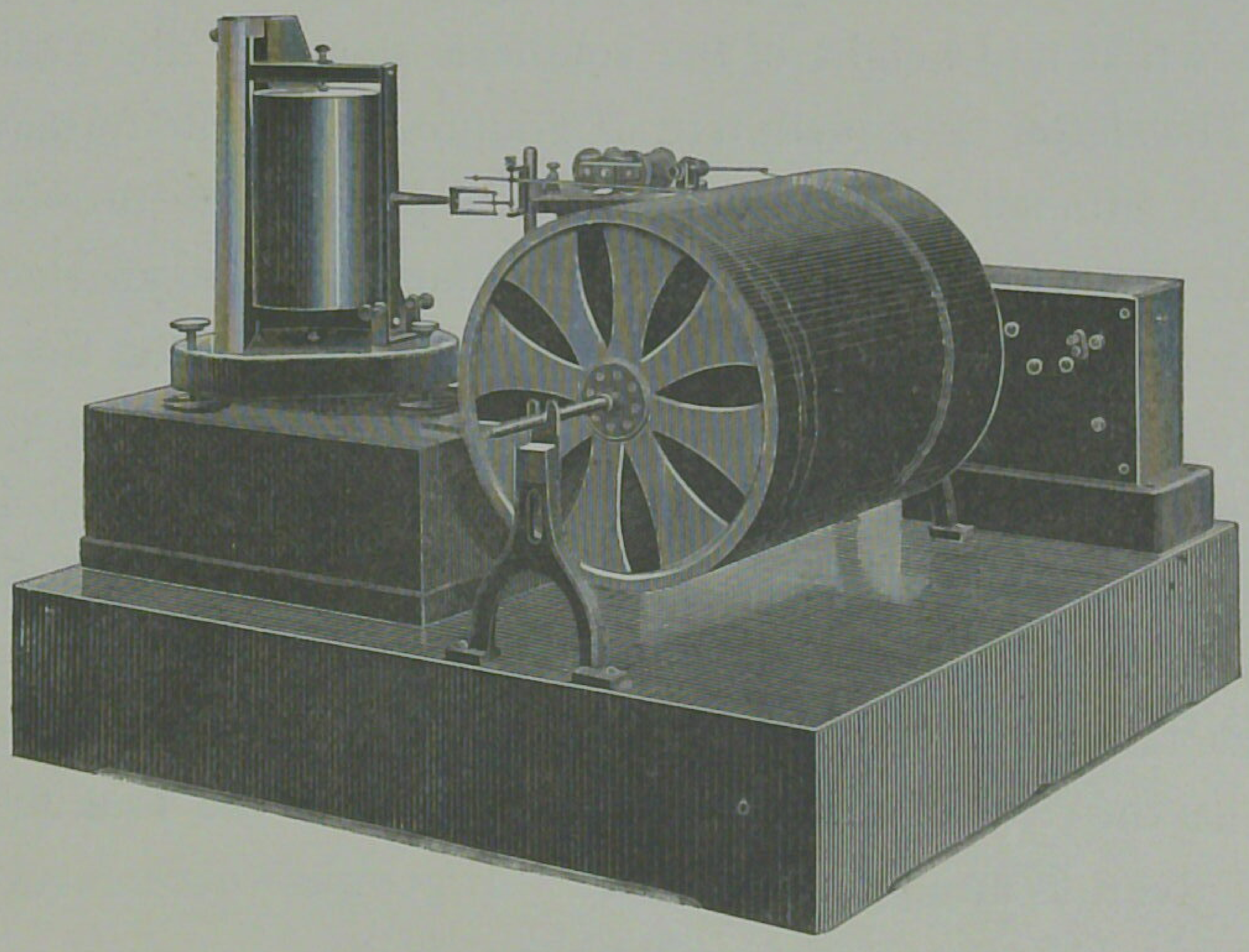
Weight of the heavy bob=about 15 kg.

Multiplication ratio of the pointer=90.

Natural period of the horizontal pendulum=about 4 sec.

Rate of motion of the smoked paper wrapped round the revolving drum=about 8–16 mm per minute.

As the town of Tsukuba is very quiet and free from the effect of traffic and similar artificial disturbances, the site of the meteorological station is particularly well adapted to the observation of the small local shocks ; there being no great amount of the pulsatory oscillations, due to the rocky nature of the mountain. On account of the same latter circumstance, the majority of the sensible earthquakes were preceded or accompanied by sounds.



* This instrument is similar to those described in the "Publications," No. 18, and the "Bulletin," Vol. I, No. 4.

The observations have been carried on by Mr. J. Sato, chief observer of the Tsukuba observatories, Mr. H. Tsutsui, assistant observer, and others.

List of the earthquakes observed in 1905. The tremor-recorder is sensible only to the quicker component of the seismic motion, and recorded, in 1905, four hundred and eighty-seven earthquakes, whose epicentral distances were each less than 1,000 km, which is nearly equal to the distance of the Tsukuba-san from either the north-eastern end of Hokkaido on the north, or the northern part of Kyushu on the south-west. The accompanying list gives for the EW component of each of these shocks the following particulars:—

(1) Date.

(2) Time of earthquake occurrence, given in the 1st Normal Japan Time, or that of longitude 135° E. of Greenwich.

(3) Intensity of motion, distinguished as *slight*, or *moderate*. None of the earthquakes was *strong* or destructive.*

(4) Total duration.

(5) Duration of the preliminary tremor.

(6) Maximum range of motion in the preliminary tremor.

(7) ,, ,, ,, ,, principal portion.

(8) Remarks.

The preliminary tremor was in most cases quite sharply defined.

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* The intensity of the non-destructive earthquake motion is indicated as slight, moderate, or strong. A slight shock is one which is very feeble and just enough to be felt; a moderate shock is one whose motion is well-pronounced but not so severe as to cause general alarm; and a strong shock is one which is sufficiently intense to cause people to run out of doors, to overturn furnitures, etc.

List of 487 Earthquakes observed on Mount Tsukuba in 1905.

(* denotes an *insensible* shock.)

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	January.						
	h m s		sec.	sec.	mm.	mm.	
1	4 30 30 a.m.	Slight.	106	16.4	0.010	0.082	
„	8 53 10 p.m.	Do.	26	14.2	—	0.013	
2	2 27 25 a.m.	*	37	11.3	—	0.006	
„	4 25 30 a.m.	*	31	8.2	0.007	0.014	
5	0 25 06 a.m.	Slight.	30	5.6	0.004	0.028	Accompanied by loud sound.
7	10 57 00 a.m.	Moderate.	64	9.9	0.013	0.033	
9	4 00 50 p.m.	*	29	9.4	—	0.009	Sound only perceived.
11	1 23 10 a.m.	*	23	8.7	—	0.011	Do.
13	11 25 30 a.m.	Slight.	23	6.0	0.006	0.044	Accompanied by sound.
14	1 09 00 p.m.	*	40	41.0	—	0.002	
„	5 38 30 p.m.	Moderate.	65	5.9	0.004	0.058	Accompanied by sound.
17	4 19 00 a.m.	Slight.	22	6.7	0.015	0.080	
„	10 59 20 a.m.	Do.	36	10.4	—	0.008	Accompanied by sound.
21	7 44 27 a.m.	Do.	35	5.9	—	0.011	Accompanied by loud sound.
„	5 29 00 p.m.	*	70	6.0	—	0.004	Sound only perceived.
22	2 53 00 a.m.	Slight.	78	13.1	0.008	0.026	
„	0 58 40 p.m.	*	16	8.1	—	0.039	
25	8 30 37 p.m.	Slight.	31	8.4	0.011	0.060	
26	1 55 15 p.m.	*	—	10.3	—	—	
„	4 02 30 p.m.	Moderate.	106	11.0	0.028	0.220	
„	5 19 28 p.m.	*	120	46.0	—	0.003	
„	7 14 10 p.m.	*	90	(?)	—	0.004	Origin distant.
27	9 23 10 p.m.	*	60	(?)	—	0.002	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in Prel. Tremor.	Max. Motion in Principal Portion	Remarks.
	January.						
	h m s		sec.	sec.	mm.	mm.	
28	1 48 30 a.m.	*	30	6.6	—	—	
	February.						
2	8 17 00 a.m.	*	133	63.0	—	0.010	
„	9 08 25 a.m.	Slight.	98	24.0	—	0.022	
4	0 54 30 a.m.	Do.	30	9.5	0.020	0.037	
5	3 58 00 p.m.	*	35	11.6	—	0.022	
6	5 21 00 a.m.	*	40	16.8	—	0.017	
7	11 33 00 a.m.	*	85	22.5	—	0.011	
„	2 46 45 p.m.	Moderate.	100	17.0	0.036	0.120	
„	8 49 05 p.m.	Slight.	20	0.0	—	0.072	Accompanied by loud sound.
11	7 05 30 a.m.	Moderate.	70	25.0	0.022	0.073	Accompanied by sound.
13	1 55 10 p.m.	Slight.	32	8.0	—	0.010	Do.
14	10 55 45 p.m.	Moderate.	140	18.5	0.001	0.047	Do.
15	10 13 00 a.m.	*	65	16.4	—	0.022	
„	5 29 30 p.m.	Slight.	66	7.1	0.011	0.038	Accompanied by sound.
„	9 12 00 p.m.	*	20	0.0	—	0.022	
17	2 06 40 a.m.	Slight.	21	0.0	—	—	Accompanied by sound.
„	3 27 25 a.m.	Do.	87	19.5	0.009	0.054	Do.
„	10 56 30 a.m.	*	14	8.0	—	0.016	Do.
„	5 14 25 p.m.	Slight.	72	5.7	0.013	0.076	Do.
„	6 44 30 p.m.	Moderate.	144	14.1	0.027	0.180	Do.
18	6 56 05 p.m.	Slight.	100	10.1	—	0.024	Do.
„	7 08 10 p.m.	*	36	13.2	—	—	Sound only perceived.
20	1 47 33 p.m.	Slight.	24	8.5	0.012	0.064	Accompanied by sound.
21	2 26 30 p.m.	*	44	0.0	—	—	Sound only perceived.
23	9 03 20 a.m.	*	46	6.0	—	—	Do.

Date.	Time of Occurrence	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in Prel. Tremor.	Max. Motion in Principal Portion.	Remarks.
	February.						
	h m s		sec.	sec.	mm.	mm.	
23	11 35 00 p.m.	*	24	9.2	0.004	0.010	
24	4 18 50 a.m.	Slight.	40	14.1	0.004	0.038	
25	2 45 00 a.m.	*	34	7.7	—	0.010	
„	3 13 00 a.m.	*	—	—	—	—	Only loud sound perceived.
„	6 44 15 a.m	Moderate.	47	14.3	0.017	0.098	Accompanied by sound.
„	0 54 00 p.m.	*	22	7.0	0.003	0.008	
27	1 19 45 a.m.	Slight.	59	12.1	0.009	0.036	Accompanied by sound.
	March.						
3	4 12 05 p.m.	*	53	6.0	0.004	0.012	
„	5 17 40 p.m.	*	20	7.1	—	0.014	
4	3 39 45 a.m.	Slight.	43	8.9	—	0.024	Accompanied by sound.
„	9 18 30 p.m.	Moderate	76	9.0	0.022	0.170	Do.
6	6 04 25 a.m.	Slight.	40	8.2	0.004	0.047	Accompanied by sound.
„	6 08 15 a.m.	Do.	65	8.8	0.004	0.060	Do.
8	7 04 00 a.m.	*	47	15.3	—	0.012	
9	3 33 00 a.m.	Slight.	183	14.6	0.024	0.057	Accompanied by sound.
12	8 19 30 a.m.	Do.	34	11.3	0.002	0.014	Do.
„	8 12 30 p.m.	Do.	21	6.2	0.020	0.043	Do.
14	4 10 45 p.m.	*	49	8.4	0.004	0.028	
„	7 16 40 p.m.	*	33	11.0	—	0.006	
16	1 06 11 p.m.	Slight.	41	9.4	0.024	0.044	Accompanied by sound.
18	1 09 35 p.m.	Do.	33	11.8	0.006	0.060	Do.
„	10 30 00 p.m.	Do.	27	7.0	—	0.039	Do.
19	11 11 30 p.m.	*	64	35.0	—	0.009	
21	2 58 20 a.m.	Slight.	63	7.8	—	0.021	Accompanied by sound.
„	10 57 25 a.m.	Do.	106	36.0	0.002	0.020	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	March.						
	h m s		sec.	sec.	mm.	mm.	
23	7 02 25 a.m.	*	67	15.0	—	0.013	
„	5 59 00 p.m.	Slight.	40	13.1	0.007	0.038	Accompanied by sound.
24	11 16 00 a.m.	*	31	14.2	—	0.009	
25	2 00 00 a.m.	*	52	19.6	—	0.006	
26	8 04 00 a.m.	Slight.	30	3.5	—	0.028	Accompanied by sound.
„	9 33 30 p.m.	*	18	5.2	0.002	0.039	
	April.						
3	7 50 00 p.m.	*	94	18.6	—	—	
6	9 29 10 p.m.	Moderate.	68	6.7	0.093	0.490	Loud sound heard toward S., 5 or 6 sec. before the shock. Houses were much shaken, and liquids thrown out. The rain gauge was displaced slightly toward SW.
„	11 33 40 p.m.	*	39	6.3	0.008	0.029	
10	0 25 30 a.m.	*	34	9.6	0.004	0.021	
11	3 44 40 a.m.	*	21	0.9	—	0.036	
12	7 23 10 a.m.		19	6.0	0.003	0.042	Sound only perceived.
13	0 37 25 p.m.	*	51	17.2	—	0.016	
„	6 02 40 p.m.	Slight.	70	9.0	0.018	0.064	Loud sound heard toward S. before the shock.
14	1 00 00 a.m.	*	21	7.3	—	0.011	
„	7 37 00 a.m.	Slight.	48	25.2	—	0.044	
17	3 11 05 a.m.	*	31	7.8	—	0.028	
„	7 13 00 p.m.	*	123	65.0	—	0.006	
9	1 02 00 a.m.	*	10	5.6	—	0.006	
„	5 29 00 a.m.	*	35	10.3	—	0.004	
20	8 45 30 a.m.	*	45	17.4	—	0.016	
21	1 28 00 a.m.	*	24	7.4	—	0.011	
„	11 07 30 p.m.	*	42	7.7	—	0.006	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion	
	April.						
	h m s		sec.	sec.	mm.	mm.	
22	3 34 00 a.m.	*	84	17.3	—	0.008	
24	1 04 00 a.m.	*	85	22.2	—	0.016	
„	5 15 02 a.m.	Moderate.	65	15.7	0.017	0.153	Accompanied by sound.
„	6 31 00 a.m.	Do.	60	11.6	0.024	0.094	Do.
25	3 42 00 a.m.	*	45	8.5	—	0.016	
27	0 31 00 p.m.	Slight.	18	5.4	0.004	0.021	Loud sound heard toward SW.
29	7 17 30 a.m.	*	Very Short.	0.0	—	—	The diagram consisted only of a single stroke.
30	9 34 10 a.m.	*	50	12.2	0.013	0.024	
„	7 37 30 p.m	Slight.	25	4.9	—	0.036	Preceded by loud sound, which was heard toward S. The principal portion of the diagram lasted only 3.5 sec.
	May.						
2	3 00 45 p.m.	*	58	9.8	—	0.016	
4	5 51 50 p.m.	*	11	0.0	—	0.014	
5	4 04 05 a.m.	*	28	8.7	—	Small.	
„	8 13 20 a.m.	*	30	9.0	—	0.010	
7	6 27 00 p.m.	*	40	10.6	—	0.004	
„	10 20 10 p.m.	*	39	6.1	—	0.016	
„	10 24 20 p.m.	*	100	35.0	—	Small.	
8	8 12 55 p.m.	Moderate.	80	19.0	—	0.051	Accompanied by sound.
9	2 54 10 a.m.	Do.	140	11.0	0.051	0.204	Loud sound heard toward S.
13	7 32 00 p.m.	*	31	7.9	—	0.004	
15	8 07 25 a.m.	Slight.	68	9.2	0.017	0.061	Accompanied by sound.
16	2 51 00 a.m.	*	52	8.3	—	0.029	
17	2 06 30 a.m.	*	130	62.0	—	0.013	
„	8 32 10 a.m.	*	30	6.2	—	0.011	
„	10 03 00 a.m.	Slight.	43	5.3	0.006	0.044	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	May.						
	h m s		sec.	sec.	mm.	mm.	
20	4 53 30 p.m.	*	95	49.3	—	0.016	
22	6 23 30 p.m.	*	30	8.9	0.008	0.024	
23	5 18 15 a.m.	*	23	6.1	0.006	0.028	
"	1 33 25 p.m.	*	20	7.4	—	0.028	
"	7 45 00 p.m.	*	70	12.3	—	0.014	
24	8 32 30 p.m.	Slight.	109	41.0	—	0.024	
25	1 29 30 a.m.	Do.	41	5.2	0.009	0.077	
26	2 00 25 a.m.	Do.	60	10.1	0.010	0.058	Accompanied by souud.
"	3 46 50 p.m.	Moderate.	107	19.4	0.043	0.160	Loud sound heard toward S., 3 sec. before the shock.
28	0 50 00 a.m.	*	17	—	—	Small.	
"	1 49 00 a.m.	*	18	—	—	"	
31	8 56 00 p.m.	*	65	12.0	0.002	0.011	
	June.						
2	1 17 50 p.m.	*	27	8.3	—	0.017	
3	0 44 30 a.m.	*	53	15.0	—	0.006	
"	11 21 30 a.m.	Slight.	53	8.8	0.004	0.016	Accompanied by sound.
4	8 45 30 a.m.	*	70	6.4	—	0.003	
5	8 43 30 a.m.	*	35	(?)	—	0.008	
"	10 01 30 a.m.	*	25	8.9	—	0.008	
6	0 40 00 a.m.	*	28	(?)	—	Small.	
"	0 43 00 a.m.	*	31	19.6	—	0.007	
"	1 13 00 a.m.	*	55	19.1	—	0.009	
"	1 18 00 a.m.	*	40	(?)	—	0.004	
6	1 49 00 a.m.	*	57	18.0	—	0.013	
"	2 04 00 a.m.	*	62	21.2	—	0.019	
"	2 25 00 a.m.	*	60	17.8	—	0.008	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	June.						
	h m s		sec.	sec.	mm.	mm.	
6	2 27 00 a.m.	*	60	?	—	Small.	
„	5 17 00 a.m.	*	58	20.3	—	0.009	
„	5 57 30 a.m.	Moderate.	54	7.0	0.013	0.106	Loud sound heard toward SW.
„	9 19 00 a.m.	*	8	?	—	Small.	
„	9 23 00 a.m.	*	27	?	—	0.009	
„	11 45 30 a.m.	*	10	?	—	Small.	
7	6 12 30 a.m.	Moderate	74	6.1	0.032	0.190	Loud sound heard toward SW.
„	2 39 50 p.m.	Do.	75	17.7	0.027	0.093	Loud sound heard toward SE.
„	2 41 05 p.m.	Slight.	91	17.2	0.027	0.083	
„	3 28 50 p.m.	*	10	?	—	Small.	
„	3 41 50 p.m.	*	7	?	—	„	
„	3 42 30 p.m.	*	—	18.3	—	0.008	
„	10 05 30 p.m.	*	40	16.7	—	0.031	
10	3 09 50 p.m.	Slight.	106	36.4	0.017	0.042	Accompanied by sound.
11	11 50 10 p.m.	Moderate.	49	5.6	0.066	0.220	Loud sound heard toward SW., 3 sec. before the shock.
12	5 17 30 p.m.	Do.	154	18.4	0.054	0.190	Sound heard toward S., 5 sec. before the shock, and ceased during the motion.
13	2 48 30 p.m.	*	95	29.0	—	Small.	
14	8 44 30 a.m.	*	28	11.1	—	0.012	
16	7 08 20 p.m.	*	20	?	—	Small.	Origin distant.
17	2 12 00 a.m.	*	20	7.7	—	0.007	
„	5 33 00 a.m.	*	30	?	—	Small.	Origin distant.
18	1 16 24 a.m.	Moderate.	100	13.2	0.023	0.190	Accompanied by sound.
„	2 15 30 a.m.	*	15	?	—	Small.	Origin distant.
„	3 33 15 a.m.	*	25	?	—	0.013	Do.
„	9 50 00 a.m.	*	10 ?	?	—	0.016	Do.
„	11 02 00 a.m.	*	5	?	—	0.021	The diagram consisted of a single stroke.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in Prel. Tremor	Max. Motion in Principal Portion	Remarks.
	June.						
	h m s		sec.	sec.	mm.	mm.	
19	6 38 30 a.m.	Slight.	18	6.6	—	0.027	Accompanied by sound.
20	5 31 00 a.m.	Do.	75	18.3	0.007	0.050	Do.
„	0 34 10 p.m	*	15	6.1	—	0.010	
„	0 37 40 p.m.	*	145	114.0	—	0.009	
26	1 23 00 a.m.	Slight.	55	16.0	0.012	0.056	Accompanied by sound.
„	1 38 20 p.m.	Do.	50	13.3	0.008	0.039	Loud sound heard toward S.
27	1 09 30 a.m.	*	160	54.0	0.007	0.039	
„	3 17 10 a.m.	Slight.	50	12.1	0.028	0.183	Accompanied by sound.
„	3 46 30 p.m.	*	35	9.9	—	0.006	
29	10 29 00 a.m.	Slight.	30	8.1	0.002	0.008	Accompanied by sound.
„	4 59 00 p.m.	*	20	7.1	0.002	0.007	
	July.						
2	10 58 00 p.m.	*	10	?	—	0.002	
3	4 43 00 p.m.	*	30	17.8	—	0.008	
„	11 14 20 p.m.	*	40	10.3	—	0.002	
4	6 58 20 p.m.	*	?	13.1	—	0.013	
5	2 08 30 a.m.	*	30	13.2	0.003	0.007	
„	9 00 30 a.m.	*	60	?	0.006	0.011	Origin distant.
„	2 37 10 p.m.	Slight.	40	10.1	0.003	0.010	Sound heard toward S.
7	1 21 25 a.m.	Moderate.	275	?	0.032	0.690	Origin distant. No sound.
„	1 26 00 a.m.	Slight.	95	32.0	0.012	0.071	
„	4 51 40 a.m.	*	35	?	—	0.010	Origin distant.
„	7 17 25 a.m.	Moderate.	225	62.0	0.077	0.170	Accompanied by sound.
„	9 06 30 a.m.	*	25	?	—	Small.	Origin distant.
„	10 19 00 a.m.	*	30	?	—	0.006	Do.
„	10 38 00 a.m.	*	100	60.0	0.006	0.011	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	July.						
	h m s		sec.	sec.	mm	mm.	
7	9 27 45 p.m.	*	50	9.9	—	0.016	
„	10 38 35 p.m.	*	70	?	—	0.013	Origin distant.
8	3 13 00 a.m.	*	70	37.5	—	0.014	
„	7 20 30 a.m.	*	20	?	—	Small.	Origin distant.
„	11 08 00 a.m.	*	50	23.0	—	0.018	
9	7 11 55 a.m.	Moderate.	160	29.3	0.050	0.150	Accompanied by weak sound.
„	7 21 30 a.m.	*	15	?	—	0.004	Origin distant.
„	11 23 00 a.m.	Slight.	45	9.1	—	0.049	Accompanied by loud sound.
10	2 49 20 a.m.	*	60	?	—	0.003	Origin distant.
„	7 55 00 a.m.	*	—	28.0	—	0.010	
11	4 55 00 a.m.	*	30	10.1	—	0.028	
„	6 18 25 a.m.	Slight.	105	22.5	0.012	0.048	Accompanied by sound.
12	0 38 25 a.m.	*	75	?	—	0.024	Origin distant.
„	0 41 00 a.m.	*	90	?	—	0.087	Do.
„	11 56 10 a.m.	*	21	4.7	0.002	0.004	Loud sound heard toward S.
13	5 05 15 a.m.	*	50	?	—	Small.	Origin distant.
„	1 53 00 p.m.	*	50	?	—	Do.	Do.
„	9 27 25 p.m.	*	40	?	—	0.004	Do.
14	6 02 30 a.m.	*	40	?	—	Small.	Do.
„	3 56 45 p.m.	*	75	18.2	—	0.011	
„	11 17 20 p.m.	*	—	9.5	—	0.003	
15	3 09 10 a.m.	Slight.	20	5.3	0.003	0.027	Accompanied by sound.
„	8 01 55 a.m.	Do.	60	11.5	0.004	0.033	Do.
„	7 07 30 p.m.	*	50	9.7	—	0.036	
16	3 38 25 p.m.	*	20	9.7	—	0.007	
„	4 08 30 p.m.	*	45	7.0	—	0.014	
19	3 27 30 a.m.	*	35	?	—	0.006	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion	
	July.						
	h m s		sec.	sec.	mm.	mm.	
19	5 03 12 p.m.	Moderate.	70	9.3	0.022	0.120	
,,	6 39 00 p.m.	*	40	?	—	Small.	Origin distant.
20	4 33 15 a.m.	Slight.	25	5.7	—	0.022	Accompanied by sound.
,,	5 35 20 a.m.	Do.	15	8.0	0.002	0.061	Do.
,,	11 54 00 a.m.	Do.	30	4.4	0.027	0.082	Sound heard toward SW. before the shock.
,,	5 49 10 p.m.	Slight.	55	?	—	0.028	
21	6 03 00 a.m.	*	75	10.9	—	0.039	
22	6 15 10 p.m.	*	70	28.0	—	0.007	
,,	11 56 30 p.m.	*	26	?	—	Small.	Origin distant.
23	5 25 30 p.m.	Slight.	85	25.0	—	0.056	Accompanied by sound.
,,	6 27 00 p.m.	Do.	40	19.7	—	0.051	Do.
,,	7 00 20 p.m.	Moderate.	105	19.0	0.031	0.107	Sound heard toward S.
24	6 11 05 a.m.	*	60	?	—	Small.	Origin distant.
25	3 09 30 a.m.	*	45	?	—	0.017	Do.
26	0 49 20 a.m.	*	60	20.0	—	0.008	
,,	1 04 30 a.m.	*	60	11.4	—	0.007	
,,	4 30 07 a.m.	Slight.	55	6.2	0.016	0.073	Loud sound heard toward SW.
,,	2 40 35 p.m.	Do.	65	16.0	—	0.022	
,,	4 16 30 p.m.	*	60	20.5	—	0.028	
27	1 38 15 a.m.	Moderate.	100	7.9	0.039	0.340	Accompanied by loud sound.
,,	2 09 30 p.m.	*	35	?	—	0.006	Origin distant.
29	4 57 30 a.m.	*	60	?	—	0.016	Do.
,,	6 05 45 a.m.	Slight.	30	6.9	—	0.060	Loud sound heard toward SW., before the shock.
30	3 36 00 a.m.	*	90	58.0	—	0.007	
,,	1 27 15 p.m.	*	?	32.5	—	Small.	
,,	10 46 00 p.m.	*	30	?	—	Do.	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	August.						
	h m s		sec.	sec.	mm.	mm.	
1	8 08 30 a.m.	*	20	8.3	—	0.006	
2	4 24 30 a.m.	*	40	?	—	Small.	Origin distant.
,,	2 17 50 p.m.	*	40	?	—	Do.	Do.
4	3 40 00 a.m.	*	95	30.0	0.008	0.018	
,,	8 51 30 a.m.	*	85	30.0	0.008	0.024	
,,	9 02 00 a.m.	*	60	30.0	—	Small.	
5	2 29 30 p.m.	*	45	—	—	Do.	Origin distant.
6	9 19 00 a.m.	*	40	?	—	0.006	
,,	6 28 40 p.m.	*	50	12.2	—	0.006	
9	5 17 20 a.m.	Slight.	45	16.2	0.003	0.076	Accompanied by sound.
10	6 26 10 p.m.	*	55	15.7	—	0.012	
,,	9 00 45 p.m.	*	50	?	—	Small.	Origin distant.
11	0 19 25 a.m.	*	110	23.6	0.011	0.028	
12	9 27 30 p.m.	Slight.	40	8.3	—	0.039	Accompanied by sound.
15	9 23 30 a.m.	*	60	?	—	Small.	Origin distant.
,,	10 40 30 a.m.	*	140	69.0	—	0.011	
,,	5 12 50 p.m.	*	100	?	—	0.009	Origin distant.
,,	5 37 10 p.m.	*	100	?	—	Small.	Do.
16	7 47 21 a.m.	*	50	19.4	—	0.003	
,,	9 02 51 a.m.	*	80	27.0	—	0.011	
17	9 37 10 p.m.	*	80	30.0	—	0.030	
18	1 08 48 a.m.	Slight.	90	9.0	0.008	0.053	Accompanied by sound.
,,	10 51 38 a.m.	*	60	19.0	—	0.006	
20	0 47 40 a.m.	Slight.	10	2.5	—	0.022	Accompanied by loud sound. The diagram consisted almost only of a single stroke.
21	2 28 37 a.m.	*	40	?	—	0.002	
22	11 32 07 p.m.	*	90	35.0	—	0.006	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Dura-tion.	Dura-tion of Prel. Tremor.	Max. Motion in Prel. Tremor.	Max. Motion in Principal Portion.	Remarks.
	August.						
	h m s		sec.	sec.	mm.	mm.	
23	2 03 42 p.m.	*	35	?	—	Small.	Origin distant.
„	11 45 57 p.m.	*	30	6.7	0.002	0.004	
24	1 33 55 a.m.	Slight.	55	13.3	0.003	0.031	
„	3 01 17 a.m.	*	40	?	—	0.003	Origin distant.
„	0 05 38 p.m.	Moderate.	75	6.3	0.044	0.780	Loud sound heard toward S.
25	6 49 10 p.m.	Slight.	235	99.0	0.061	0.097	Accompanied by sound.
26	3 52 10 p.m.	Do.	26	6.7	0.002	0.009	Do.
„	4 18 00 p.m.	*	30	?	—	Small.	Origin distant.
„	5 33 10 p.m.	*	30	?	—	Do.	Do.
27	3 40 56 p.m.	*	70	?	—	0.020	Origin distant.
28	4 10 00 a.m.	*	80	?	—	0.014	Do.
„	8 56 00 a.m.	*	40	?	—	0.002	Do.
29	1 27 30 a.m.	Slight.	60	8.4	—	0.028	Accompanied by sound.
„	3 04 28 a.m.	*	30	14.5	—	0.004	
„	1 23 57 p.m.	*	30	?	—	Small.	Origin distant.
„	7 51 54 p.m.	*	55	25.0	—	0.007	
„	7 55 35 p.m.	Slight.	40	9.6	—	0.018	
30	1 15 42 a.m.	*	30	7.9	—	0.009	
„	9 27 02 a.m.	*	40	23.0	—	Small.	
31	7 40 15 a.m.	*	40	9.7	—	0.006	
„	1 17 46 p.m.	Slight.	55	8.8	—	0.030	Accompanied by sound.
„	1 35 45 p.m.	*	50	12.5	—	0.017	
	September.						
1	9 39 44 a.m.	Slight.	95	40.0	—	0.022	Accompanied by sound.
„	11 48 30 a.m.	Moderate.	220	79.0	0.032	0.150	Sound heard toward S.
2	0 53 23 a.m.	*	120	36.0	—	0.013	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in Prel. Tremor	Max. Motion in Principal Portion	Remarks.
	September.						
	h m s		sec.	sec.	mm.	mm.	
2	3 35 12 p.m	*	20	?	—	Small.	Origin distant.
„	3 48 25 p.m.	*	110	34.3	0.002	0.017	
„	4 26 30 p.m.	Moderate.	90	13.1	0.006	0.094	Loud sound heard toward S.
„	7 05 10 p.m.	*	70	12.3	—	0.016	
3	2 03 20 a.m.	Moderate.	140	10.6	0.012	0.150	Sound heard toward S.
4	7 32 30 a.m.	Slight.	30	6.9	—	0.006	Accompanied by sound.
„	8 49 35 a.m.	Do.	70	9.2	0.003	0.044	Do.
6	1 02 00 a.m.	*	60	?	—	0.007	Origin distant.
8	0 01 12 a.m.	*	60	?	—	0.002	Do.
9	11 35 17 p.m.	*	40	?	—	0.010	Do.
10	4 54 21 a.m.	*	40	?	—	0.004	Do.
11	4 38 38 p.m.	*	90	30.0	—	0.010	
„	7 52 10 p.m.	*	30	?	—	Small.	Origin distant.
„	10 16 20 p.m.	*	20	?	—	Do.	Do.
12	10 03 45 a.m.	*	20	?	—	Do.	Do.
„	11 36 25 a.m.	*	—	8.3	—	0.002	
13	5 36 15 p.m.	Slight.	70	7.4	0.003	0.017	Accompanied by loud sound.
14	2 44 05 a.m.	Do.	25	6.8	0.003	0.022	Accompanied by sound.
„	8 36 50 p.m.	*	50	8.4	—	0.003	
15	1 21 25 a.m.	*	40	?	—	0.002	Origin distant.
„	2 13 35 p.m.	Slight.	50	12.0	0.002	0.022	Accompanied by sound.
16	6 35 30 a.m.	*	40	14.6	—	0.002	
17	3 54 01 a.m.	*	60	?	—	0.004	Origin distant.
„	4 34 43 a.m.	*	30	?	—	0.003	Do.
„	4 58 54 p.m.	*	40	17.6	—	0.004	
„	9 03 00 p.m.	*	80	32.8	—	0.003	
„	9 46 30 p.m.	*	30	9.3	—	Small.	

