THE USU-SAN ERUPTION AND EARTHQUAKE AND ELEVATION PHENOMENA.

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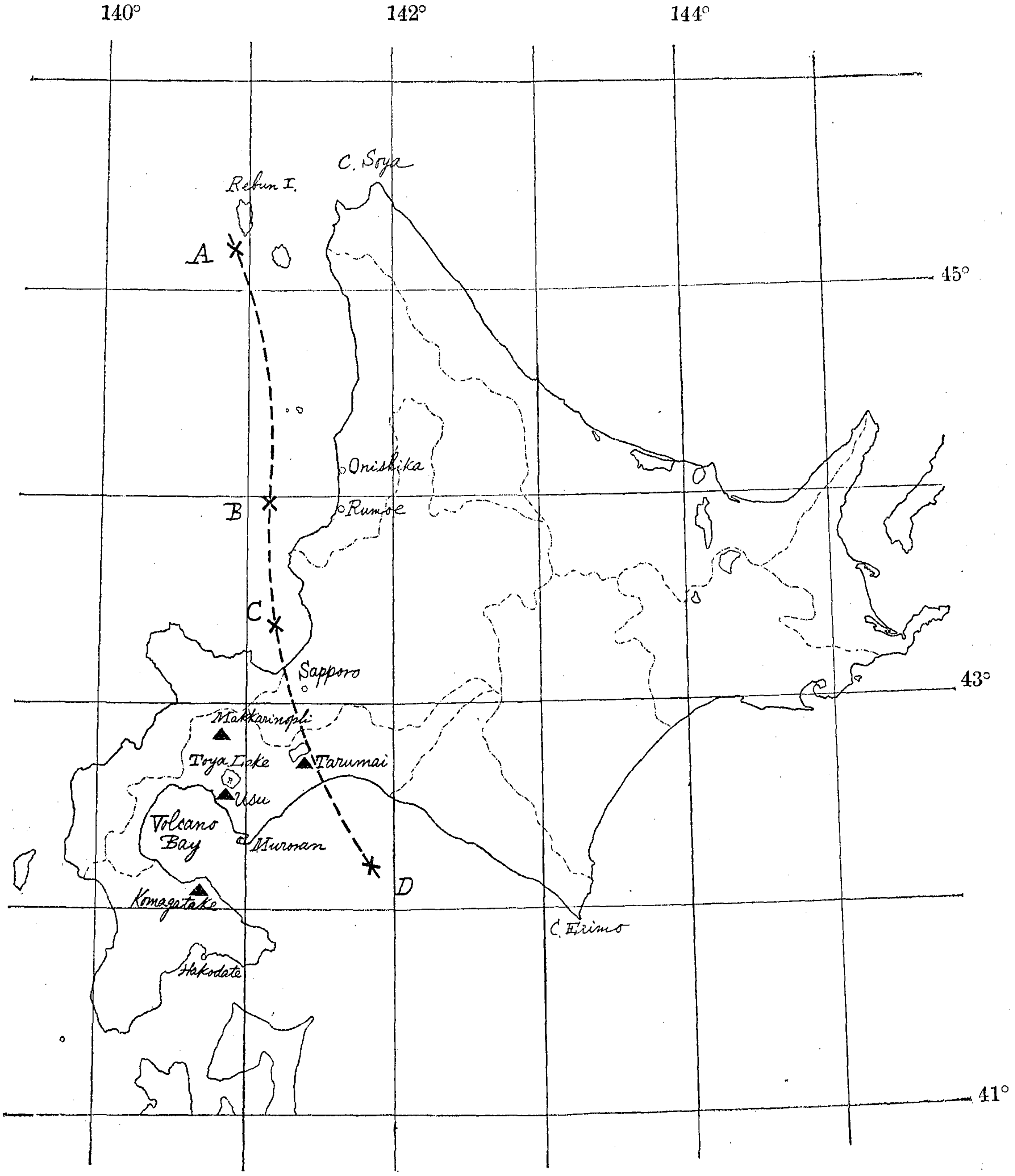
With Plates I—XIII.

1. ***Introduction.*** The eruption of the Usu-san, which began in the latter part of July 1910, and which resulted in the formation of nearly 50 craterlets, was preceded and accompanied by numerous earthquakes. The epoch of the maximum explosive activity, which was brought to an end at the commencement of August, was followed by a remarkable event of mountain elevation; this being probably an unique instance of a rapid upheaval of ground other than the formation of a lava spine or lava dome. The present author visited the scene of disturbance soon after the commencement of the eruption, namely, from July 30th to Aug. 10th, and again, after three months, from the 7th to the 12th in November. The tromometer observations, made in the Usu volcanic district at the time of the first visit, furnished highly interesting results, indicating, amongst others, the existence of small quick vibrations of the ground.