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in Prel. Tremor	Max. Motion in Principal Portion	Remarks.
	September.						
	h m s		sec.	sec.	mm.	mm.	
18	10 17 20 a.m.	*	80	21.0	—	0.018	
,,	9 01 45 p.m.	*	120	39.0	—	0.006	
19	10 48 00 a.m.	*	60	?	—	0.007	Origin distant.
,,	10 38 30 p.m.	*	30	7.8	—	0.010	
20	4 22 10 p.m.	Slight.	65	8.4	0.002	0.038	Loud sound of some duration heard toward S.
21	9 58 40 p.m.	*	40	?	—	0.002	Origin distant.
,,	10 00 55 p.m.	Moderate.	120	9.7	0.250	0.860	No sound.
22	11 45 30 a.m.	*	70	?	—	0.011	Origin distant.
,,	6 07 25 p.m.	*	120	40.2	0.006	0.024	
23	3 34 10 a.m.	*	25	10.0	—	0.002	
,,	3 42 25 a.m.	*	25	?	—	0.004	Origin distant.
,,	11 21 30 a.m.	*	30	?	—	0.007	Do.
,,	4 42 30 p.m.	*	25	?	—	0.002	Do.
24	2 08 40 a.m.	Moderate.	85	7.8	0.031	0.210	Sound heard toward SW.
25	9 16 28 p.m.	Slight.	Short.	0.0	—	0.022	Accompanied by sound.
26	3 25 36 p.m.	Do.	70	9.0	0.017	0.056	Loud sound heard toward SW.
27	9 47 28 p.m.	*	120	24.0	0.006	0.025	
29	7 22 00 p.m.	Slight.	25	5.8	0.002	0.007	Accompanied by sound.
30	8 44 55 p.m.	*	70	?	—	0.014	Origin distant.
	October.						
1	6 18 00 a.m.	Slight.	25	7.6	—	0.013	
2	7 47 10 a.m.	*	40	6.6	—	0.006	
,,	10 56 20 a.m.	Moderate.	160	10.0	0.097	0.580	
3	2 53 45 a.m.	Slight.	35	10.6	—	0.002	
,,	4 12 25 p.m.	Do.	35	8.6	—	0.036	Accompanied by loud sound.
,,	7 50 46 p.m.	Do.	60	9.1	0.014	0.026	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in Prel. Tremor.	Max. Motion in Principal Portion.	Remarks.
	October.						
	h m s		sec.	sec	mm.	mm.	
4	8 15 55 a.m.	*	Long.	—	—	—	Origin distant.
„	2 40 55 p.m.	Slight.	Short.	Short.	—	—	Accompanied by loud sound.
5	1 56 44 a.m.	*	60	14.7	—	0.017	
6	8 51 40 p.m.	Slight.	25	5.9	—	0.007	Accompanied by loud sound.
8	6 11 10 a.m.	*	50	18.0	—	0.002	
10	5 10 55 a.m.	*	180	88.0	0.007	0.017	
„	10 54 10 a.m.	Moderate	145	9.2	0.061	0.430	Loud sound heard toward S.
„	11 10 55 a.m.	Slight.	30	?	—	0.020	
„	1 49 20 p.m.	Do.	60	?	—	0.039	Origin distant.
„	2 08 00 p.m.	Dp.	240	95.0	0.011	0.076	
„	2 28 20 p.m.	Do.	90	?	—	0.056	Origin distant.
„	2 36 10 p.m.	*	90	?	—	0.017	Do.
„	2 58 50 p.m.	*	120	?	—	0.020	Do.
„	3 22 10 p.m.	*	60	?	—	0.038	Do.
„	4 52 30 p.m.	*	40	?	—	Small.	Do.
„	8 51 15 p.m.	Slight.	90	39.0	—	0.038	Loud sound heard toward S.
„	9 34 35 p.m.	*	70	1.14	—	0.011	
„	9 46 40 p.m.	*	60	23.4	—	Small.	
11	9 13 05 a.m.	*	70	?	—	Do.	Origin distant.
„	3 43 18 p.m.	*	60	16.0	—	0.011	
12	8 06 00 a.m.	*	40	10.0	—	0.004	
13	9 27 15 p.m.	*	40	?	—	Small.	Origin distant.
14	11 54 20 a.m.	Moderate.	80	5.7	0.044	0.240	Accompanied by sound.
„	4 33 05 p.m.	Slight.	Short.	10.0	—	0.018	
15	6 46 35 a.m.	Do.	60	12.0	—	0.030	Accompanied by sound.
16	0 34 27 p.m.	*	60	15.1	—	0.011	
„	4 20 55 p.m.	*	60	?	—	Small.	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	October.						
	h m s		sec.	sec.	mm.	mm.	
17	1 21 00 p.m.	*	40	?	—	0.006	Origin distant.
,,	4 52 10 p.m.	*	30	?	—	0.033	Do.
18	4 59 45 a.m.	*	40	?	—	0.003	Do.
,,	5 00 50 a.m.	*	50	10.0	—	0.006	
,,	5 04 55 a.m.	*	50	9.3	—	0.002	
,,	9 54 05 p.m.	*	70	10.2	—	0.013	
19	9 10 20 a.m.	Moderate.	85	9.8	0.060	0.120	Accompanied by sound.
,,	9 04 20 p.m.	*	50	?	—	0.004	Origin distant.
20	2 43 30 a.m.	*	60	?	—	0.017	Do.
,,	1 42 10 p.m.	*	40	?	—	0.004	Do.
,,	2 16 00 p.m.	*	90	43.0	—	0.011	
22	9 38 10 a.m.	*	75	?	—	0.018	Origin distant.
,,	9 39 55 a.m.	*	60	?	—	0.018	Do.
,,	11 42 30 a.m.	*	85	?	—	0.028	Do.
,,	11 43 35 p.m.	*	60	14.4	—	0.031	
23	6 00 00 p.m.	*	40	8.9	—	0.012	
24	0 48 10 p.m.	Moderate.	180	50.0	0.008	0.058	
25	11 12 40 p.m.	*	100	?	—	0.004	Origin distant.
26	6 01 50 a.m.	*	90	?	—	0.003	Do.
27	1 29 25 a.m.	*	60	?	—	0.003	Origin distant.
28	6 47 15 p.m.	*	60	?	—	0.013	Do.
30	7 36 00 a.m.	*	60	8.3	0.006	0.013	
,,	11 32 30 p.m.	*	60	?	—	0.003	Origin distant
31	1 02 40 p.m.	*	35	10.4	—	0.003	
	November.						
1	2 01 50 p.m.	Moderate.	180	?	—	0.140	No sound. Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	November.						
	h m s		sec.	sec	mm.	mm.	
1	2 11 15 p.m.	Slight.	60	?	—	0.007	Accompanied by sound.
,,	3 35 10 p.m.	*	70	?	—	0.007	Origin distant.
,,	7 46 45 p.m.	Slight.	50	10.9	—	0.012	Accompanied by sound.
2	11 22 48 a.m.	Moderate.	110	12.9	0.073	0.190	No sound.
4	8 36 10 a.m.	Do.	80	11.4	0.019	0.120	Accompanied by sound.
5	2 12 40 a.m.	*	40	13.0	—	0.011	
,,	3 32 50 p.m.	*	40	8.4	—	0.010	
8	11 11 20 p.m.	*	60	8.6	0.011	0.030	
9	5 56 00 a.m.	*	70	?	—	0.011	Origin distant.
,,	7 19 50 p.m.	*	70	?	—	0.011	Do.
10	7 34 00 p.m.	Slight.	15	6.6	0.002	0.019	Accompanied by sound.
11	3 41 25 a.m.	*	60	19.7	—	0.018	
,,	7 25 35 p.m.	Slight.	60	19.5	—	0.027	Accompanied by sound.
12	1 52 00 a.m.	Do.	80	10.6	0.007	0.071	Do.
,,	8 53 10 a.m.	Do.	60	18.9	—	0.039	
16	10 28 30 p.m.	*	60	?	—	0.006	Origin distant.
19	0 49 50 a.m.	*	85	37.5	—	0.007	
,,	2 51 24 a.m.	Slight.	50	4.5	0.003	0.044	Accompanied by loud sound.
,,	6 08 05 p.m.	Do.	30	2.2	—	0.007	,, ,, sound.
20	8 19 55 a.m.	*	45	16.0	—	0.007	
22	1 02 00 a.m.	*	25	—	—	—	
,,	4 27 50 a.m.	*	60	—	—	—	
23	0 04 00 a.m.	*	30	—	—	—	
,,	0 11 00 a.m.	*	120	50.0	—	—	
,,	7 30 10 a.m.	*	85	—	—	—	
,,	3 34 20 p.m.	*	80	—	—	—	
24	6 31 20 a.m.	Slight.	50	15.9	—	0.050	Accompanied by sound.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	November.						
	h m s		sec.	sec.	mm.	mm.	
24	8 29 00 p.m.	Slight.	35	12.8	—	0.041	Accompanied by loud sound.
26	6 16 20 p.m.	Do.	70	11.1	0.006	0.044	„ „ sound.
27	0 34 10 p.m.	Do.	150	31.3	0.007	0.037	Do.
28	6 02 10 p.m.	Do.	40	8.3	—	0.018	Do.
29	8 05 10 a.m.	*	50	11.4	—	0.014	
„	11 45 55 p.m.	*	30	?	—	Small.	Origin distant.
30	10 31 00 p.m.	*	50	13.7	—	0.003	
	December.						
2	2 15 45 p.m.	Slight.	85	24.0	—	0.028	Accompanied by sound.
„	11 27 10 p.m.	*	55	9.9	—	0.016	
3	1 40 45 a.m.	*	60	9.8	—	0.020	
„	0 40 55 p.m.	Slight.	80	17.2	—	0.022	Accompanied by sound.
„	1 46 40 p.m.	Do.	140	29.0	0.014	0.061	
„	9 02 20 p.m.	Do.	30	6.2	—	0.003	Accompanied by sound.
5	1 07 10 a.m.	*	35	9.5	—	0.002	
„	1 20 40 a.m.	*	100	23.0	0.007	0.032	
„	4 38 45 a.m.	*	120	52.0	—	0.010	
6	10 20 10 p.m.	*	70	23.2	—	0.006	
„	11 09 40 p.m.	*	35	11.2	—	0.013	
7	6 39 10 a.m.	Slight.	80	7.1	—	0.049	Accompanied by sound.
„	6 47 55 a.m.	*	40	7.3	—	0.013	
8	11 40 15 a.m.	*	60	11.0	—	0.010	
9	8 14 50 p.m.	Slight.	45	8.1	0.003	0.013	Sound heard toward S.
11	5 29 10 a.m.	*	80	22.4	—	0.010	
„	11 06 15 a.m.	*	60	?	—	Small.	Origin distant.
„	11 39 25 a.m.	*	75	?	—	0.006	Do.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor	Principal Portion.	
	December.						
	h m s		sec.	sec.	mm.	mm.	
11	2 41 20 p.m.	*	30	?	—	Small.	Origin distant.
12	5 01 45 a.m.	*	25	6.9	—	0.006	Sound only perceived.
14	5 48 30 p.m.	Slight.	50	8.4	—	0.016	Accompanied by sound.
16	11 25 36 a.m.	Do.	70	11.8	—	0.077	
"	1 26 50 p.m.	*	80	15.8	—	0.006	
17	10 58 00 a.m.	Slight.	70	9.4	—	0.004	
"	8 24 15 p.m.	*	50	8.0	—	0.011	
18	1 04 50 p.m.	*	Short.	Short.	—	Small.	Loud sound was perceived.
"	7 56 00 p.m.	*	Do.	Do.	—	Do.	Do.
19	4 10 30 a.m.	*	80	?	—	0.004	Origin distant.
21	2 09 20 a.m.	Slight.	45	6.7	—	0.010	Accompanied by sound.
"	5 20 30 a.m.	Do.	30	?	—	Small.	Origin distant.
"	8 16 08 a.m.	Do.	100	8.0	—	0.033	
23	7 57 40 a.m.	*	60	14.1	—	0.007	
"	11 38 05 a.m.	Moderate.	195	33.6	0.017	0.160	Accompanied by sound.
24	4 29 30 p.m.	*	50	17.5	—	0.010	
25	6 19 40 p.m.	Slight.	50	8.4	—	0.007	
"	6 42 50 p.m.	Do.	80	9.2	—	0.033	
26	3 40 20 a.m.	*	10	—	—	—	
"	6 45 00 a.m.	*	50	—	—	—	
"	11 04 20 a.m.	Slight.	35	7.0	—	—	
"	0 11 45 p.m.	Moderate.	240	12.0	—	0.188	Accompanied by sound.
"	2 38 25 p.m.	*	20	—	—	—	
"	7 10 20 p.m.	*	40	—	—	—	
27	0 50 50 p.m.	*	60	21.8	—	0.010	
"	9 06 30 p.m.	*	50	?	—	0.007	
28	2 03 25 a.m.	*	40	?	—	0.008	Origin distant.