In the following pages is given a short account of the eruption and of the accompanying earthquake and elevation phenomena.

2. *Topography.* The Usu-san, in the province of Iburi, Hokkaido (Island of Yezo), is situated on the NE coast of the Volcano Bay, about 27 km to the NWN of the port of Muroran.

Fig. 1. Map showing the Relation of Volcanic and Seismic Phenomena in West Hokkaido.



Boundary of provinces.

On the opposite side of the bay there rises the Komaga-take volcano, at a distance of 55 km to the S12°.5W of the Usu-san. Again, about 48 km to the N69°E of the latter, there stands the Tarumai-san volcano, which, like the other two, made repeated eruptions in modern times. Finally, the beautiful Fuji-yama like cone of the Makkari-nopli is situated about 32 km to the N4°W of the Usu-san. (See Fig. 1.)

The geographical position of the centre of the Usu-san, whose distances from the two cities of Sapporo and Hakodate are respectively 71.1 and 86.5 km, is as follows :—

$$\varphi = 42^\circ\ 32'\ 32''\ \mathrm{N},$$
$$\lambda = 140^\circ\ 50'\ 06''\ \mathrm{E}.$$

The villages and towns at, or near, the base of the Usu-san are as follows :—

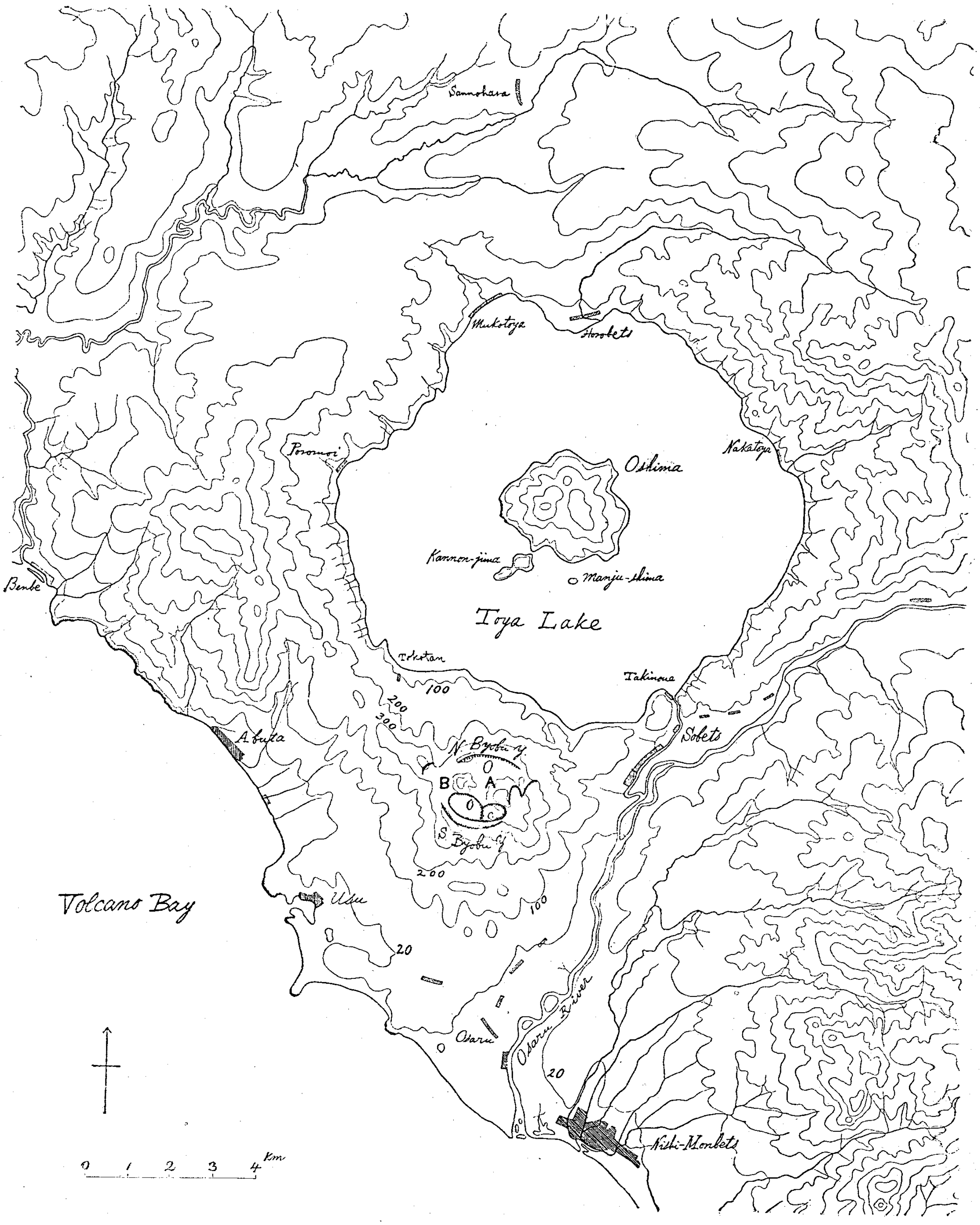
Village.	Distance from Centre of Usu-san.	Direction from Centre of Usu-san.
Nishi-Monbets	8.4 km	S 23°E
Usu	4.6	S 55°W
Abuta	6.0	N 79°W
Tokotan	3.3	N 35°W
Sobets	4.7	N 72°E