Date.	Time of Occurrence.	Intensity.	Total Duration.	Duration of Prel. Tremor.	Max. Motion in		Remarks.
					Prel. Tremor.	Principal Portion.	
	December.						
	h m s		sec.	sec.	mm.	mm.	
28	4 03 40 p.m.	*	120	52.0	—	0.022	
29	6 59 30 p.m.	*	40	?	—	Small.	Origin distant.
,,	7 02 40 p.m.	*	20	?	—	Do.	Do.
30	7 52 10 p.m.	*	80	9.6(?)	—	0.030	Do.

Typical Diagrams. Typical diagrams are reproduced in Pls. I to V, as follows.

Plate.	Figure.	Date.	Time of Occurrence.	Intensity.	Remarks.
Sharp Local Earthquakes.					
I	1	April 6	h m s 9 29 10 p.m.	Moderate.	Loud sound heard 5 or 6 sec. before the shock.
	2	July 27	1 38 15 a.m.	Do.	Accompanied by loud sound.
	3	June 11	11 50 10 p.m.	Do.	Do.
	4	„ 7	6 12 30 a.m.	Do.	Do.
	5	„ 27	3 17 10 a.m.	Slight.	Accompanied by sound.
Large Earthquakes.					
II	6	September 21	10 00 55 p.m.	Moderate.	No sound.
	7	October 2	10 56 20 a.m.	Do.	Do.
Small Local Shocks.					
III	8	September 2	4 26 30 p.m.	Moderate.	Accompanied by loud sound.
	9	April 6	11 33 40 p.m.	Unfelt.	
	10	May 26	2 00 25 a.m.	Slight.	Accompanied by sound.
	11	September 20	4 22 10 p.m.	Do.	„ loud sound.
	12	October 2	7 47 10 a.m.	Unfelt.	
	13	September 19	10 38 30 p.m.	Do.	
Earthquakes of some Distant Origin. (a)					
IV	14	July 7	1 21 25 a.m.	Moderate.	No sound.
	15	November 1	2 01 50 p.m.	Do.	Do.
	16	June 12	5 17 30 p.m.	Do.	Sound heard 5 sec. before the shock.
	17	May 26	3 46 50 p.m.	Do.	Loud sound heard 3 sec. before the shock.
	18	October 10	1 49 20 p.m.	Slight.	

Plate.	Figure.	Date.	Time of Occurrence.	Intensity.	Remarks.
			Earthquakes of some Distant Origin. (*b*)		
	19	July 7	h m s 7 17 25 a.m.	Moderate.	Accompanied by sound.
	20	August 25	6 49 10 p.m.	Slight.	Do.
	21	June 7	{ 2 39 50 p.m. { 2 40 20 ,,	{ Moderate. { Slight.	Accompanied by loud sound.
V	22	July 7	10 38 00 a.m.	Unfelt.	
	23	October 10	5 10 55 a.m.	Do.	
	24	June 27	1 09 30 a.m.	Do.	
	25	September 2	3 48 25 p.m.	Do.	

The characteristics of a sharp local shock are the shortness of the duration of the preliminary tremor, and the occurrence of the maximum vibration of the latter and the principal portion at the commencement of each of the respective phases. In the cases of the four *moderate* earthquakes of April 6, July 27, and June 11 and 7, (Figs. 1 to 4, Pl. I), which were each accompanied or preceded by a loud sound, the duration of the preliminary tremor varied between 5.6 and 7.9 sec., the maximum double amplitude in the principal portion being 0.190 to 0.490 mm. In the *slight* earthquake of June 27 (Fig. 5, Pl. I), the duration of the preliminary tremor was 12.1 sec., the maximum motion being 0.183 mm.

The two earthquakes of Sept. 21 and Oct. 2, (Figs. 6 and 7, Pl. II), which were larger than those above mentioned were, according to the report of the observers, not accompanied by sound.

Of the six small local shocks whose diagrams are given in Pl. III, that on Sept. 2, (Fig. 8), was accompanied by loud sound and was moderate in intensity, although its maximum motion was only 0.094 mm; the preliminary tremor having lasted 13.1 sec.

The *slight* earthquakes on May 26 and Sept. 20, (Figs. 10 and 11), were also accompanied by sound, which was loud in the case of the second shock. Of the remaining three insensible earthquakes, (Figs. 9, 12, and 13), those on Oct. 2 and Sept. 19 were extremely small.

Of the four *moderate* earthquakes (PL. VI), whose origins were at some distance from Tsukuba, those on July 7 and Nov. 1, (Figs. 14* and 15), are reported as having been accompanied by no sound. The other two shocks, which happened on June 12 and May 26, were each preceded by loud sound. The slight earthquake on Oct. 10 (Fig. 18) was similar to, but much smaller than, that on May 26 (Fig. 17).

The diagram of the earthquake of July 7 (Fig. 19), which was accompanied by sound, presents an appearance of two shocks happening in succession, the motion being comparatively large in the preliminary tremor, which was of a long duration and lasted 62 sec. In fact, this earthquake has been reported by the observers at Tsukuba as two distinct ones, whose intensities were *slight* and *moderate* respectively. The diagram of the earthquake of Aug. 25 (Fig. 20), indicates the similar peculiarity still more markedly; the motion in the preliminary tremor, which lasted 99 sec., being not much smaller than that in the principal portion. This earthquake was also reported as two separate ones, each of which was *slight* and was accompanied by sound. The latter circumstance is very interesting, as it gives support to the view that the earthquake sound occurs not only in the preliminary tremor, but also in the principal portion. The two unfelt earthquakes on July 7 and Oct. 10, (Figs. 22 and 23), are much similar in character to

* The zero-position of the recording pointer of the instrument suffered some displacement during the shaking.

the two shocks above mentioned. Fig. 21 represents, on the other hand, a case of two really distinct earthquakes one of which was *moderate* and the other *slight*, happening in quick succession. Finally, the two earthquakes on June 27 and Sept. 2 are examples of shocks of somewhat distant origin, whose preliminary tremor is small.

Duration of the preliminary tremor. The relative frequencies of the different lengths of the duration of preliminary tremor less than 40 sec., measured in the cases of 329 earthquakes, were as shown in the following table

Duration of Prel. Tremor.	Number of Earthquakes.	Duration of Prel. Tremor.	Number of Earthquakes.
sec. sec.		sec. sec.	
0.0—0.9	9	20.0—20.9	3
1.0—1.9	0	21.0—21.9	3
2.0—2.9	2	22.0—22.9	4
3.0—3.9	2	23.0—23.9	6
4.0—4.9	4	24.0—24.9	3
5.0—5.9	15	25.0—25.9	4
6.0—6.9	29	26.0—26.9	0
7.0—7.9	24	27.0—27.9	1
8.0—8.9	36	28.0—28.9	2
9.0—9.9	35	29.0—29.9	3
10.0—10.9	21	30.0—30.9	5
11.0—11.9	18	31.0—31.9	1
12.0—12.9	13	32.0—32.9	3
13.0—13.9	11	33.0—33.9	1
14.0—14.9	11	34.0—34.9	1
15.0—15.9	8	35.0—35.9	3
16.0—16.9	9	36.0—36.9	3
17.0—17.9	11	37.0—37.9	2
18.0—18.9	9	38.0—38.9	0
19.0—19.9	12	39.0—39.9	2

The number of cases, in which the duration of the preliminary tremor was over 40 sec., is 24, as follows:—

Duration of the Prel. Tremor.	40 sec.	58 sec.
	40.2	60
	41	62
	41	62
	43	63
	46	65
	49.3	69
	50	79
	50	88
	52	95
	52	99
	54	114

As graphically illustrated in Fig. 26, Pl. VI, the duration of the preliminary tremor most frequently occurring was between 6 and 10 sec., the number of the corresponding earthquakes being equivalent to the two-thirds of all the others. The relation between the duration of the preliminary tremor and the corresponding frequency of earthquakes will be of course different for different places of observation.

Number of sensible shocks. The total number of the sensible shocks was 171, while that of mere sounds (not accompanied by perceptible earth movement) was 12, as follows.

Month.	Sensible and Insensible Eqkes.	Number of		
		Sensible Eqkes.	Mere Sounds.	Sensible Eqkes, accompanied by Sound.
I	24	12	2	10
II	31	17	5	18
III	24	14	0	13
IV	26	7	1	7
V	27	8	0	5
VI	50	15	0	14
VII	67	21	1	17
VIII	48	11	0	9
IX	49	15	0	14
X	57	18	0	9
XI	35	16	0	13
XII	49	17	3	12
Sum	487	171	12	141

Thus the number of the sensible earthquakes, (including the cases of mere sounds), was 183, so that such shocks occurred at Tsukuba on the average once nearly every two days. The number of the insensible shakings was 304.

Earthquake sounds. At Tsukuba, earthquake sounds are perceived very often, which may be likend to the noises of distant thunders or of a wagon passing over a wooden bridge, those like the rushing of winds being comparatively rare. The monthly numbers of the sensible shocks accompanied by sound, including the cases of sounds without sensible motion, are given in the last column of the above table. From the latter it will be seen that earthquake sounds occurred in 141 cases, or in 77% out of the 183 sensible shocks. It is possible that all of the latter, or nearly so, are found to be accompanied by more or less sound, when very attentively observed.

There were 27 cases, in which the direction of the sound was noted, as follows:—

Sound heard toward the South	....	17 cases.
,, South-West	......	9 ,,
,, South-East	....	1 ,,

The resultant, or mean, direction was thus South-West by South. That the sounds were perceived as coming from this quarter may be due to the fact that the lower part of the southern slope of the mountain, where the town of Tsukuba is situated, is horse-shoe shaped and opens in the same direction to the low plane.

In a majority of cases the sound was first perceived, followed immediately or a few seconds later by the tremblings of the ground, as in the following examples.

Eqke of May 26....... { Duration of Prel. tremor=19.4 sec.
Sound heard 3 sec. before the shock.

Eqke of June 12....... { Duration of Prel. tremor=18.4 sec.
Sound heard 5 sec. before the shock.

It is probable that the commencement of the sound is generally at the same instant as that of the preliminary tremor, whose earlier part may often be insensible while the sound is perceptible. This explanation can not, however, be applied to the following two cases, provided the report of the observers be accurate:—

Eqke of April 6....... { Duration of Prel. tremor=6.7 sec.
Sound heard 5 or 6 sec. before the shock.

Eqke of June 11....... { Duration of Prel. tremor=5.6 sec.
Sound heard 3 sec. before the shock.

In each of these two shocks, which were *moderate* in intensity, the motion at the commencement of the preliminary tremor was quite large and perfectly sudden. Hence it seems impossible that sound should be heard a few seconds prior to the arrival of the sensible motion, unless the vibrations of the ground giving rise to the sound phenomena form a sort of an *ultra* preliminary tremor and are so extremely minute that the seismograph used could give no visible trace. Such a supposition may not be entirely wrong, since there are cases of loud sounds hardly accompanied by any movement.

Earthquake sound and duration of preliminary tremor. The numbers of sensible earthquakes and of those accompanied by sounds, for the different lengths of the preliminary tremor, are given in the following table.

Duration of Prel. Tremor.	Total Number of Sensible Earthquakes=e.	Eqkes accompanied by Sound*=s	Ratio : $\frac{s}{e}$
(i) 0—5.0 sec.	18	18	100 %
(ii) 5.1—10.0	77	66	86
(iii) 10.1—15.0	35	28	80
(iv) 15.1—20.0	20	16	80
(v) 20.1—25 0	5	4	80
(vi) >25.1	18	10	56
Sum : (i) to (v)	155	132	85

(* Including the cases of mere sound.)

Thus it will be observed that the sensible earthquakes of near origin of the duration of the preliminary tremor under 5 sec., were invariably accompanied by sound. The percentage number of the more distant shocks remained practically constant for the duration of the preliminary tremor between 5 and 25 sec., varying only between 86 and 80%, with the mean value of 85%. Even for the earthquakes of the duration of the preliminary tremor over 25 sec., the sound was by no means uncommon, the frequency amounting to 56%.

Distant earthquakes accompanied by sounds. Among the 183 sensible earthquakes, there were ten, which were accompanied by sounds, and the duration of whose preliminary tremor was longer than 25 sec., as follows.

Date.		Intensity.	Duration of Prel. Tremor.	Maximum Motion.
			sec.	mm.
March	21	Slight.	36.0	0.020
June	10	Do.	36.4	0.042
July	7	Moderate.	62.0	0.173
Do.	9	Do.	29.3	0.150
August	25	Slight.	99.0	0.097
September	1	Do.	40.0	0.022
Do.		Moderate.	79.0	0.150
October	10	Slight.	39.0	0.038
November	27	Do.	31.3	0.037
December	23	Moderate.	33.6	0.160

In these 10 earthquakes, the duration of the preliminary tremor varied between 29.3 and 99.0 sec., which correspond respectively to the epicentral distances of about 250 and 760 km; the maximum (EW component) motion in the principal portion varying between 0.020 and 0.173 mm. It is probable that even an earthquake at an epicentral distance of 1,000 km is able, when of a sufficient intensity, to produce sound phenomena at Tsukuba or any other district composed of hard rocks.

Earthquakes accompanied by loud sound. There were 35 cases in which the shock was accompanied by loud sound. The elements of motion in these earthquakes, arranged according to the length of the duration of the preliminary tremor, were as in the following table; the maximum movements in the preliminary tremor and the principal portion being denoted by 2a′ and 2a respectively.

Date.		Duration of Prel. Tremor.	Intensity.	Max. Motion in Prel. Tremor =2a′	Max. Motion in Princ. Portion =2a
		sec.		mm.	mm.
Jan.	25	0.0	Unfelt	—	(No. motion indicated)
Feb.	7	0.0	Slight	—	0.072
Oct.	4	(short)	Do.	—	Small
,,	18	(Do.)	Unfelt	—	Do.
,,	,,	(Do.)	Unfelt	—	Do.
Aug.	20	2.5	Slight	—	0.022
Oct.	3	3.6	Do.	—	0.036
Nov.	19	4.5	Do.	0.003	0.044
July	12	4.7	Unfelt	0.002	0.004
April	30	4.9	Slight	—	0.036
,,	27	5.4	Do.	0.004	0.021
Jan.	5	5.6	Do.	0.004	0.027
June	11	5.6	Moderate	0.066	0.230

Date.		Duration of Prel. Tremor.	Intensity.	Max. Motion in Prel. Tremor =2a′	Max. Motion in Princ. Portion =2a
		sec.		mm.	mm.
Oct.	6	5.9	Slight	—	0.007
June	7	6.1	Do.	0.032	0.190
July	26	6.2	Do.	0.016	0.073
Aug.	24	6.3	Moderate	0.044	0.770
April	6	6.7	Do.	0.093	0.490
July	29	6.9	Slight	—	0.060
June	6	7.0	Moderate	0.013	0.106
July	27	7.9	Do.	0 039	0.340
Sept.	13	7.4	Slight	0.003	0.017
,,	20	8.4	Do.	0.002	0.038
April	13	9.0	Do.	0.018	0.064
Sept.	26	9.0	Do.	0.017	0.056
July	9	9.1	Do.	—	0.049
Oct.	3	9.1	Do.	0.014	0.026
,,	10	9.2	Moderate	0.061	0.430
May	9	11.0	Do.	0.051	0.204
Nov.	24	12.8	Slight	—	0.041
Sept.	2	13.1	Moderate	0.006	0.094
June	26	13.3	Slight	0.008	0.039
,,	7	17.7	Moderate	0.027	0.093
May	26	19.4	Do.	0.043	0.160
Oct.	10	39.0	Slight	—	0.038

Thus it will be seen that loud sounds occurred most frequently in the earthquakes, whose preliminary tremor lasted less than about 9 or 10 sec., corresponding to an epicentral distance of about 100 km. In three cases, the duration of the preliminary tremor was much longer, being from 17.7 to 39.0 sec. Again, of the 35 earthquakes tabulated above, 10 were *moderate*, 21 were *slight*, and the remaining 4 were unfelt shocks; each of the last having a very short preliminary tremor or apparently none whatever. The maximum motion in the preliminary tremor (=2a′) varied between 0.002 and 0.093 mm, and that in the principal portion (=2a) between 0.004 and 0.770 mm.* It is thus seen that the intensity of motion is not a necessary factor in the production of the sound phenomena, although a violent earthquake will always be accompanied by a very loud sound.

Ratio of maximum motion in preliminary tremor to that in principal portion. The maximum movements in the preliminary tremor and principal portion of the 7 sharp local shocks, whose diagrams are given in Pls. I and II, were as follows.

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor =2a′.	Max. Motion in Princ. Portion =2a.	Ratio : $\frac{2a}{2a'}$
		sec.	mm.	mm.	
April	6	6.7	0.093	0.490	5.3
July	27	7.9	0.039	0.340	8.7
June	11	5.6	0.066	0.220	3.3
,,	7	6.1	0.032	0.190	5.9
,,	27	12.1	0.028	0.183	6.5
Sept.	21	9.7	0.250	0.860	3.4
Oct.	2	10.0	0.097	0.580	6.0
		Mean ...	...	... ...	**5.6**

Thus the motion in the preliminary tremor increased generally

* Excepting a few cases in which the motion was immeasurably small,

with the strength of the shaking and was on the average 1/5.6 of that in the principal portion. Hence it is likely that a violent destructive shock of near origin begins abruptly with quite large vibrations, so that its preliminary tremor may be much stronger than the principal portion of an ordinary earthquake.

In the following table, I give the 2a′ and 2a in the 19 earthquakes of moderate intensity, whose duration of the preliminary tremor was under 20 sec. and whose absolutely greatest motion (2a) was over 0.1 mm; the shocks being arranged according to the magnitude of the latter element of motion.

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor =2a′.	Max. Motion in Princ. Portion =2a.	Ratio : $\frac{2a}{2a'}$
		sec.	mm.	mm.	
Aug.	24	6.3	0 044	0.780	17.7
Oct.	10	9.2	0.061	0.430	7.0
„	14	5.7	0.044	0.240	5.5
Jan.	26	11.0	0.028	0 220	7.9
Sept.	24	7.8	0.031	0.210	6.8
May	9	11.0	0.051	0.204	4.0
June	18	13.2	0.023	0.190	8.3
Nov.	2	12.9	0.073	0.190	2.6
June	12	18.4	0.054	0.190	3.5
		Mean …	…	… …	**7.0**
Feb.	17	14.1	0.027	0.180	6.7
March	4	9.0	0.022	0.170	7.7
May	26	19.4	0.043	0.160	3.7
April	24	9.0	0.017	0.153	9.0

Date.		Duration of Prel. Tremor.	Max. Motion in Prel. Tremor $=2a'$	Max. Motion in Princ. Portion $=2a$	Ratio : $\frac{2a}{2a'}$
		sec.	mm.	mm.	
Sept.	3	10.6	0.012	0.150	12.5
Feb.	7	17.0	0.036	0.120	3.3
July	19	9.3	0.022	0.120	5.4
Oct.	19	9.8	0.060	0.120	2.0
July	23	19.0	0.031	0.107	3.4
June	6	7.0	0.013	0.106	8.1
			Mean	... ...	**6.2**

Dividing the 19 earthquakes tabulated above into two groups, of $2a>0.19$ mm and of $2a<0.18$ mm, the average values of the ratio $2a/2a'$ come out to be 7.0 and 6.2 respectively; the variation of this ratio with the 2a being apparently not significant. The mean value of this ratio deduced from the preceding tables is 6.3.

Finally, confining our attention to those sensible earthquakes, which were not accompanied by sound, the mean value of the ratio of $2a/2a'$ is found to be 5.7. This is not materially different from the mean value, namely, 7.0, of the corresponding quantity for those shocks accompanied by loud sound (page 35).