Of the five places in the above list, the two towns of Nishi-Monbets and Abuta and the village of Usu are situated on the coast of the Volcano Bay, while the village of Tokotan is at the south-western part of the shore of the Toya Lake. The town of Sobets is about 1 km from the south-eastern corner of the latter, and is on the Sobets river, which is the only outlet of the lake water.

The Usu-san, although small in size, is very characteristic in topographical features, and has an irregularly circular base, about 35 square km in area, being bounded on the north by the Lake of Toya. The nearest distances of the centre of the mountain from the latter and from the Volcano Bay are respectively 2.2 and 4.7 km. As will be understood from the photographs (Figs. 13 and 15) and the maps (Figs. 2 and 4), the volcano may be regarded as being essentially composed of a flat plateau-like elevation with a central crater, whose major and minor diameters are respectively about 2.1 km and 1.7 km. The northern and southern halves of the crater wall, whose height is 540 metres, are known respectively as the North Byobu-yama and the South Byobu-yama, on account of the evenness of their edges, the Japanese word "byobu" signifying a folding-screan. At the ESE part of the crater area, there rises the conspicuous rock dome, of 692 metres height, which is known as O-Usu or Greater Usu. Opposite to the O-Usu, that is, at the WNW part of the crater, there is a massive rock peak of 675 metres height, known as the Ko-Usu or Smaller Usu, which, although not preserving the same round form as the other, was probably at first also a dome. These huge bodies of rock must have been formed each by the pushing up of molten lava mass which solidified during the process. The three small lakes in the crater, known respectively by the names of Gin-numa (Silver pond), Kin-numa (Golden pond), and Cha-numa (Tea pond) evidently mark the sites of the explosions, which took place subsequent to the elevation of the domes.

It may be remarked that the inclination of the mountain

Fig. 2. Map showing the Topographical Features of the Usu-san and the Vicinity.



slope is steepest on the northern side, where the volcano is bounded by the Toya Lake. The surface of the latter is about 85 metres above sea-level, while the greatest water depth is 103 fathoms; consequently the lowest part of the lake bottom is about 102 metres below the sea-level. This amount is practically equivalent to the greatest depth of the Volcano Bay, namely, 59 fathoms=107 metres.

3. *Mutual relations of volcanic and seismic phenomena.* The eruptions and earthquakes, which recently took place in the western part of Hokkaido seem to indicate a close mutual relation between the volcanic and seismic phenomena in the Island, as follows.

(i) *Volcanic Eruptions.* For nearly 32 years after the great eruption of the Tarumai-san in 1874, the volcanic outbursts in Hokkaido were insignificant; there being, in the interval of 1874-1894, only five small explosions, namely, four of the Tarumai-san and one of the Komaga-take, while there was no explosion at all during the 11 years between 1894 and 1905. In Aug. 1905 began the eruption of the Komaga-take, which lasted half a month, and which marked the commencement of the recent epoch of the telluric activity. 3 years 5 months later on, in January 1909, began the remarkable eruption of the Tarumai-san, which lasted over three months, resulting in the formation of a lava dome 134 metres in height. Finally, after the further interval of 1 year and 3 months, in 1910, took place the present eruption of the Usu-san, which is situated between the two other mountains. To mention another instance of the correlative occurrence of eruptions of different volcanoes in a given region, the Bandai-san made, after an apparent quiescence for ten centuries, a tremendous outburst on July 15th, 1888; this event being followed by the explosions of the Azuma-san and of the Adatara-san, after the successive intervals of 4 years 10 months and of 7 years 2 months, respectively on May 19th, 1893, and on July 17th, 1900. The sides of the triangle formed by these three mountains, which are all in the province of Iwashiro, are smaller than those for the Hokkaido volcanoes: the Adatara-san and the Azuma-san, whose mutual distance is 9.4 km, are respectively 19 and 20 km distant from the Bandai-san.

(ii) *Seismic Disturbances.* In 1908, about 1 year previous to the recent eruption of the Tarumai-san, the Rebun-shima, situated off the northern point of Hokkaido, was disturbed by numerous earthquakes and *jinari* (earth sounds), which continued from April 20th to the end of May, the origin being under the sea to the south-west of the island. Again, on June 15th. 1910, namely, 36 days before the commencement of the present eruption of the Usu-san, there was a violent local earthquake, which originated off the coast of Teshio and caused some damage in the vicinity of the town of Rumoe. On Sept. 8th, of the same year, while the Usu-san disturbance was still going on, there took place a similar, but slightly less intense, earthquake, which was followed by numerous after-shocks. The only other known earthquake, which was violently felt at Rumoe and the vicinity had occurred 36 years previously, on Feb. 28th, 1874, causing landslips and destroying houses and bridges; on the 8th of the same month and year, there had taken place a strong eruption of the Tarumai-san, referred to in (i). Going back to an earlier epoch, there was, on Aug. 23rd, 1856, an earthquake, which was accompanied by tidal waves, and which was felt strongly in the vicinity of Yufuts, namely, along the coast of the provinces of Iburi and Hidaka; 32 days later, the Komaga-take made a large eruption.

On the map, Fig. 1, are indicated the sites of the different volcanoes and the approximate positions of the origins of the Rebun (A), the Rumoe (B), and the Yufuts (D) earthquake shocks. These latter, together with the Ishikari earthquake (C) of Feb. 9th, 1834, constitute an earthquake zone (A B C D), which runs in a NWN-SES direction and parallel to the Soya-Erimo diagonal of Hokkaido formed by the Hidaka and Teshio mountain ranges. The existence of the zone here supposed is highly probable, more especially as its southern part coincides with the Sapporo-Yufuts depression tract separating the W. from the E. part of the island.

Taking together the considerations in (i), and (ii), we may conclude that the eruptions of the different volcanoes in SW. part of Hokkaido and the earthquakes of the Rebun-Yufuts seismic zone have a marked tendency, in epochs of activity of telluric forces, to occur in close succession to one another. This relation is certainly not to be considered as merely accidental, since the earthquakes disturbing the W. part of the island are extremely rare.

4. *History of Usu-san eruptions.* The dates of the former eruptions of the Usu-san are as follows :—

(i) Aug. 16th, 1663.
(ii) January, 1769.
(iii) March 12th, 1822.
(iv) April 22nd, 1853.

Of these four cases, the first and the third were large disturbances, of which we have detailed accounts.

(i) *Eruption of Aug.*, 1663. Small earthquakes and *jinari* began on the 13th of August, while the first smoke explosion took place first in the early morning of the 16th.

(iii) *Eruption of March*, 1822. The first slight earthquake occurred at about 10 pm. of the 9th, there being two more before the morning. During the two successive 24 hours intervals there were respectively 44 and 75 shocks and *jinaris*. The seismic frequency continued to increase rapidly, so that there were nearly 100 disturbances in the course of the 6 hours preceding the noon of the 12th, the first explosion taking place first at about 2 pm. of the same day. The eruption, accompanied by lightnings, attained its maximum fury on the 15th, thereafter gradually decreasing in intensity. After 14 days from the first explosion, however, there occurred at 7 am., on the 23rd, the final catastrophe, hurling down into the Volcano Bay a tremendous avalanch of heated rocks and mud from the flank of the South Byobu-yama, and destroying the old native village of Abuta-Tokotan.

A special feature in the Usu-san eruptions is the occurrence of numerous shocks and *jinaris*, which, in the cases of (i) and (iii), preceded the first smoke explosions respectively by the time intervals of 3 days and of 2 days 16 hours. The eruption of 1910 had likewise numerous premonitary seismic disturbances, which I now proceed to discuss.

THE USU-SAN ERUPTION OF 1910.

5. *Premonitary seismic disturbances.* The premonitary earth shakings began already on July 21st. On the following day, the 22nd, 25 shocks were felt at the town of the Nishi-Monbets, which is situated 8.4 km to the S 23°E of the centre of the Usu-san. On the 23rd, the number increased to 110 ; the inhabitants of Abuta, Usu, Tokotan, and other villages at the immediate base of the mountain, fearing the occurrence of eruption, had already began, during the previous night, to leave their homes and seek shelter mostly in Benbe and Nishi-Monbets. In the course of the same day, the people of the last-named town began, in their turn, to fled to Muroran and some other places. As the seismic frequency continued to increase in a marked way, the Police Authority of the district took, in the evening, compulsory measures ordering the people in the vicinity of the volcano to go out of the radial distance of 3 *ri* (=12 km) from the latter. On the 24th, the earthquake number at Nishi-Monbets amounted to about 351, the first eruption occurring finally on the 25th, at about 10 pm. From the 25th, the seismic frequency decreased. The hourly number of earthquakes felt at Nishi-Monbets are according to the report of the Municipal Office, as follows.