Least limit of sensible motion. In the sensible earthquakes, unaccompanied by sound, the maximum motion 2a was usually greater than 0.013 mm, there being only three cases in which it was less than this limit. With the earthquakes accompanied by sound, however, the limit of sensible motion was still lower, due probably to the predominance of quick vibrations in these shocks; there being 14 cases in which the maximum motion 2a was less than 0.01 mm, as follows:—

mm	Number of Eqkes.
2a = 0.010	3
2a = 0.009	1
2a = 0.008	2
2a = 0.007	5
2a = 0.006	1
2a = 0.004	1
2a = 0.003	1

Making an allowance for the possible error in the measurement of very small movements, and provisionally excluding the last three cases, we may take the double amplitude of **0.007** mm as the limit of sensible vibration, the EW component motion alone being taken into account. Assuming the corresponding NS component to be of an equal range, the resultant double amplitude of the sensible motion would be about **0.01** mm. This latter value is to be regarded as the lowest limit of the earthquake motion which is intense enough to be felt without instrumental aid by people living in wooden houses at a quiet rocky district, where the earth vibrations are rapid.

The result here obtained is in accordance with that relating to the small vibrations of the ground caused artificially by an oil engine, etc. (See my paper, A Horizotal Tremor Recorder, in the *Publications*, No. 18). For Tokyo, the intensity of the lowest limit of the sensible motion was found to be an acceleration of 17 mm per sec. per sec. This is to be regarded as defining the feeblest earthquake motion sensible to people living in a large city or some other place where there is much disturbances arising from traffic, the working of steam engines, dynamos, etc. (See the *Publications*, No. 11.)

Conclusion. One of the principal objects in making the seismographic observations at Tsukuba was the comparison of the results there obtained with those simultaneously obtained in Tokyo and Mito, to determine thereby the accurate positions of the origins of the different local shocks, and also the relation between the epicentral distance and the duration of the preliminary tremor for near earthquakes. Further discussions on the Tsukuba observations in these connections are reserved for a future occasion. The instrumental study of the minute vibrations giving rise to sound phenomena is of course very important.

Tokyo, March 1908.

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 1.

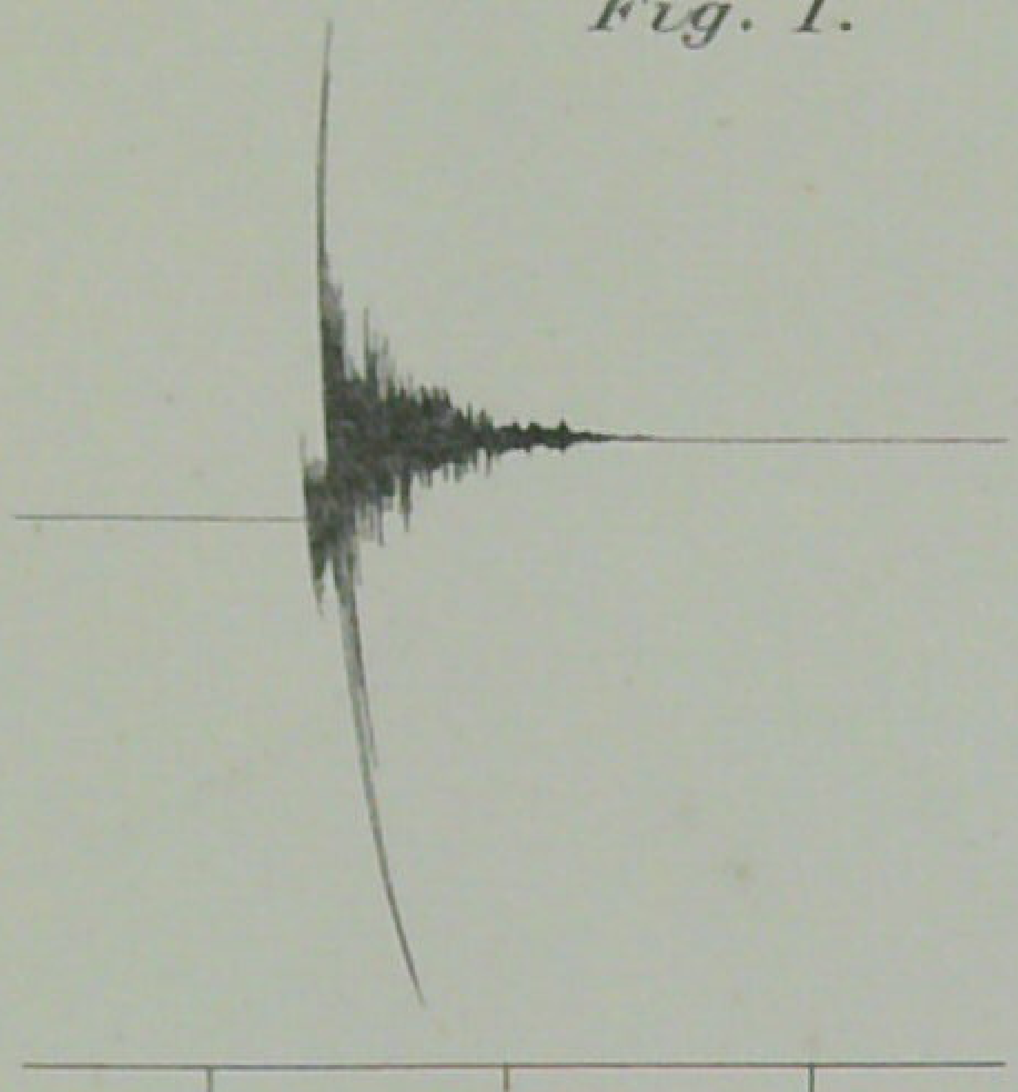


Fig. 3.

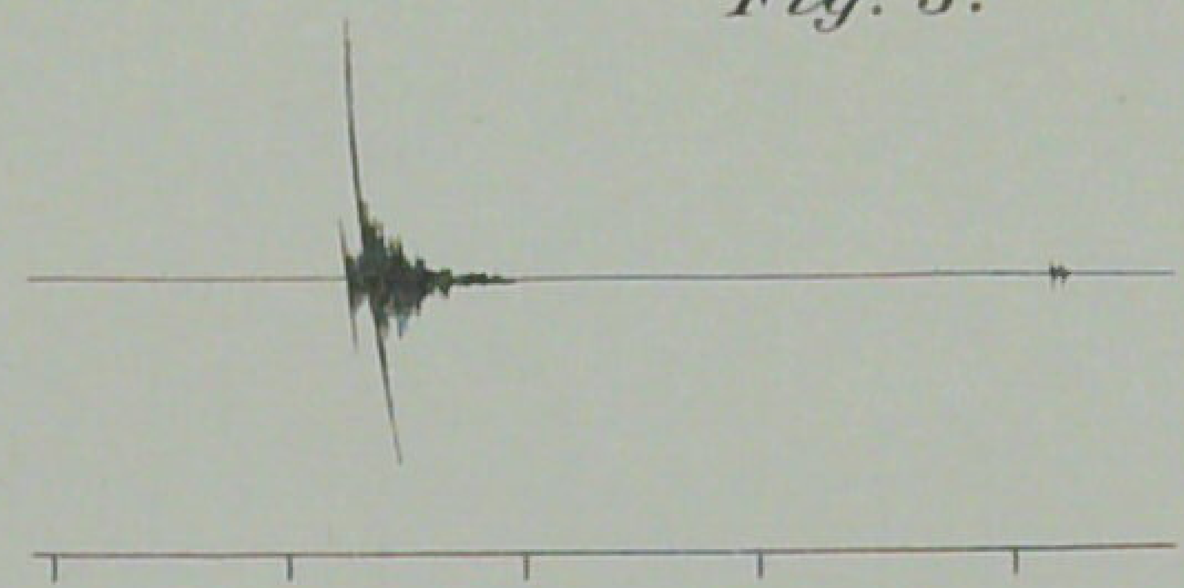


Fig. 4.

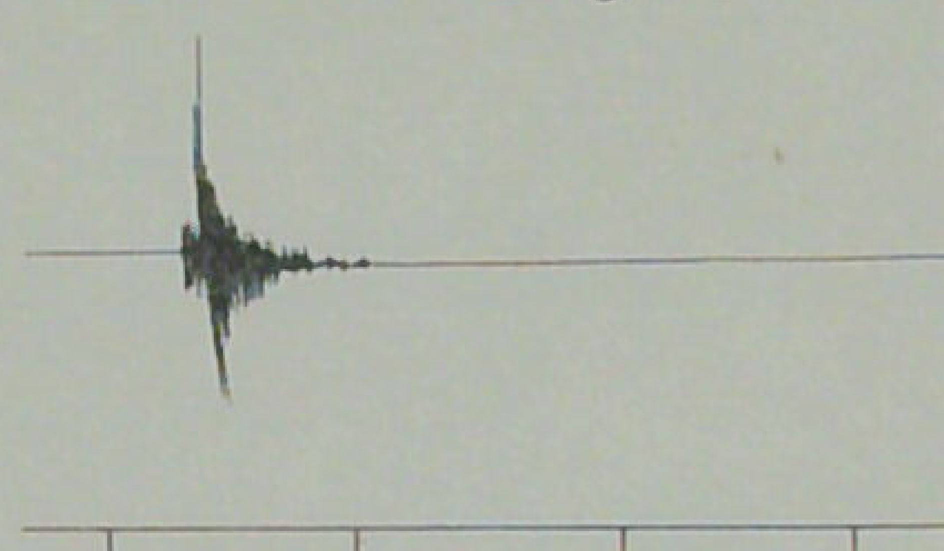


Fig. 2.

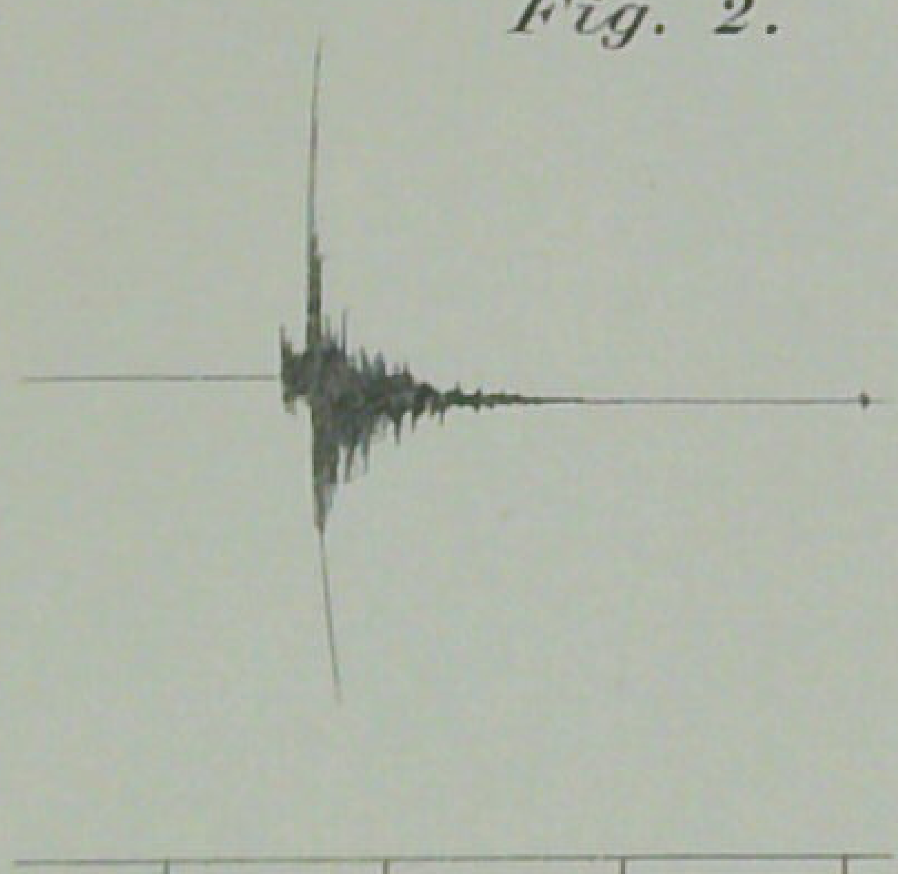


Fig. 5.

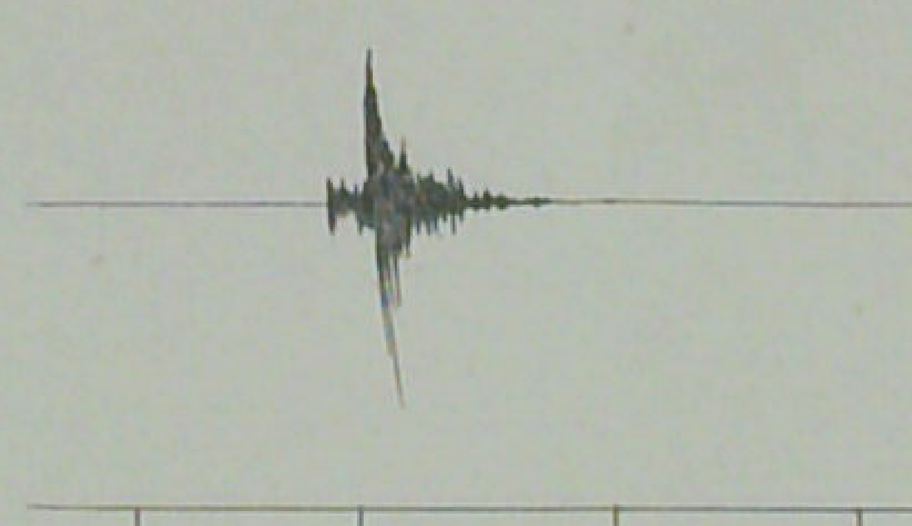


Fig. 1.	April	6 ;	9h	29m	10s P.M.	*Moderate.* Loud Sound heard 5 or 6 sec. before the shock.
" 2.	July	27 ;	1	38	15 A.M.	*Moderate.* Accompanied by loud sound.
" 3.	June	11 ;	11	50	10 P.M.	Do.
" 4.	"	7 ;	6	12	30 A.M.	Do.
" 5.	"	27 ;	3	17	10 A.M.	*Slight.* Accompanied by sound.

PL. II.

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 6.

Sept. 21 : $10^h 00^m 55^s$ Pm

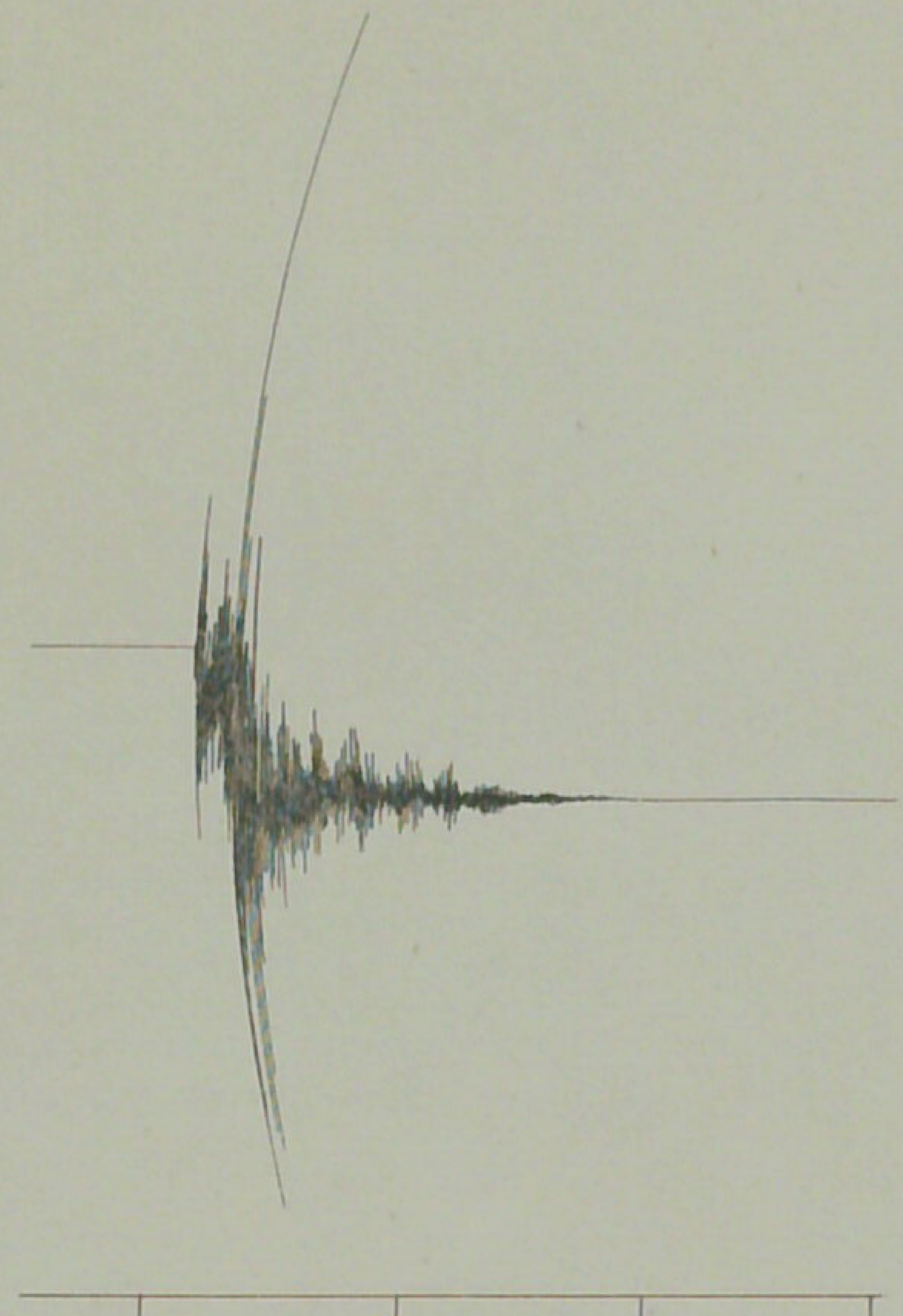
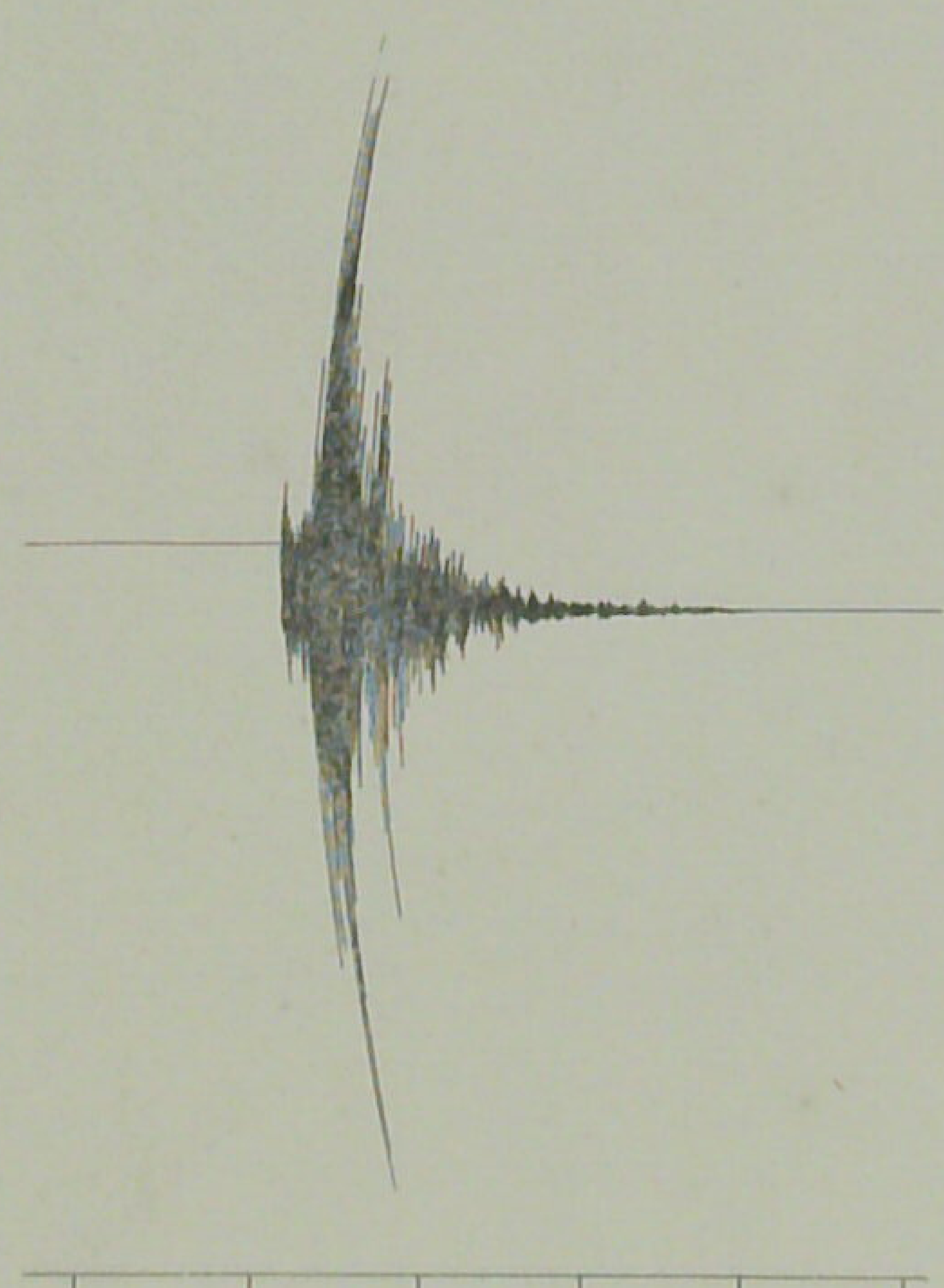


Fig. 7.

Oct. 2 : $10^h 56^m 20^s$ Am.



Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 8.

Fig. 9.