HOURLY NUMBER OF SENSIBLE EARTHQUAKES UNINSTRUMENTALLY OBSERVED AT NISHI-MONBETS. JULY 1910.

Hour.	22nd.		23rd.		24th.		25th.		26th.
	AM.	PM.	AM.	PM.	AM.	PM.	AM.	PM.	AM.
0^h—1^h		4	0	3	18	15	17	3	0
1—2		3	1	1	14	9	11	8	1
2—3		2	0	4	15	13	17	9	2
3—4		2	1	4	17	16	25	0	0
4—5		2	2	3	13	5	12	2	0
5—6		3	2	2	9	15	9	0	2
6—7		0	2	0	* 13.5	18	13	1	
7—8	1	1	4	11	* 13.5	14	9	0	

Hour.	22nd.		23rd.		24th.		25th.		26th.
	AM.	PM.	AM.	PM.	AM.	PM.	AM.	PM.	AM.
8^h— 9^h	0	3	0	14	* 13.5	20	7	2	
9 —10	1	0	4	10	11	26	7	0	
10 —11	0	1	5	14	15	21	5	0	
11 —12	2	0	3	20	16	10	4	1	
Sum	4	21	24	86	169	182	136	26	
Daily Number	**25**		**110**		**351**		**162**		

The figures in the above table, which are to be regarded as giving only approximate values of the seismic frequency for Nishi-Monbets, show nevertheless that the earthquakes were most numerous during some hours previous to the volcanic outburst. This relation can be ascertained more definitely from the observation with an E-W horizontal pendulum seismograph (magnification =30) at the meteorological observatory of Sapporo, which is situated 71.1 km to the N 36°E of the Usu-san. The first premonitary earthquake recorded at Sapporo occurred on the 21st (July) at 4^h 18^m 06^s pm, there being altogether 240 shocks in the interval of the 10 days, July 21st to 30th, as follows :—

* The observation for 6—9 am, on the 24th, is wanting: the assumed hourly frequency of 13.5 is that deduced by taking the mean of the earthquake numbers for the 3 preceding and the 3 succeeding hours.

Date (July 1910).	Number of shocks Sapporo.
21st	1
22nd	3
23rd	23
24th	76
25th	84
26th	26
27th	15
28th	5
29th	6
30th	1

The following table gives the hourly and 6-hourly frequencies of the Usu-san earthquakes recorded at Sapporo.

HOURLY NUMBER OF EARTHQUAKES OBSERVED AT SAPPORO.
JULY 21st—30th, 1910.

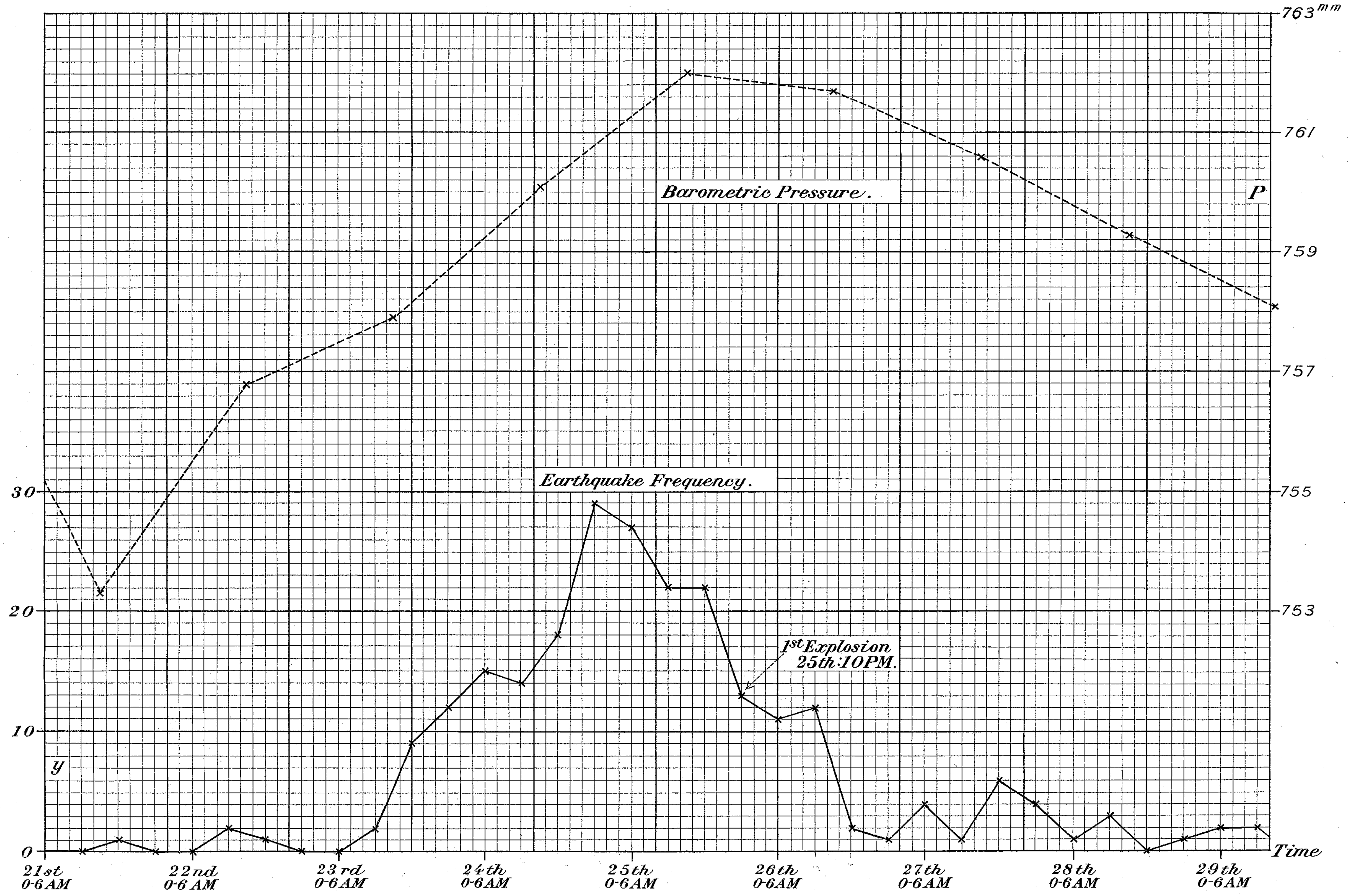
Hour \ Day	21	22	23	24	25	26	27	28	29	30
0—1 am.	0	0	0	3	4	1	1	0	0	0
1—2	0	0	0	3	5	1	0	0	0	0
2—3	0	0	0	3	5	4	0	1	0	0
3—4	0	0	0	2	5	1	2	0	1	0
4—5	0	0	0	2	5	0	0	0	1	0
5—6	0	0	0	2	3	4	1	0	0	0
Sum	**0**	**0**	**0**	**15**	**27**	**11**	**4**	**1**	**2**	**0**
6—7	0	0	0	1	5	3	0	0	0	0
7—8	0	0	0	3	5	2	1	0	0	0

Hour \ Day	21	22	23	24	25	26	27	28	29	30
8—9 am.	0	0	0	3	6	3	0	0	0	0
9—10	0	1	1	2	2	3	0	0	1	1
10—11	0	0	0	3	2	0	0	1	1	0
11—12	0	1	1	2	2	1	0	2	0	0
Sum	**0**	**2**	**2**	**14**	**22**	**12**	**1**	**3**	**2**	**1**
0—1 pm.	0	0	2	4	2	0	2	0	0	0
1—2	0	0	1	2	4	0	2	0	0	0
2—3	0	0	3	4	7	1	2	0	0	0
3—4	0	0	1	3	3	0	0	0	0	0
4—5	1	0	1	2	4	0	0	0	0	0
5—6	0	1	1	3	2	1	0	0	0	0
Sum	**1**	**1**	**9**	**18**	**22**	**2**	**6**	**0**	**0**	**0**
6—7	0	0	1	5	2	0	0	0	0	0
7—8	0	0	2	6	3	0	0	0	2	0
8—9	0	0	2	4	3	0	1	0	0	0
9—10	0	0	1	4	0	1	0	0	0	0
10—11	0	0	2	6	3	0	2	0	0	0
11—12	0	0	4	4	2	0	1	1	0	0
Sum	**0**	**0**	**12**	**29**	**13**	**1**	**4**	**1**	**2**	**0**
Total Sum	**1**	**3**	**23**	**76**	**84**	**26**	**15**	**5**	**6**	**1**

Fig. 3. Time Variation of the Frequency of the Earthquakes which preceded the Usu-san Eruption.

y = 6-hourly number of the Usu-san Eqkes observed instrumentally at Sapporo.

p = Daily mean barometric pressure at Hakodate.