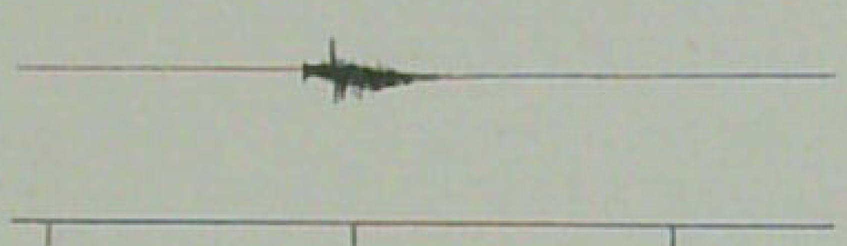


Fig. 10.

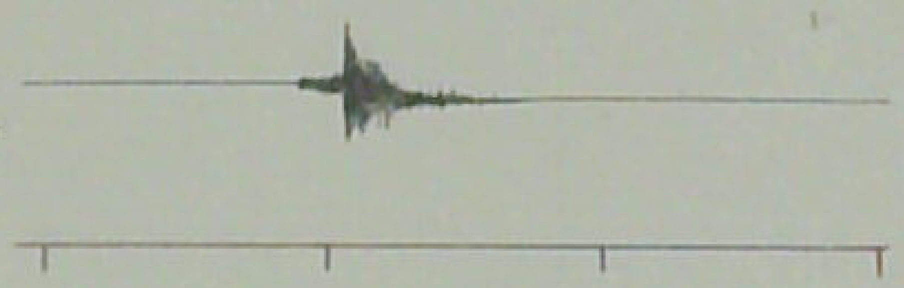


Fig. 11

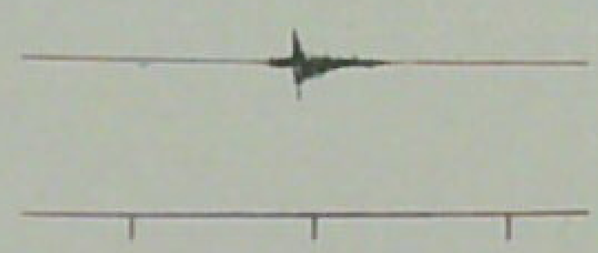


Fig. 12.

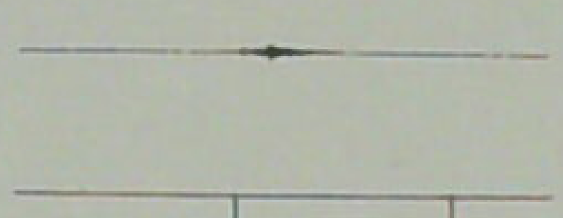


Fig. 13.

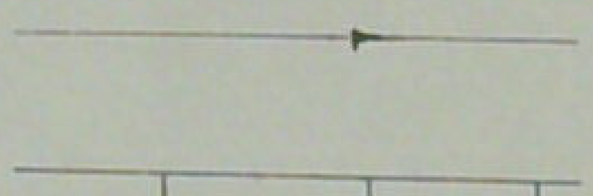


Fig. 8.	Sept.	2;	4h	26m	30s	P.M.	*Moderate.*	Accompanied by loud sound.
„ 9.	April	6;	11	33	40	P.M.	Unfelt.	
„ 10.	May	26;	2	00	25	A.M.	*Slight.*	Accompanied by sound.
„ 11.	Sept.	20;	4	22	10	P.M.	*Slight.*	Accompanied by loud sound.
„ 12.	Oct.	2;	7	47	10	A.M.	Unfelt.	
„ 13.	Sept.	19;	10	38	30	P.M.	Unfelt.	

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 15.

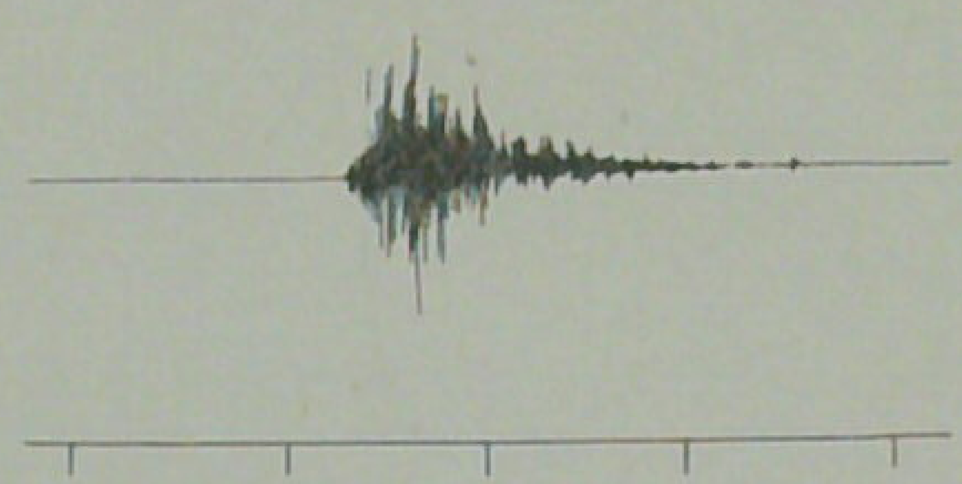


Fig. 14.

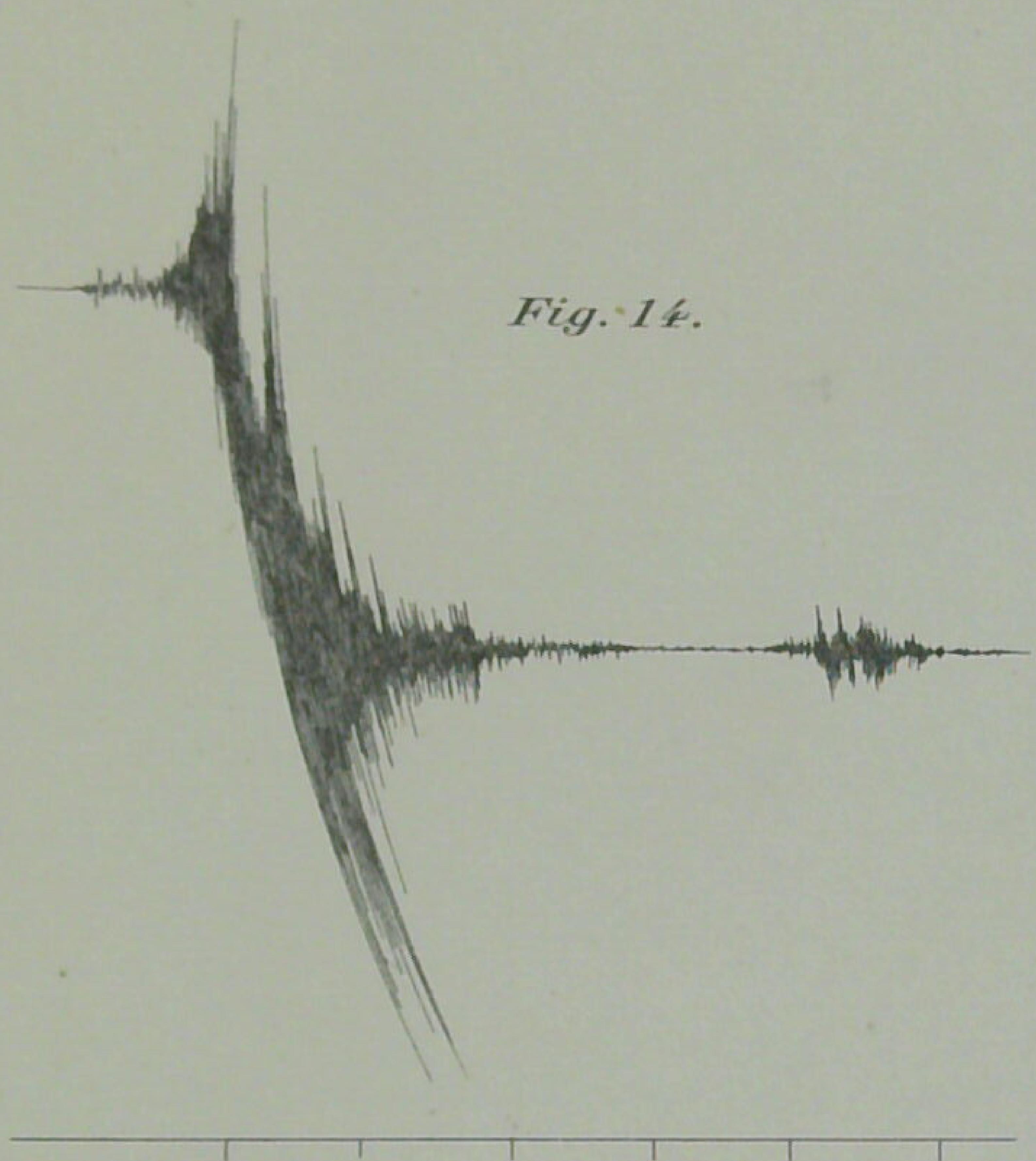


Fig. 16.

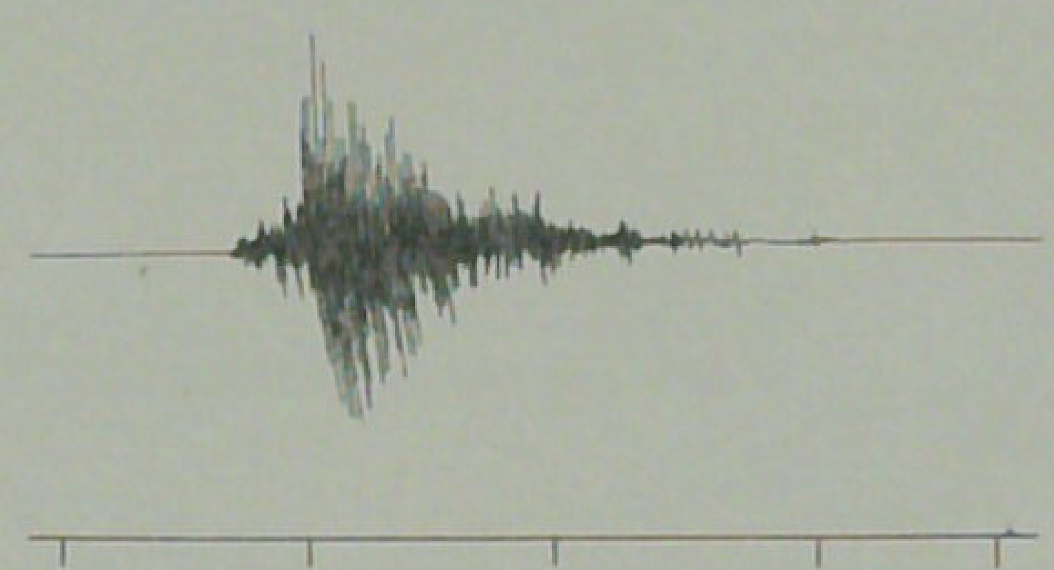


Fig. 18.

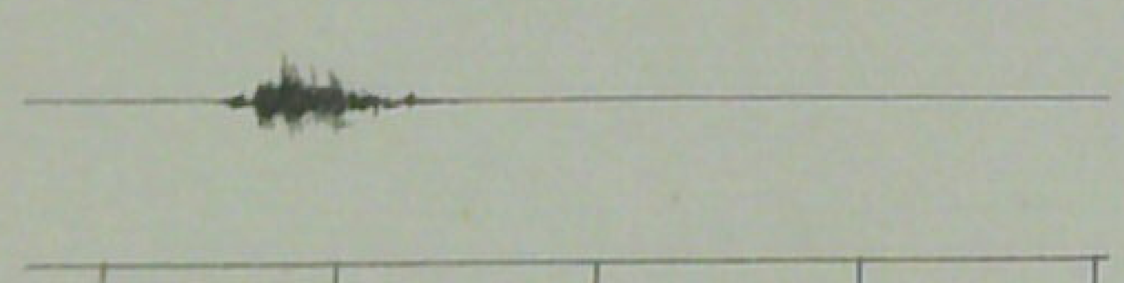


Fig. 17.

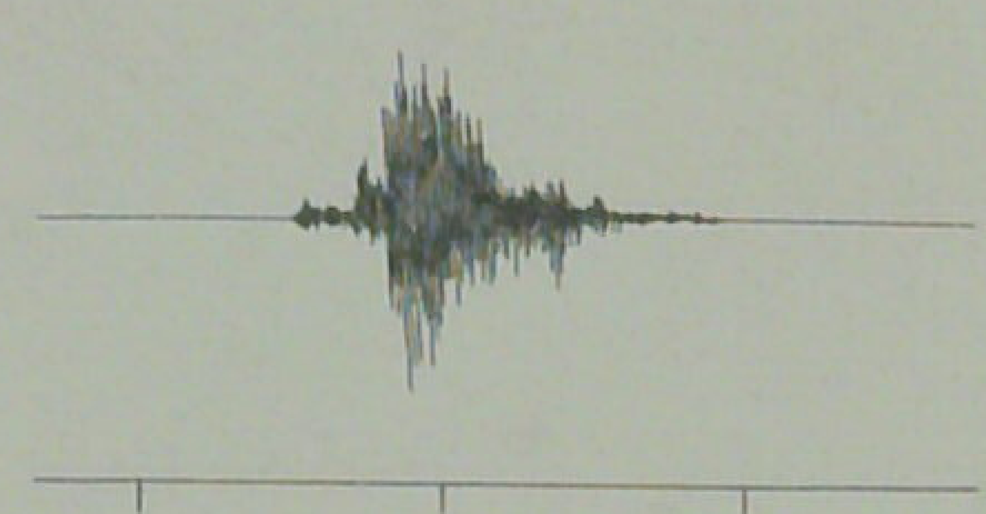


Fig. 14.	July 7;	1h	21m	25s	A.M.	*Moderate.* No sound.
„ 15.	Nov. 1;	2	01	50	P.M.	*Moderate.* No sound.
„ 16.	June 12;	5	17	30	P.M.	*Moderate.* Sound heard 5 sec. before the shock.
„ 17.	May 26;	3	46	50	P.M.	*Moderate.* Loud sound heard 3 sec. before the shock.
„ 18.	Oct. 10;	1	49	20	P.M.	*Slight.*

Earthquake Observation on Mount Tsukuba.

EW Component. Multiplication=90.

Time : 1 interval=1 minute.

Fig. 19.

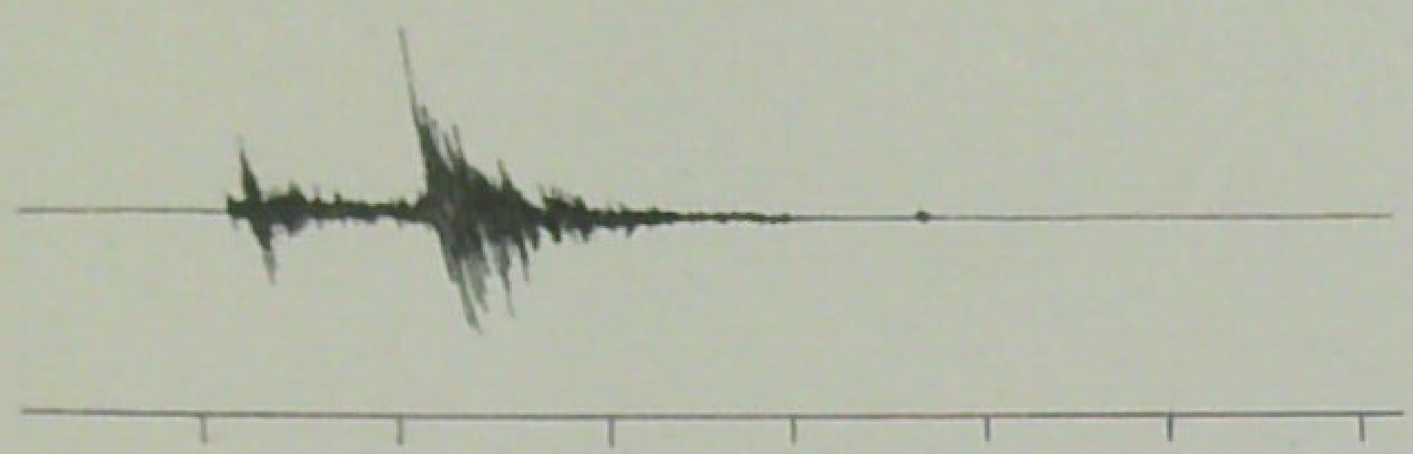


Fig. 22.

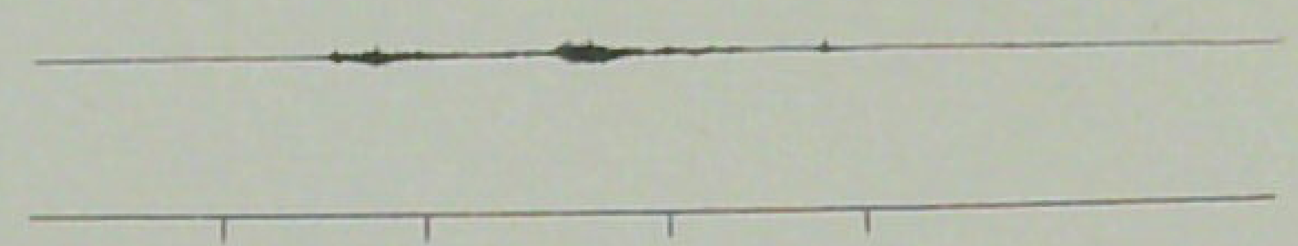


Fig. 20.

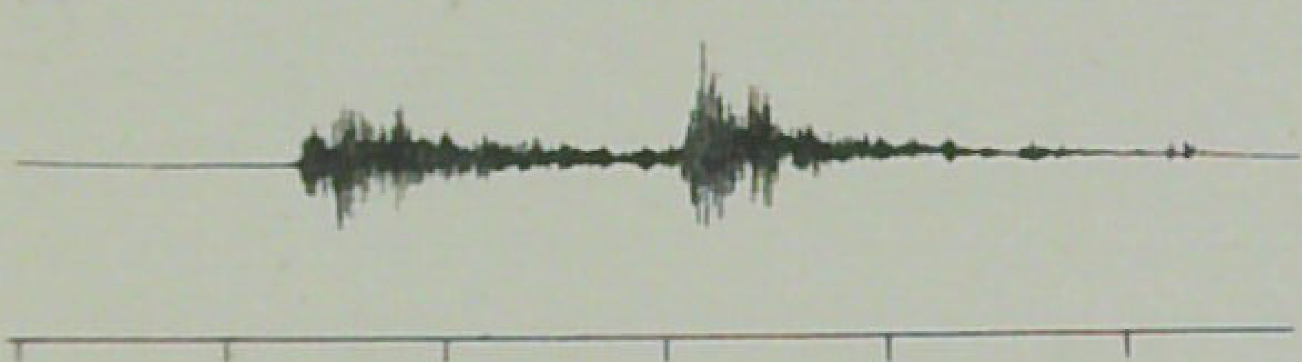


Fig. 23.

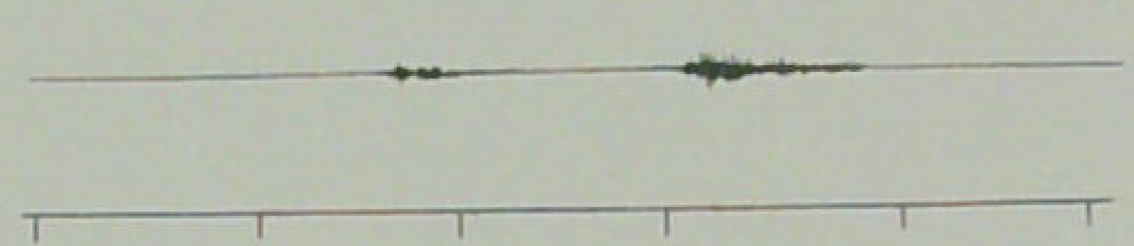


Fig. 24.

Fig. 21.