According to the above table, the earthquakes were most numerous from 6 pm. on the 24th to 9 am. on the 25th, during which interval the hourly seismic frequency was nearly constant and had an average value of 4.8 shocks. During the next 13 hours, at the end of which interval the first volcanic explosion took place, the earthquakes were already considerably reduced in number, the average frequency being 2.8 shocks per hour. The mean seismic frequencies during the 12-hours intervals succeeding the first eruption were respectively 2.3 and 0.33 shocks per hour. I tabulate below the mean hourly seismic frequencies during the successive epochs between July 23rd and 26th :—

(i)	23rd, 9 am.—23rd, 7 pm. :	1.2	shocks per hour.
(ii)	„ , 7 pm.—24th, Noon :	2.3	„
(iii)	24th, Noon — „ 6 pm. :	3.0	„
(iv)	„ , 6 pm.—25th, 9 am. :	**4.8**	„
(v)	25th, 9 am.— „ 10 pm. :	2.8	„
(vi)	„ , 10 pm.—26th, 10 am. :	2.3	„
(vii)	26th, 10 am.— „ , 10 pm. :	0.33	„

In each of these seven epochs, the seismic frequency remained approximately constant, while the lengths of (ii), (iv), (v), (vi), and (vii) were from 12 to 17 hours. The variation with time of the 6-hourly earthquake frequency is illustrated in Fig. 3, from which it will be seen that the rate of increase of the earthquakes between the 22nd and the 24th is nearly equal to that of their decrease between the latter date and the 26th.

The increase rate from the 21st to the 24th of the premonitary shocks observed at Sapporo may approximately be represented by the equation :

$$\log y = 0.1619\ x - 0.5829 \quad \ldots\ldots\ldots\ldots (1)$$

in which y is the number of the earthquakes occurring in the 6-hours denoted by x, whose origin ($x=0$) corresponds to the time interval of 0–6 am. of the 21st (July).

The comparison of the actual and calculated values of y corresponding to different x's are as follows :

	Date.	y (actual)	y (calc.)
$x=0-7$:	21st, 0 am. to 23rd, noon	0.75	0.97
$x=8-9$:	23rd, 0 pm. to 12 pm.........	10.5	6.2
$x=10-11$:	24th, 0–12 am...............	14.5	13.1
$x=12$:	„ , 0– 6 pm..............	18.0	22.9
$x=13$:	„ , 6–12 pm...............	29.0	33.3

Again, the decrease rate, after the 24th, 6 pm., of the frequency of the Usu-san earthquakes observed at Sapporo may approximately be represented by the equation

$$\log y=1.742\ x-0.1693 \quad \text{..........} \quad (2)$$

in which y is the number of the earthquakes occurring in the 12-hours denoted by x, whose origin ($x=0$) corresponds to the time interval of 6 pm., 24th—6 am., 25th. The comparison of the actual and calculated values of y are as follows :

Date.	y (actual)	y (calc.)
$x=0$ (6 pm., 24th—6 am., 25th)	56.0	55.2
$x=1$ (6 am., 25th—6 pm., „)	44.0	37.4
$x=2$ (6 pm., „ —6 am., 26th)	24.0	25.2
$x=3$ (6 am., 26th—6 pm., „)	14.9	17.1
$x=4-10$ (6 pm., 26th—6 am., 30th)	3.9	3.6

The agreement of the actual and calculated values of y is not so satisfactory, if we adopt the usual hyperbola relation : $y=k/(x+h)$, in which h and k are constants, and which represents with considerable accuracy the time relation of the frequency of after-shocks of a great earthquake. It is thus probable that the

Usu-san earthquakes, which happened after the epoch of the maximum seismic frequency, are essentially different in nature from the ordinary after-shocks. The shakings, which preceded the maximum epoch, are, however, probably similar to the fore-shocks of a destructive earthquake.

To sum up: The premonitary earthquakes which began on the 21st (July) attained the maximum frequency during the 15 hours between 6 pm., on the 24th, and 9 am., on the 25th. The first volcanic eruption took place 13 hours further on. The strongest of these fore-shocks occurred on the 24th and 25th, as is described in the next §.

6. *Strongest fore-shocks.* The severest among the numerous Usu-san earthquakes occurred on the 24th (July) at 3.49 pm., and the next strongest on the 25th at 4.39 pm., namely, respectively, 30 hours and $5\frac{1}{2}$ hours before the first volcanic outburst. In Abuta, these shocks were sufficiently strong to partially destroy two similar brick ware-houses, in the manner illustrated in Fig. 18. From the latter it will be readily understood that the extremely defective construction of these buildings was responsible for the damage done to them; the internal timber framing knocking down the external brick walls, which in turn crushed down the adjacent wooden houses. In the same town, a small stone building and a stone monument were entirely overthrown by the shock on the 25th, due, entirely to bad foundation making. No serious damage was, however, done to the wooden houses in the whole disturbed area.

The radius of the area of sensible motion of the strong earthquake of July 24th was limited, in the NE direction, to about 60 km, but extended, in the SW direction, to 140 km. This markedly unsymmetrical propagation of the earthquake motion evidently depended on the differences in the geological formations of the district. Thus, to the NE of the Volcano Bay there lies an extensive district of volcanic rocks about 70 km in diameter, which must reflect back in a great measure the seismic waves originating at the Usu-san from the foci of small depth. On the other hand, the region to the W and SW of the Volcano Bay is for the main part made up of soft tertiary formations, the motion being there consequently much magnified.