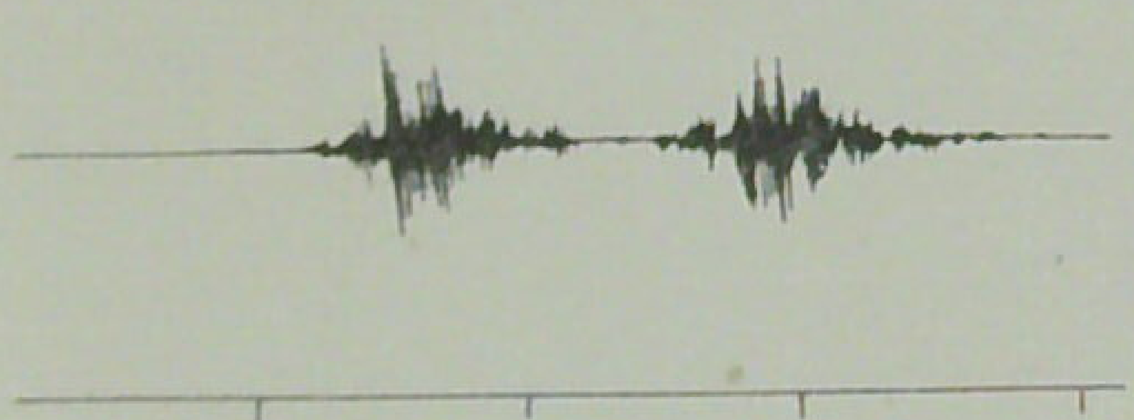


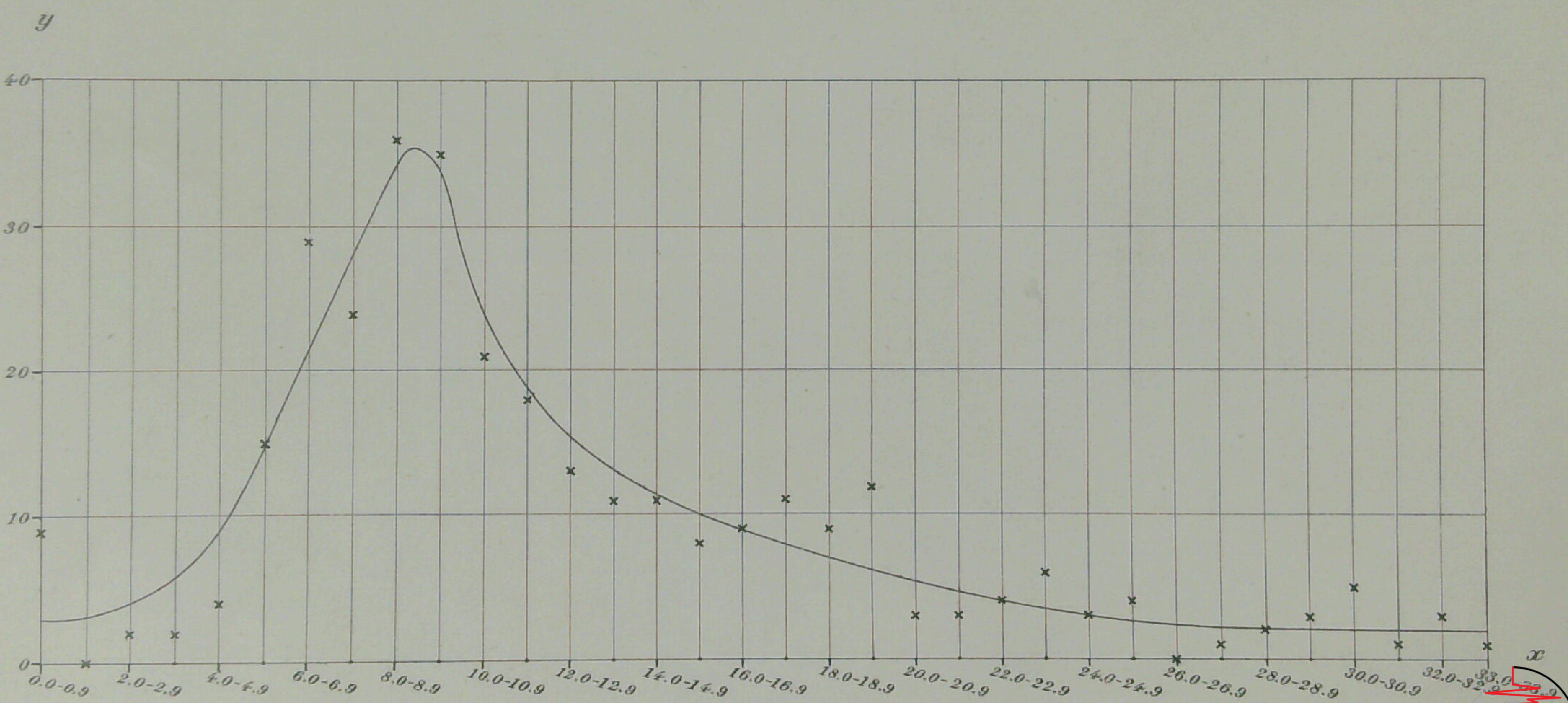
Fig. 25.

Fig. 19.	July 7;	7h	17m	25s	A.M.	*Moderate.*	Accompanied by sound.
„ 20.	Aug. 25;	6	49	10	P.M.	*Slight.*	Accompanied by sound.
„ 21,	June 7;	2	39	50	P.M.	*Moderate.*	Accompanied by loud sound.
		2	40	20	„	*Slight.*	
„ 22.	July 7;	10	38	00	A.M.	Unfelt.	
„ 23.	Oct. 10;	5	10	55	A.M.	Do.	
„ 24.	June 27;	1	09	30	A.M.	Do.	
„ 25.	Sept. 2;	3	48	25	P.M.	Do.	

Fig. 26. Relative Frequencies of the Earthquakes of different lengths of the Duration of the Preliminary Tremor.

x = Duration of the Preliminary Tremor, in second.

y = Number of the Earthquakes, the duration of whose preliminary tremor is equal to x.



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Earthquake Investigation Committee

IN

FOREIGN LANGUAGES.

NO. 22 B. Art. 4.

TŌKYŌ, 1906.

PUBLICATIONS OF THE EARTHQUAKE INVESTIGATION COMMITTEE, SECTION B, ART. IV.

On the Geyser in Atami.

BY

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With Plates I–XII

I. INTRODUCTION.

The remarkable feature of the periodic eruptions of geysers has attracted the attention of many observers. Mackenzie,[1] who travelled in Iceland in 1811 and observed the Great Geyser, first tried to explain the phenomenon; but his theory proved unsatisfactory. Bunsen,[2] travelling on the same island in 1847, made observations on the Great Geyser, and explained the phenomenon by his well-known theory of the vertical pipe. According to him, the origin of the eruption lies in the lower part of the vertical pipe which does not exceed 20m in the case of this geyser. Müller[3] constructed a model after Bunsen and showed that it works periodically, if two portions of the vertical pipe be heated. His theory, however, is not free from objections. Contrary to the Bunsen's view, O. Lang[4] considered the seat of the eruption to lie at a great depth in a canal connected with the vertical one, the water in which acts as a valve for the enclosed vapour. Models given by Julius Ziegler[5] and by G. Wiedemann[6] explain the

1) Mackenzie, Travels in Iceland, 1811.

2) Bunsen, "Physikalische Beobachtungen über die hauptsächlichsten Geysir, Islands," Geblers Physikalisches Wörterbuch (2te Auflage), LXXII; Pogg. Ann., 72, 1847.

3) Müller, Lehrbuch der Kosmischen Physik, Braunschweig, 1894, S. 619.

4) O. Lang, "Ueber die Bedingungen der Geysir," Göttinger Gelehrten Nachrichten, S. 225.

5) Ziegler, Vorträge des phys. Vereins in Frankfurt a. M., 1872, demonstrated by Dr. Nippoldt.

6) G. Wiedemann, "Ueber einen Apparat zur Darstellung der Erscheinungen der Geysir," Ann. der Phys. u. Chem. (2), 12.

phenomenon of the geyser from similar points of view. The models consist of a vertical pipe and a large cavity containing hot water and connected to a water tank placed at a suitable height The constant heating of the cavity produces periodic eruptions of water and steam. Models constructed by J. Petersen, A. Andreae and others[1] do not differ much in principle from those just referred to. The experimental investigations by Andreae[2] and E. Ebert[3] shew that by proper modification of different parts of the models, the several types of eruptions observed in natural geysers can easily be imitated; but the latter remarks that it seems difficult to explain by such a simple theory all the diversities of the manner of eruptions observed in numerous geysers in Iceland, North America and New Zealand.

In Japan, we have two geysers, one at Atami and another at Onikōbe, the force of eruption of the latter being very weak. Twenty years ago, we had another one in Noboribetsu in Hokkaidō, the eruption of which is said to have recurred a few times per hour, projecting hot water a few meters above the ground. At present, it has completely lost its periodical character.

The geyser of Atami is situated on the eastern slope of the coast mountain range of Izu. Its orifice is about 1 km distant from the sea shore and about 22 m above the sea level. Differing from other geysers, the geyser of Atami is characterized by the regularity of its eruption, which consists of alternate projections of hot water and steam, usually five times in succession. The orifice, which originally opened vertically upward, has been covered by a heap of stones to prevent the dangers caused by the eruption, and directed horizontally, so that

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1) J. Petersen, "Darstellung der Geysir Erscheinungen," Neues Jahrbuch für Mineralogie, Geologie u. Palaeontologie, 1879, 2.

A. Andreae, "Ueber einen künstliche Nachbildung der Geysir-phänomene," ibid, 1893, 2.

K. Antolik, Zeitschrift f. d. phys. u. chem. Unterricht, 1890–91.

A model given by A. C. Munby, Nature, LXV, p. 247, is of a somewhat different principle.

2) A. Andreae, loc. cit.

3) H. Ebert, "Versuch mit dem G. Wiedemannschen Geysir-Apparat," Ann. d Phys. u. Chem. (2), LXIII.

the water projected does not return to the mouth, as it does in many other geysers. At present, three orifices (A, a, a′, Pl. I) are exposed, among which the one (A) is to be distinguished as the principal opening. There is besides, another mouth, hidden underground. The water projected by these orifices is distributed to numerous bath-houses by a system of conduits.

According to the result of the analysis by Dr. Martin in 1874 and by Dr. Tawara in 1883, the mineral constituents of the water of the spring in 1 litre are as follows;—

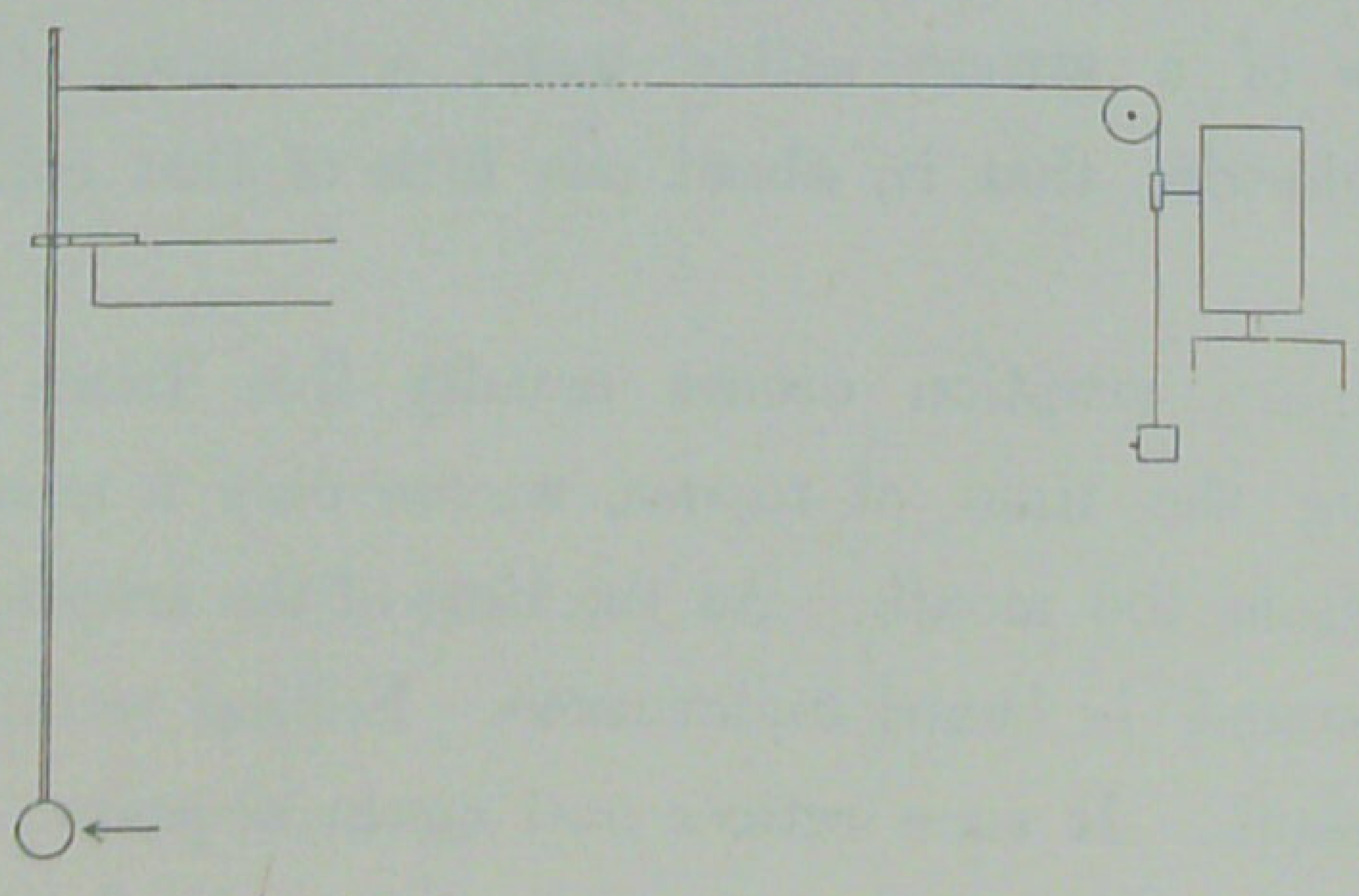
Mineral constituents	Martin	Tawara
Solid residuals	10.0104 gr.	9.235 gr.
Sodium chloride	3.79	5.409
Potassium chloride	1.81	0 354
Calcium chloride	1.767	2.893
Magnesium chloride	2.333	0.0145
Calcium sulphate	0.193	0.1313
Ferrous bicarbonate	0.0031	0.002
Calcium bicarbonate	0.0042	trace
Silica	0.110	0.5249
Manganese chloride	trace	trace
Sodium bromide	,,	,,
Potassium bromide	,,	,,

The water is of a strong saline taste, containing about ½ percent of sodium chloride, that is, about one fifth of that contained in sea water.

The ordinary eruption occurs usually five times in a day and night. During the time of repose, we see only a small quantity of steam rising from the mouth. As the time of the eruption approaches, a rumbling sound is heard underneath. Boiling water appears just inside the mouth. It soon retires and again appears. This state is continued for about three quarters of an hour. Next a small quantity of hot water flows out intermittently. This is followed by an intermittent stream of moderate quantity with a longer period. The activity soon attains its maximum. A torrent of hot water gradually increasing in force, is torn into a violent splash and projected with great velocity by the steam, which gradually increases with the diminishing water. When the roaring sound of the steam reaches its maximum, the water almost disappears. The steam now diminishes and is soon followed by a second gush of water. When these discharges of the water and steam have been repeated five or six times, activity ends with the last discharge of steam, which gradually subsides into an amount as inconsiderable as at the beginning. It takes above two hours from the beginning to the last stage of the eruption. The time of repose is a little less than three hours on the average. These regular recurrences are often interrupted by an abnormal outburst called *nagawaki*, at which the water and the steam come out incessantly for above twelve hours, after which as a rule a long repose follows. In years most noticeable for this anomaly, it has occurred almost monthly, whereas in the last few years only two or three times.

II. ARRANGEMENTS FOR OBSERVATIONS.

To make detailed observations of the general manner of eruptions, the following arrangements were used.



A pendulum was made of a brass rod, at the lower end of which a lead ball was fixed (3 cm in diameter), and vertically suspended by a short horizontal axis fixed to the rod and pivoted to a catch at the end of a large wooden beam laid horizontally over the principal orifice. The pendulum hung nearly vertically, the lead ball facing closely to the mouth. To the upper end of the rod was attached a string, which passed horizontally to a pulley of the recording instrument. The string after passing over the pulley was attached to a suitable weight. The whole system was so adjusted that the pendulum hung vertically under the balancing action of its own weight and the tension of the string going to the recorder. When the eruption begins, the pendulum is deflected by the pressure of the water and steam. The vertical part of the string below the pulley conveys a pen, which is guided as in the limnimeter[1] used by one of us for recording the level change of artesian wells. The motion of the pen is recorded on a cylinder rotating about a vertical axis. From the records obtained, we can easily distinguish the water and steam-pressure from each other. The part of the record representing the water pressure is much disturbed by zigzags.

Since it was, however, desirable to record the water and the steam separately, the pendulum was transferred to a place in front of the orifice, where all the water ejected flows through a narrow canal to a tank. The whole system was shielded off from the impulsive action of the splash and the steam by a screen of wooden planks. The records thus obtained were completely free from steam pressure.

To record the pressure of the steam only, was a matter of considerable difficulty. Just before the orifice, the steam pressure was tolerably strong; but, there, it was impossible to separate the steam pressure from that of the water. Where the ball of the pendulum did not receive any pressure from the splash of the water, the steam pressure was not strong enough to cause any sensible deflection of the pendulum, so that the arrangement failed to give any

1) K. Honda, Publications of the Imp. Earthq. Inv. Comm., No. 18, p. 73.

satisfactory result. The aspiration method was also tried, but it failed to produce sensible diminution of the pressure in our recording apparatus. We, at last, adopted the following arrangement, which was essentially nothing more than an air-thermograph. A hollow cylinder or a bulb of iron sheet (radius=2 cm, length=9 cm) was introduced into a side orifice (a), where the water flows out slowly, and where it was possible to find a position such that the bulb was exposed to the heating actions of the steam only. To avoid too rapid expansion and contraction of the enclosed air, the bulb was covered with two layers of cloth. Since this orifice is a small branch of the principal orifice, and the manner of the eruption quite similar for both mouths, the side orifice may be considered as representing the mode of eruption in the principal one on a reduced scale. The bulb was connected by a fine copper capillary tube (diameter=2 mm.) to one of the arms of an U-tube containing mercury. In another arm of the tube, a float carrying a light vertical pen-holder was introduced. The motion of the float caused by the expansion and contraction of the air inside the bulb, was recorded on a vertical drum by the pen, guided as in the case of the limnimeter.

For the statistical investigations, a simple apparatus which might continuously record the exact time of eruption and also, if possible, the general manner of each eruption was desirable. For this purpose, a mercury tide gauge constructed after Mr. S. Nakamura's design[1] erved very well. The lead pipe of the instrument was inserted in the neck of the geyser. At the beginning of activity, the instrument records the periodic level-change of the head of water inside the orifice. When the velocity of the water increases, it records the kinetic pressure of the ejected water. The steam pressure does not display itself on the records. The instrument has been working satisfactorily since the end of March, 1904.

For the determination of the temperature, a maximum thermometer which was graduated up to 150°C, was used.

1) S. Nakamura, Proc. of Tōkyō Math.-Phys. Soc., Vol. I, p. 123.

III. RESULTS OF OBSERVATIONS.

1. *Ordinary Eruption.*

a) Flow of water and steam. Fig. 1.

To record the initial stage of eruption, the lead ball of the pendulum was lowered as near as possible to the bed of the canal just outside the mouth, and the small initial quantity of water was compelled to flow entirely through a narrow aperture cut in the edge of a wooden board fixed to the bed close to the mouth. The ball hung just outside the aperture.

Referring to Fig. 1, we see that there exist three distinct series of intermittences. The first series which appears as an introduction to the display, consists of a small quantity of water with an average period of $1^m\,40^s$. After this intermittence has been repeated a score of times, the second series follows. A moderate quantity of water comes out three or four times with a mean interval of 6 minutes. The water increases in quantity and force, till at last the third or principal series sets in. On the first outburst of the third series, we see always the superposition of the last one of the second series. The third series is to be distinguished from the previous series by both its violence and the quantity of the water and steam put out. Besides, the roaring sound of the steam is a remarkable characteristic of this series. The sequence of the water and steam occurs with a mean period of about 11 minutes, and is repeated usually five or six times, not rarely four or seven times.

The pendulum was actuated by the impulsive force of the water and steam; the diagram shows a greatest excursion somewhat later than the actual maximum of the water. In this stage, the velocity of the steam is gradually increasing. When the water decreases to an inconsiderable spray and the steam predominates, the pendulum draws back. The disappearance of zigzags in the curve shows the prevalence of the steam.

b) Flow of water only. Figs. 2 and 3.

The records are generally similar to those given in Fig. 1, except that in this case, the impulsive pressure of the steam and splash is almost entirely eliminated. In these diagrams, we also see the superposition of the second series at the beginning of the third one. It will be observed that the last one of the third series is often distinguished by the small quantity and the weak force of the water.

c) *Flow of steam only. Figs. 4 and 5.*

In these diagrams, the zero line falls abruptly as soon as the cloth of the bulb is wetted by the condensed steam; this is due to the cooling caused by the evaporation. The ordinate of the curve may be considered as indicating in some measure the velocity of the steam at any instant and hence the area enclosed by this curve and the zero line is a rough measure of the quantity of the steam expelled. In subsequent experiments, it was found better to take the envelope off the bulb, whereby the falling of the zero line is avoided.

When two corresponding diagrams, Figs 2 and 4, or 3 and 5 are placed one upon another so as to bring their abscissae into coincidence, the recurrence of the alternate ejections of the water and steam can clearly be seen.

d) *Level-change during the time of repose. Figs. 6 and 7.*

The end of the lead pipe of the tide-gauge was inserted in the neck of the geyser as deep as possible. It was estimated that the end was only a half meter below the mouth. Since the neck is crooked in a very irregular manner, further attempt to insert the tube deeper than this failed. The record was continuously taken from the end of one eruption to the beginning of the next one.

The diagram obtained reveals to us a remarkable fact that within about 40 to 50 minutes after the end of an eruption, the head of hot water appears within a half meter below the mouth. The head seems to oscillate about its position of equilibrium for about one and a half to two hours, till the next activity begins. This interval may be considered as the time of preparation for the next eruption.

e) *Time of occurrence. Figs. 8, 9 and 10.*

The end of the lead pipe was drawn up to just inside the mouth. The clockwork gives one revolution every 24 hours. The records have been taken continuously from April, 1904. up to the present. From the statistical investigation of these records, we may infer the following facts:—

i) From April, 1904, to March, 1905, the mean period of the eruption was very nearly 24/5 hours. In May, 1905, there occurred an abnormal decrease of the activity of the geyser and since August of the same year, the activity has decreased to about four times per day.

ii) If the times of occurrences be plotted on a diagram, the successive days as abscissae and the hours of the day as ordinates, we obtain a set of five points per day. Connecting corresponding points, five broken lines are formed. These lines show a striking parallelism with the inverted curve representing the variation of the mean atmospheric pressure for successive days. The high pressure corresponds almost without exception to the short period and the low pressure to the long period.

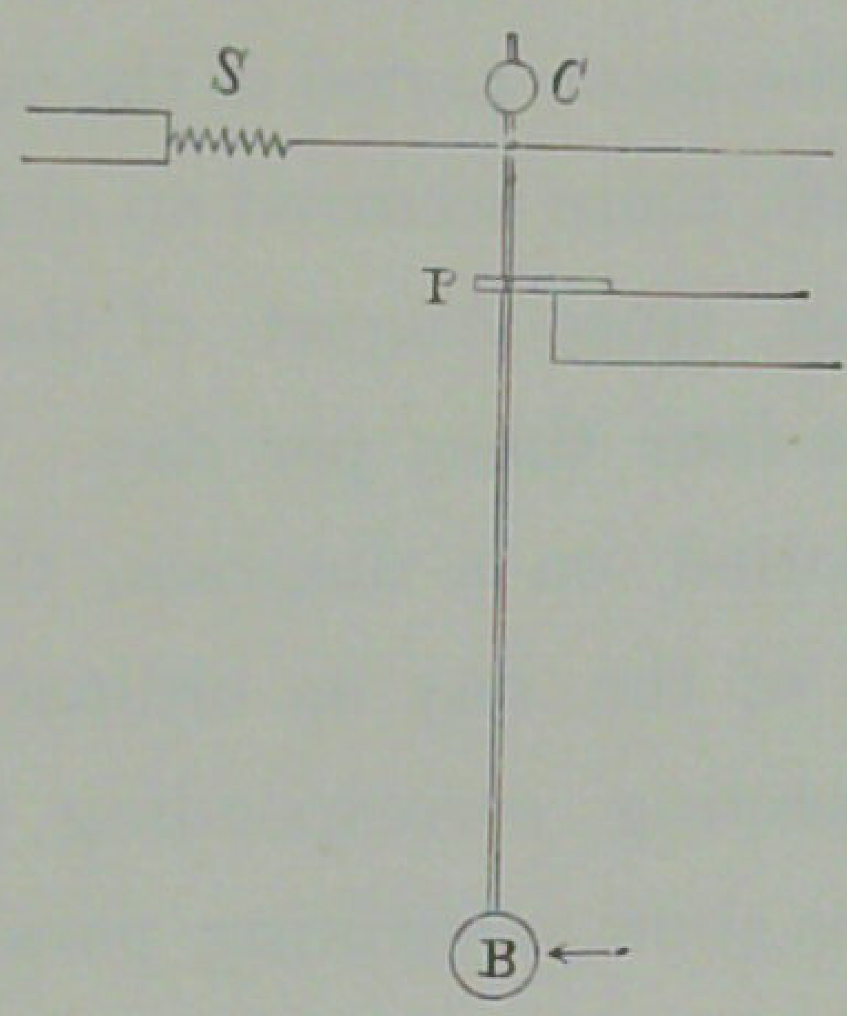
iii) The sum of the daily intermittence of water and steam given out, taken for the five daily eruptions, is generally abundant on the days in which low pressure prevails. The eruptions in which the alternations of water and steam occur more than eight times, fall in usually with approaching low pressure.

f) *Temperature of the hot water during eruptions.*

A maximum thermometer was placed about 1.5 m inside the orifice and the temperature has been read daily during about a half year. It was found that the temperature at this depth is almost invariably 103°-104°C. At the orifice, however, it was about 100°C, indicating a rapid cooling of the hot water. It may, therefore, easily be conjectured how hot the underground water would be at a depth of some ten meters.

g) *Velocities of the water and the steam.*

To determine the velocities of the water and the steam, the pendulum arrangement was modified in the following way. The pendulum bob was replaced by a larger brass one B, and the center of mass of the pendulum was brought to the axis of rotation P by using a counterweight C, as shown in the annexed figure. From the upper part of the pendulum rod, two strings were stretched in opposite directions,



one of which passed to the recording apparatus, while another one was stretched by a spring s fixed to a rigid support. The weight of the recording apparatus was so adjusted that the rod hung vertically, when it was acted upon by no pressure. When the pendulum was set to work in a proper stage of an eruption, the pressure due to the water and the steam could separately be observed. After the record has been taken in the usual manner, a series of known weights—30, 50, 80, 100, 200, and 300 grams—were successively applied to the pan hanging under the recording pen, and the corresponding deflections of the rod were recorded on the cylinder. From these observations, we could calculate the amount of the pressure exerted by the water and the steam upon the brass ball.

The total pressure exerted by a fluid stream upon a sphere is known to be approximately equal to one half of that upon a circular disc of the same diameter. Hence

$$p=\frac{\pi r^2\rho v^2}{2}, \qquad \text{or} \qquad v^2=\frac{2p}{\pi r^2\rho},$$

where p is the pressure, r the radius of the ball, ρ the density and v the velocity of the water or the steam.

For the water, the maximum velocity was calculated to vary from 1.5 to 2.0 m per sec.

For the steam, the velocity was found to vary from 18 to 24 m per sec., as given in the following table :

No. of Intermittence	Velocity
1	24 m/sec
2	25—24
3	22—18
4	24—23
5	22—18
6	22—18

In the above calculation, we took for the value of ρ, the density of saturated vapour under atmospheric pressure.

h) *Quantities of water and steam.*

Since the quantity of the water and the steam in each eruption differs considerably for different eruptions, it was sufficient to get a rough estimation of the amount. Again, to make an exact measurement of the total quantity of the water or the steam is almost hopeless, in the present condition of the orifice, as it is branched into several mouths; some of these are hidden underground, whence the hot water is distributed by a number of separate conduits.

The direct method for the quantity of the water was to measure the quantity supplied to a number of tanks and to estimate the total from the section of the conduits. The tanks chosen for this purpose were those of Kyūkikwan and of Sagamiya. The results are:

Kyūkikwan	11^h	p.m,	April	1,	'04.	3.38 m^3
Sagamiya	11^h	a.m,	,,	2,	,,	1.28.

Since the numbers of the conduits for the exposed orifices A, a, a′ are 21, 2, 3 respectively, the total quantity of the water will approximately be $1.28 \times 26\ m^3 = 33.2\ m^3$ or 184 *koku*. It was also estimated that the total quantity of the water which flows out from the hidden orifice, is $3 \times 3.38 = 10.1\ m^3$ or 56.3 *koku*. Hence the whole discharge of one eruption will approximately be $45 m^3$ or 250 *koku*. This number is a little greater than that obtained by Dr. Tawara, and nearly coincides with that given by J. Tsuyuki, a resident in Atami.

The rough estimation of the steam was carried out in the following way. Let the quantity of the steam be denoted by Q, we have

$$Q=\int Sv\rho dt,$$

where Sv is the flux of the steam. If V be the ordinate of the steam diagram, we may put

$$v=kV,$$

$$\therefore \qquad Q=S\rho k\int Vdt.$$

In our case, k was found to be 500 and S was estimated to be 300 cm^2. Hence

$$Q=121\int Vdt.$$

For an eruption, we found $\int Vdt=6500$, and therefore

$$Q=800 \text{ kg.} \;=213 \; \textit{kwan}$$

These numbers for the water and the steam must be considered as giving the orders of magnitudes of these quantities.

2. *Abnormal Eruption, the Nagawaki.*

Figs. 11 and 12.

The record of *nagawaki*, kept at Kyūkikwan is given below:

1894: Jan. 6; Feb. 22, 7^h p.m.—23, 11^h a.m.; March 30, 4^h p.m. —31, 6^{h}30^m a.m.; April 30, 6^h a.m.—2^h p.m.; June 7, 5^h a.m. —5^h p.m.; Aug. 20, 4^h p.m.—21, 6^h a.m.; Sept. 27; Nov. 17, 4^h a.m.—4^h p.m.; Dec. 28, 8^h a.m.—8^h p.m.

1895: Feb. 18, 4^h p.m.—19, 5^h a.m.; April 9, 8^h a.m.—5^h p.m.: June 12, 4^h p.m.—13, 6^h 30 a.m.; Aug. 14.

After this date, the record is missing till 1903.

1903: Sept. 8^h p.m.; Dec. 29, 3^h p.m.

1904: None.

The first *nagawaki* recorded by our arrangement began at 4^{h}30^m a.m. on Jan. 14, 1905, from the third series of the ordinary eruption. During two or three days before the *nagawaki*, the period of the successive eruptions seems to have been slightly diminished, but in such a degree that may be found not seldom in our records, without leading to either *nagawaki* or anything extraordinary. The *nagawaki* began, as it were, almost suddenly in the midst of an ordinary eruption. As given in Fig. 11, the flow of the water continued without interruption, gradually decreasing in quantity and mixed up with the steam. At 7^h40^m p.m., it came to a sudden repose; at 2^h40^m a.m. on 15th, an intermittent flow of hot water resembling the second series of an ordinary eruption began and continued for about three hours. After a repose of four hours, ordinary eruption at last set in, but with the period remarkably shortened and the general activity strikingly reduced. The number of eruptions per day was ten, a remarkable contrast to the ordinary frequency of five per day. The frequency decreased afterward very slowly with the time (Fig. 12), and recovered its original value after the lapse of about a month.

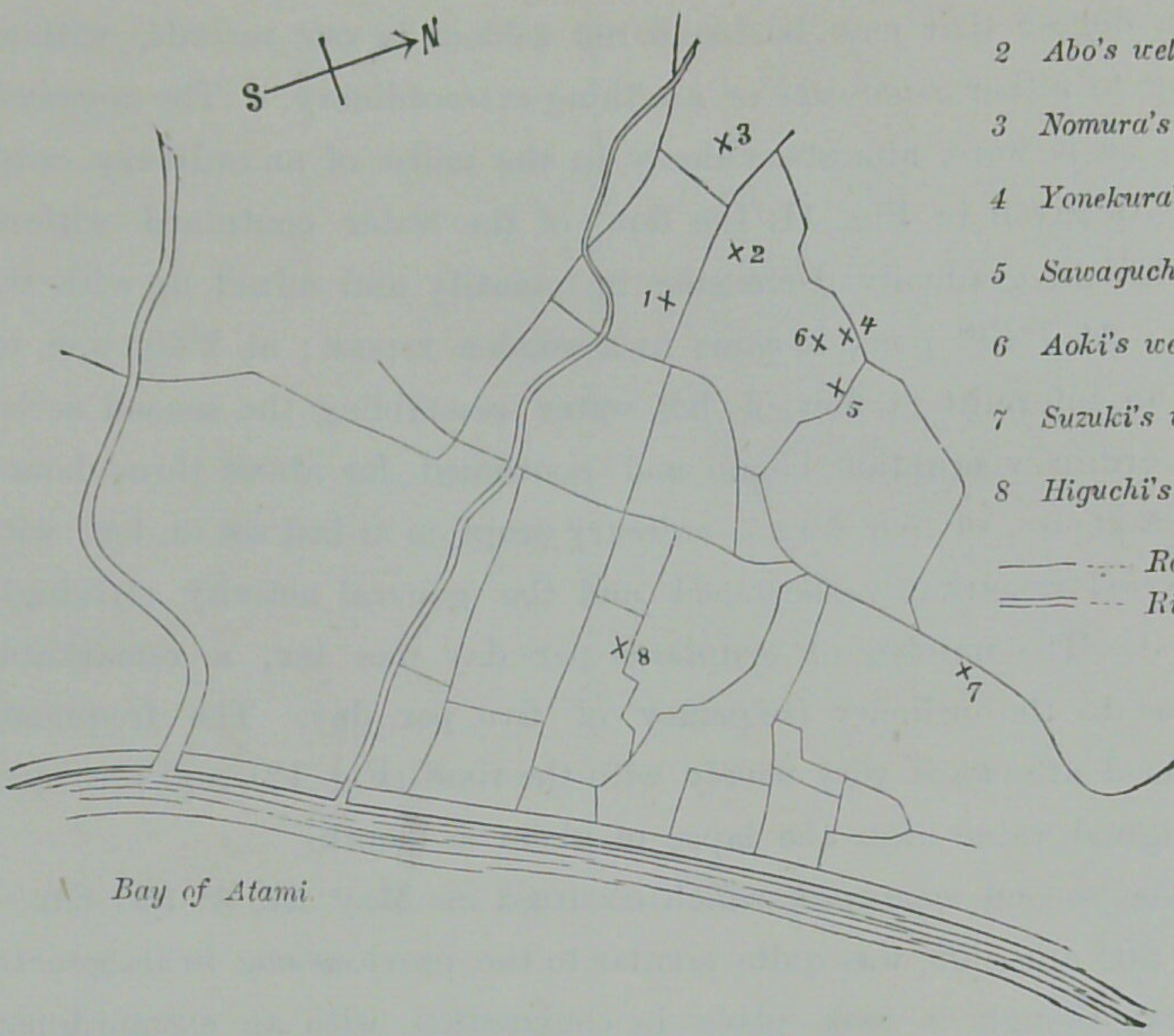
The second *nagawaki*, which occurred on May 27, 4^h 30^m a.m.—28, 6^h 20^m a.m., '05, was quite similar to the previous one in its general aspects, though it took place in conjunction with an extraordinary decrease of the general activity. The third *nagawaki* occurred on Dec. 13, 6^h p.m.—14, 9^h 40^m a.m., '05, and the fourth on March 6, 6^h 40^m a.m.—7, 2^h a.m., '06. They are quite similar in the general aspects to the one above referred to. It is an interesting coincidence that these *nagawakis* began at the same phase of the ordinary eruption, and that a center of low atmospheric pressure was approaching from the Pacific in each case.

3. Extraordinary Decrease of Activity.

Figs. 13 and 14.

During the course of the last few years, several wells have been bored in this district. Many of them give a moderate quantity of hot water only by pumping. In 1905, the number of the wells has been greatly increased, amounting to about twenty in all. Sawaguchi's well bored on March 27, '05, burst out with great force, continuously

Atami : 1 : 6000.



1 Ōyu, the geyser.
2 Abo's well.
3 Nomura's well.
4 Yonekura's well.
5 Sawaguchi's well.
6 Aoki's well.
7 Suzuki's well.
8 Higuchi's well.
——— Road,
═══ River.

throwing up a column of steam and hot water about 8 m high. On May 22, another, Yonekura's, of a much greater activity was opened within a few hundred meters from the geyser, giving out hot water at a rate of about 310 cubic meters per day. Two days afterwards, still another, Higuchi's, of not much less activity was bored. After the boring of the Sawaguchi's, a slight decrease in the frequency of the geyser was observed; on May 20, it was reduced to 4.4 times per day, though the force of each eruption presented no appreciable change. After the boring of the other two, the frequency of the geyser remarkably decreased; it was 3.6 on May 26. Moreover, the first and the second series of each eruption became considerably longer than usual and the principal series was lessened in force. After the *nagawaki* which occurred on May 27, the number of eruptions per day was temporarily increased to 6, though the quantity of the hot water was rather decreased. On June 5, the frequency again fell to 3.6 and on June 11 to only 3.2; the first and the second series were prolonged to three and a half hours, while the principal series was reduced to only three weak eruptions. The consequent decrease in the quantity of hot water caused trouble to several bath-houses supplied by the geyser, and the above three wells which must have been the probable cause of the decrease, were all stopped—Yonekura's on June 12, Sawaguchi's on the next day and Higuchi's on July 12. Immediately after the stoppage of the first two wells, the frequency of the geyser increased to 4 and moreover the preliminary series of each eruption was shortened and the principal eruption gradually tended to regain its original force. After stopping Higuchi's, the frequency gradually increased and attained 4.5 in August, which was still a little short of the original value. Since then, the frequency has gradually decreased to 4 and remained nearly constant up to the present, though it was temporarily disturbed by two *nagawakis*. As to the mode of each eruption, it has quite recovered its original force. It is to be remarked that still new wells remain open, Aoki's, which are near the geyser and give a moderate quantity of hot water.

The stoppage of wells was a matter of no small difficulty. The sight witnessed by us during the stopping of Yonekura's well may be worth recording. The well was about 25m deep and threw up a column of hot water mixed with steam about 8 m high, from an iron pipe of 4 inches diameter. Cylinders of sheet iron filled with sand and pebbles which were intended to stop the well, were violently thrown up in the air when put in the orifice. An iron rod of about 10 kg weight thrown into the mouth was held by the water near the mouth, neither falling nor rising. Next, an iron pipe of 2 inches diameter and of about 6 m length, was filled with sand and forced into the orifice. Though the quantity of the water and steam was considerably lessened by this pipe, the upward pressure still overcame the weight of the pipe and when the pipe was released, it was thrown up into the air about one meter high. Next a similar pipe filled with iron bolts and sand was applied. This pipe fell freely down the well. Immediately, the quantity of water was greatly reduced and a number of pieces of tuff imbedded with small crystals of iron-pyrites, was pelted out with the jet of steam and scattered within several meters from the spot. Then another iron pipe was thrown into the hole and cold water was poured down, which completely stopped the activity.

From the fact that the iron bar above described was held in equilibrium by the pressure of the water jet, we may roughly estimate the velocity and the mean density of the splash at the orifice. If w be the weight and S the sectional area of the rod, and if ρ be the mean density and v the velocity of the jet, we have

$$w = S\rho v^2$$

Again, if R be the radius of the orifice and Q the quantity of water given out per second,

$$\pi R^2 v\rho = Q$$

By our previous measurement, $Q=0.0036$ cubic meter per sec. The result of our evaluation is thus

$$v=12 \text{ m/sec}; \quad \rho=0.73,$$

i.e., the jet of water fills up about 7/10 of the area of the orifice. The power of the jet calculated from these data is about 3.5 H.P.

4. *Level Change and Temperature of Artesian Wells.* Figs. 15 and 16.

Level-changes of two wells near the geyser were recorded by means of Honda's limnimeter. Nomura's well, which is within 200 m of the geyser and 25 m above the sea level, shows a regular up and down motion of about 10 cm, five times per day (Fig. 15) corresponding to the eruption and repose of the neighbouring geyser. When the geyser is at the height of its activity, the level of the well is at its maximum. The slow rising of the mean level is partly due to rain. Effects of the tidal and the atmospheric pressure are also recognizable, but not very remarkable. The temperature of the water in this well is 50°-60°C.

In Suzuki's well, situated more remote from the geyser than the

Nomura's and nearer to the sea, the effect of the geyser is not observed, but the level rises and falls with the tide (Fig. 16). The record shows peculiar zigzags indicating that the surface of the water is continuously disturbed by the boiling. If the water be pumped out a little at first, it continues to flow eruptively for a while, till a definite quantity is reached and then follows repose. If the pump be actuated again after a few hours, a nearly equal quantity of boiling water flows out in a similar way. But, if pumped earlier, a small quantity may be drawn out only after hard pumping. The level of this well is about 11 m below the ground and 22 m above the sea level. On one occasion, the temperature of the water in the well at different depths was measured with a maximum thermometer and found to be remarkably high. The results are given in the following table:—

17.6 m	6.6 m	103°C.	115°C.
26.6	15.6	123°	128°
32.1	21.1	139°	135°
35.7	24.7	140°	138°
44.9	33.9	140°	147°
54.0	43.0	142°	152°

The first and the second column denote the depths measured from the surfaces of the earth and the water respectively; the third column is the actual temperature corresponding to each depth; and the last is the corresponding boiling point of water under pressure, calculated from the Regnault's results. From the above table, we see that the temperature of the water rapidly increases almost proportionally with the depth up to about 20 m from the surface of the water; then the rate of the increase becomes abruptly small. This shows that at about 20 m below the surface of the water, there is a layer or a space between layers in which highly heated water is continuously flowing. At these depths, the actual temperature is a few degrees higher than the corresponding boiling points under pressure, so that the boiling is continuously going on, as shown by the limnimeter set up in the well.

Here it is to be noticed that the rise of the boiling point due to the dissolved substances is at most one degree.

Abo's well which is situated midway between the geyser and Yonekura's well, is about 33 m deep and gives out hot water by pumping. The results of the temperature measurement at different depths, made by a maximum thermometer, are as follows:

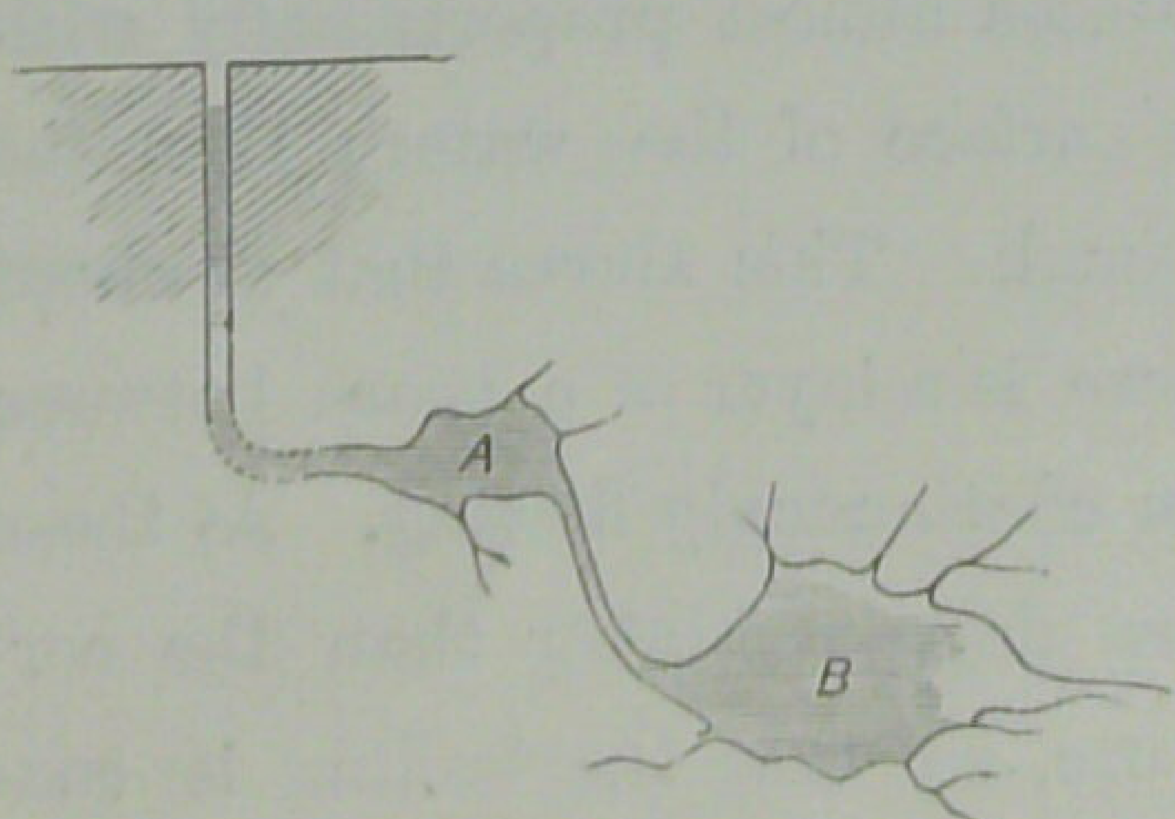
At the water surface	62.0 C.
23.0 m below,	95.5
28.5 ,,	98.3
29.7 ,,	104.3
31.0 ,,	118.2

From the results in these two wells, it is evident that in the district of Atami, there exist layers with very high temperature near the surface.

IV. EXPLANATION OF THE PHENOMENA.

Existing theories are not sufficient to explain the exact manner of the eruption of the geyser of Atami. Wiedemann's model though plausible in many respects, fails when applied to this geyser, in which water and steam are alternately projected several times in succession. We sought, therefore, for other alternatives and constructed several models for experiments.

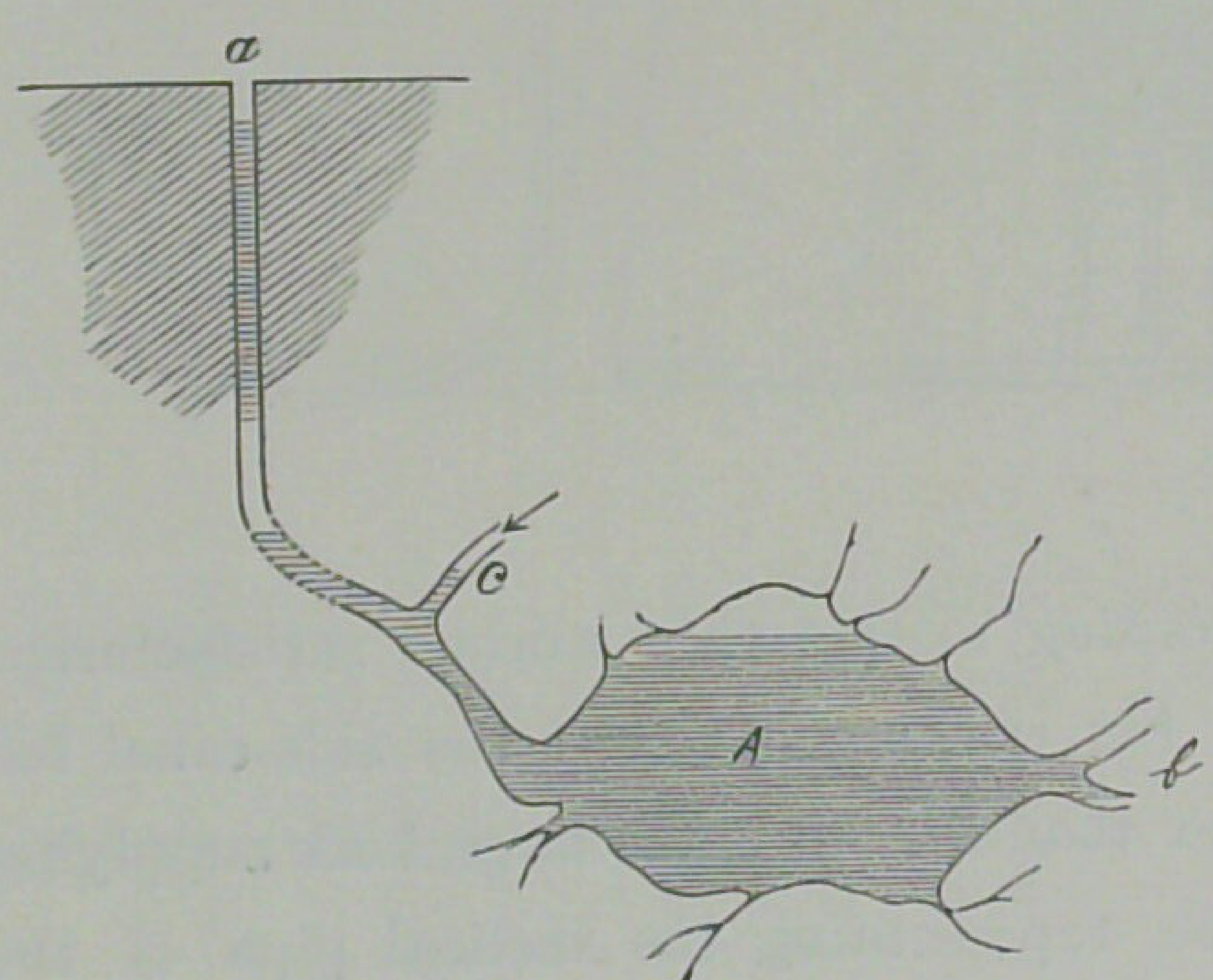
First, we conceived two subterranean cavities (*A* and *B*) connected in series, as shown in the annexed figure and supposed *B* to begin the eruption earlier than *A*, by the underground heat. The model constructed according to this supposition worked almost satisfactorily, except that the mode of intermittence in the principal series of the eruption was not quite similar to the actual geyser; for, in this model, the steam predomi-

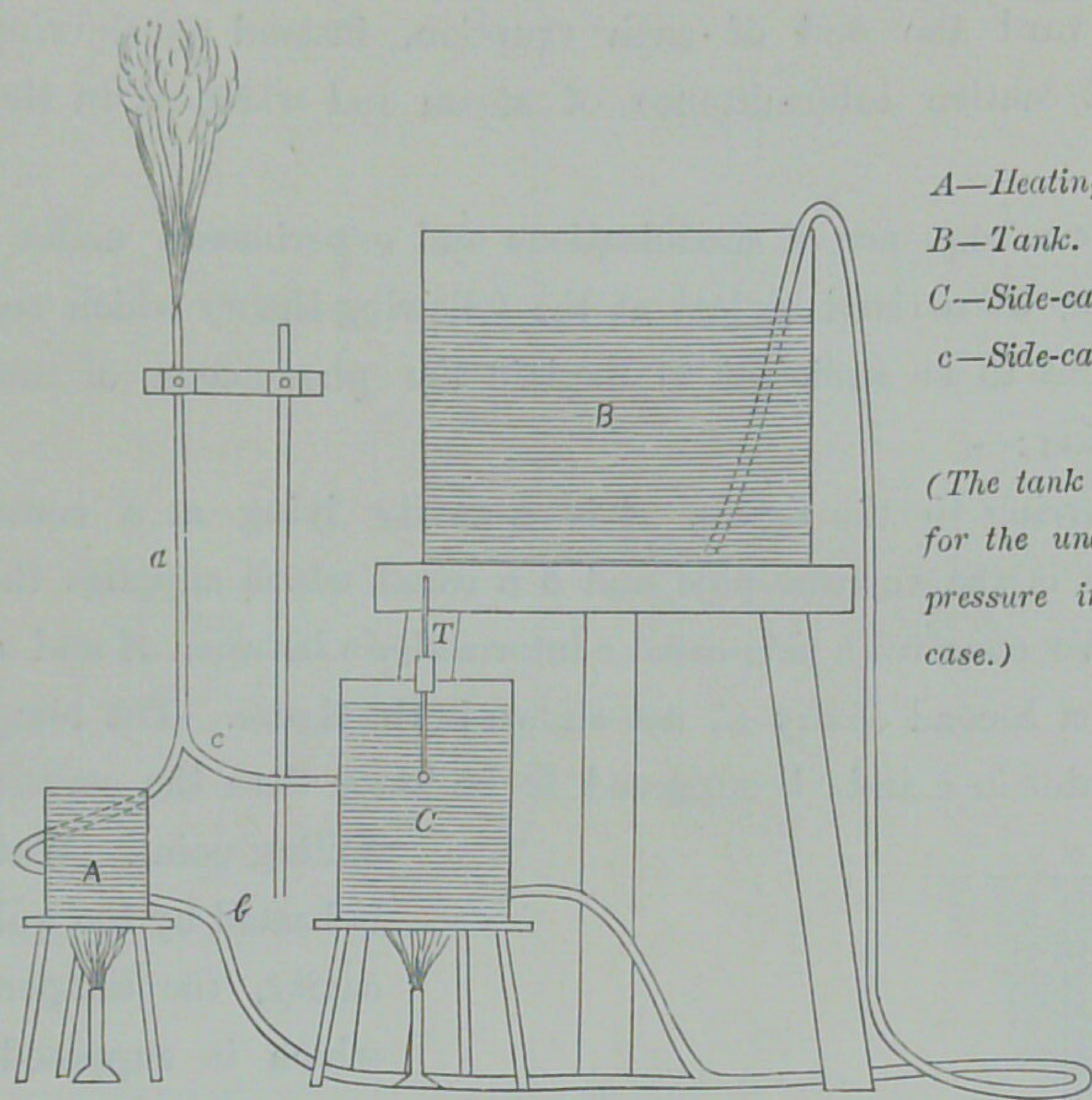


nated toward the end of each eruption, instead of showing a regular alternative intermittence of steam and water as in the actual case.

After a sequence of modifications and experiments under various conditions, we arrived at last at the following theory which seems for the present to be sufficient to explain the phenomena of the geyser in question :—

Referring to the figure, *A* is a cavity lying at a considerable depth ; *a* is the vertical pipe and *b* a canal which supplies the water to *A*. We conceive a side-canal *c* intermediate between *A* and *a*, which leads to a second cavity *C*, not shown in the figure. The temperature of the water in *a* and *c* is supposed to be lower than the corresponding boiling point. Water in *A* is heated by the wall of the cavity, the temperature of which is supposed to be decidedly higher than the boiling point at that depth. The source of the heat is probably to be attributed to the hot water and steam running through numerous veins and canals extending beneath the district. When the tension of the vapour in the cavity attains its critical value, the water is ejected and then the steam follows. When a certain amount of the steam is given off, the pressure in the neck is reduced to such a degree that the water flows in from the side-canal and stops the eruption momentarily. Soon, the downward pressure of the water column is overcome by the tension of the vapour and the second gush follows. These eruptions are repeated several times, till the vapour pressure is so reduced as to admit the comparatively cold water from the feed-canal *b* and also from *c*. Thus the activity is quenched for a while till the next eruption begins.





A—Heating cavity.
B—Tank.
C—Side-cavity.
c—Side-canal.

(The tank B stands for the underground pressure in actual case.)

A model constructed according to this view worked satisfactorily. Referring to the figure, *A* is the working cavity, *c* the side-canal fed by the second cavity *C* larger than *A*. *B* is the large tank supplying *A* and *C*; *a* is a glass tube representing the vertical pipe of the geyser. These are all connected by cauchouc tubings as shown in the figure. Both *A* and *C* are made of brass, thickly covered with asbestos to prevent cooling, and moreover, are provided with glass gauges showing the water levels inside. The cavities filled with water are heated by proper Bunsen burners, care being taken to keep the temperature of the water in *C* somewhat below the boiling point—the temperature being read by the inserted thermometer *T*. We give below the dimensions of the principal parts of our model:—

Capacity of *A*: Height = 13.0 cm; Diameter = 9 cm.
,, ,, *C*: ,, = 18.5 cm; ,, = 15 cm.
Height of the orifice above the bottom of *A* = 1 m.

Internal diameter of the vertical pipe = 5 mm.

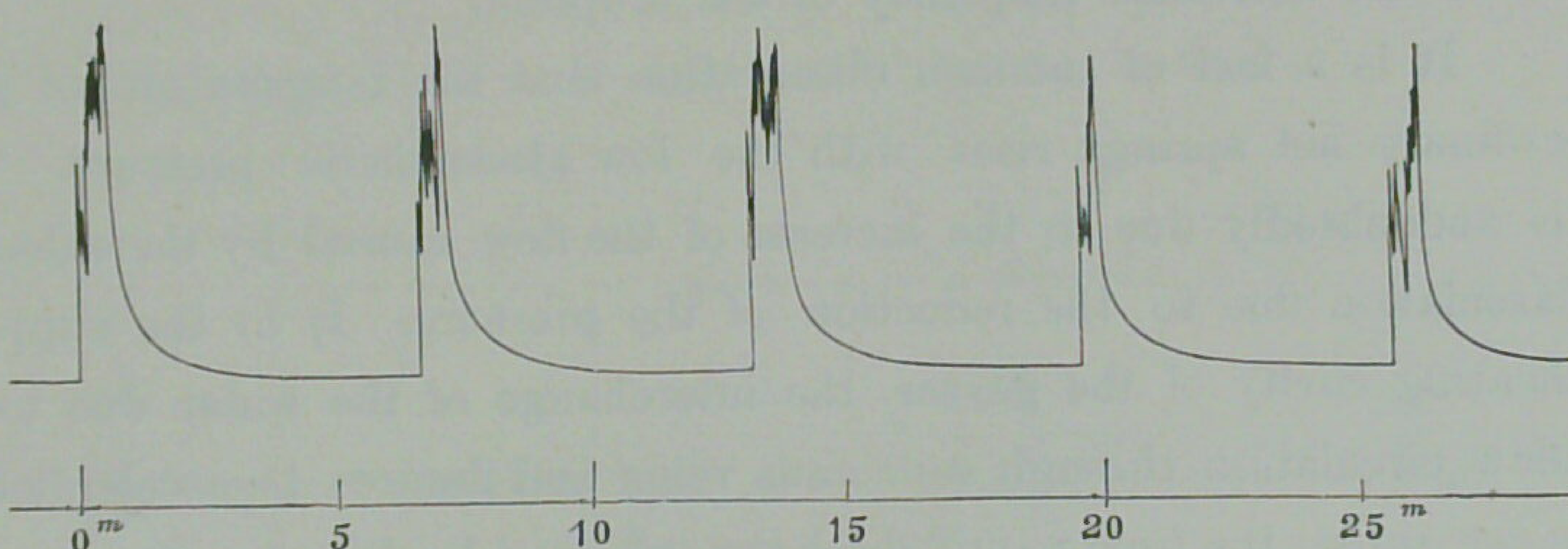
Diameter of the orifice = 2.5 mm.

,, ,, ,, tube b = 7 mm.

,, ,, ,, ,, c = 5 mm.

The period of the eruption depends on the heating of the cavity A, increased heating shortening it. The number of the intermittences increases with the temperature of the water in C. In our experiments, the mean period of the eruption was 6.5 minutes and when the temperature in C was 95°C, the number of intermittences in each eruption was 3 to 4.

In this way, the manner of the eruption was imitated even in its details. The figure here given is one of the records of the eruption



of our model, obtained by the air-thermograph already mentioned. The preliminary series of the eruption was not recorded by this arrangement, in which the air-bulb was placed somewhat high above the orifice.

The phenomena of *nagawaki* may be explained partly by the supposition that the underground temperature is raised above its normal value and so the temperature of the cavity C becomes higher than the ordinary value. If the temperature of the cavity C in our model be raised to a certain value, the eruption corresponding to *nagawaki* begins. It resembles the actual one even in some details. The cause of this occasional change of the temperature is probably the change of the subterranean volcanic activity, which keeps the underground temperature in this district considerably above the boiling point of water.

The fact that the frequency of the eruptions immediately after *nagawaki*, is nearly doubled, may partly be explained, if we consider that the temperature of the heating cavity is raised during the course of the *nagawaki* by the incessant flowing of superheated water. It may be added as a very suggestive fact that if in our model, a quantity of air be blown into the heating cavity, the frequency of the eruption increases remarkably at first and then gradually decreases with the gradual expulsion of the air by the successive eruptions; even the weakness of the activity in the actual case is imitated with great faithfulness. During a few hours after *nagawaki*, the cavity as well as the canals leading to the orifice remain drained out, so that it is possible that air or other gases may enter into the cavity and cause the increased frequency of the eruption.

It is a fact of common observation that the temperature of some ordinary hot springs rises with the low atmospheric pressure. This is undoubtedly due to the increase of the flow caused by the enhanced circulation due to the reduction of the pressure. If in the supposed heating cavity of the geyser, the interchange of the water due to the slow circulation through numerous veins and fissures be accelerated by some cause, the time required for the sufficient heating for the eruption must necessarily be prolonged. This consideration seems to explain the influence of the atmospheric pressure on the period of the eruption above mentioned. Again, the probable influence of the well-boring on the geyser, may be explained on the same basis. The wells may increase the circulation of the underground water in the vicinity and result in the retardation of the eruption of the geyser in a similar manner. Moreover, it is quite natural that the hot water would find its easier vent through a new passage opened with less resistance, at the expense of the quantity originally ejected by the old one alone. The prolongation of the first and second series of the eruption, suggests the slowness with which the pressure in the heating cavity approaches the critical value. Careful investigation of the change in the wells, leads us to the strong belief that the striking coincidence of the well-boring and the extraordinary decrease of the change in the geyser, is a necessary and not an accidental one. If the frequency of the eruption does not yet quite attain its former value, long after the stopping of the wells, we need not wonder at all, since some irreversible change in the subterranean mechanism might have happened during the period of the disturbance.

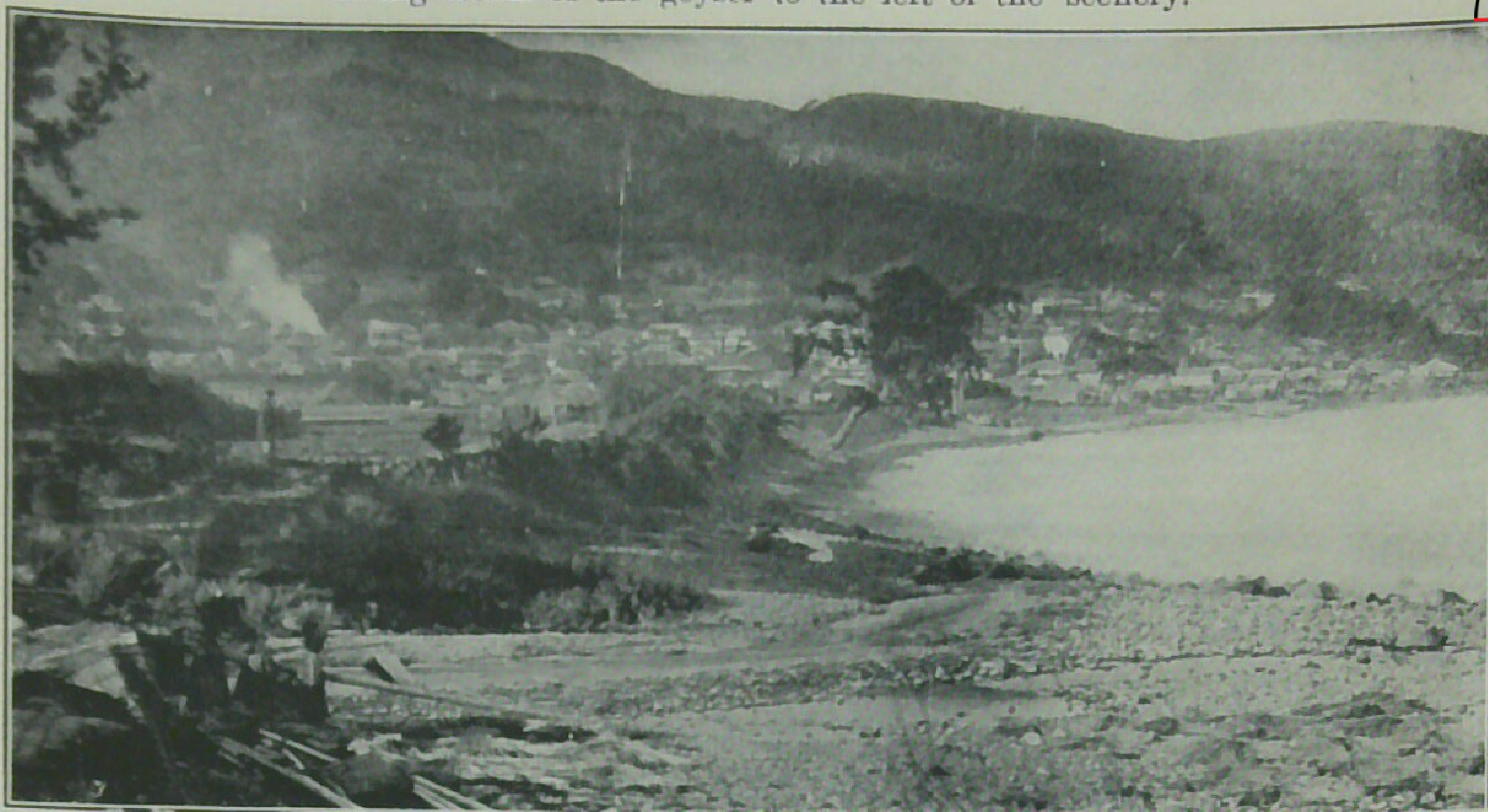
It should be noticed that almost simultaneously with the beginning of the abnormal decrease of the activity, severe shocks of earthquake were felt in the Island of Ōsima, an active volcano situated in front of Sagami Bay, about 27.5 miles from Atami. On this account, it was generally believed that the decrease was the consequence of some change of the subterranean activity associated with the earthquake. The belief seems to have its origin in the tradition that the occurrence of *nagawaki* has some relation to the activity of Ōsima. But, judging from the manner of the change of the geyser accompanying the boring and stopping of the wells, we are inclined to believe that the principal cause of the disturbance is to be attributed to the well-boring.

The question naturally arises as to the actual source of the immense quantity of the hot water poured out daily by this geyser. It seems, according to the accepted view of the modern geologists, that the water condensed from the superheated steam coming from the very depth of the earth's crust forms a considerable part of the mineral water of such a hot spring. Accepting this as a partial explanation, we feel inclined to trace the greater part of the hot water ejected by this geyser to the underground water circulating at a comparatively small depth heated by the extraordinary heat under the district. The presence of the sea-water constituents in the water of the geyser is probably due to the sea-water penetrating through several fissures in the neighbouring bay, which bears strong geological evidence to having once been the crater of an volcano.

In conclusion, we wish to express our best thanks to Mr. S. Kusumi, the apotheker to Kyūkikwan, to whom we are very much indebted for his zealous assistance during the course of our observations.

General View of Atami.

Rising steam of the geyser to the left of the scenery.



Geyser in Repose.

A: principal orifice; *a*, *a'*: minor orifices. Lead tube to the mouth.

Geyser in Full Activity.

White sprays colliding with rocks to the left.

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