That volcanic earthquakes, whether accompanying an eruption or not, never attain the magnitude of a really destructive shock, so far as Japanese wooden buildings are concerned, has been verified on several other occasions. Thus, the strong Asama earthquake of May 26th, 1908 was intense enough to break down some rock fragments from the old crater walls of the volcano; yet no house at the base of the mountain was damaged. Again, several of the Unsen-dake earthquakes, which preceded the eruptions of the volcano from Feb. 12th to May 21st, 1792, were strong enough to cause in the town of Shimabara cracks of the ground and some damage to the houses; still none of the latter was overthrown. I believe that in Japan a certain precaution taken in the construction of wooden houses would ensure their perfect immunity from volcanic shocks, however violent. The result would be entirely different if houses be built of material without tensile strength. Thus, for instance in southern Italy, where houses have no frame work, and are mostly constructed of badly cemented stone pieces volcanic earthquakes caused sometimes a considerable amount of loss of life and property.

7. *Relation to barometric pressure.* According to the observation at the meteorological observatory of Hakodate, which is 86.5 km to S 6°W of the Usu-san,* the daily mean barometric pressure in the second half of July and the first half of August (1910) was as follows :—

BAROMETRIC PRESSURE AT HAKODATE.

(With the freezing point correction).

July 16th	757.50 mm		Aug. 1st	752.43 mm	
17th	57.12		2nd	53.17	
18th	57.68		3rd	55.49	
19th	59.36		4th	57.83	
20th	57.22		5th	59.51	
21st	**53.30**	min. 751.2 mm, at 3-4 am.	6th	61.43	
22nd	56.81		7th	61.75	(max.)
23rd	57.87		8th	61.00	
24th	60.05		9th	61.18	
25th	**62.00**	max. 762.9 mm, at 9 pm.	10th	58.88	
26th	61.67		11th	55.31	
27th	60.60		12th	53.81	
28th	59.31		13th	54.95	
29th	58.12		14th	55.52	
30th	56.17		15th	58.43	
31st	52.32 (min.)		16th	61.22	

It will be noted that the premonitary shocks began to occur on July 21st when the barometric pressure was minimum (=753.3 mm), while the first volcanic explosion happened on the 25th at the moment of a barometric maximum (=762.0 mm), so that as illustrated in Fig. 3, the time variation of the seismic frequency between the 21st and 30th of July, followed approximately that of the barometric pressure.

8. *General account of eruption.* The northern flank of the Usu-san, namely, the slope of the North Byobu-yama where the

* The Usu-san belongs to the meteorological district of Hakodate.

scene of the present disturbances was laid, dips into the Toya Lake with a comparatively small angle of inclination, leaving along the southern coast, for a length of about 5 km, a narrow piece of flat ground. (See Fig. 4.) The latter, whose width varies between 500 and 700 metres, is limited on the east by a round hill, called East Maru-yama,* while at the western end there is another hill called Kompira-yama, the heights of these eminences being respectively about 260 and 240 metres above sea level, that is to say, about 175 and 155 metres above the lake level. Further, there is at about two-thirds from the east of the length of the region under consideration, there is also a small round hill called West Maru-yama,* whose height is about 180 metres above sea-level, or 95 metres above the lake level. As will be seen from the account given below these three hills, each covered by dense forest of large trees, played very important parts in the volcanic phenomena in question.

The first outburst, which was a small explosion and threw out a quantity of ashes and rock fragments, took place on July 25th, at 10 pm., from the NW side of the Kompira-yama. The newly completed Kompira Temple was just in front of, and only about 400 metres from, the origin of outburst, and suffered very badly, its roof having been pierced by numerous falling stones, the largest of which was about 10″ in diameter. (See Fig. 17.) The extreme distance of projection of the stones, which was sidewise and directed towards NW, was about 600 metres. The second explosion, similar to the first, took place on the next day, the 26th, at 2.12 pm., from the W side of the same Kompira-yama. In each of these two cases, the eruptive energy was spent by the

* Literally "round mountain", so named on account of the rotundity of form.

single explosion, leaving behind, instead of a perfect craterlet, simply a sort of opening or crack formed on soft earth hill side.

The two introductory craterlets were quickly followed by others, some of which made striking paroxysmal explosions for several days. On the 10th of August, I could estimate the total number of the craterlets to be at least 28. The explosions from new sites, however, continued to occur till the end of the year, such that I counted, on Nov. 12th, altogether 45 different crater-lets, whose diameters varied from 30 to 250 metres, and whose positions are indicated on the map (Fig. 4.). The dates of the formation of some of the craterlets, numbered 1 to 15, are, so far as can be ascertained, as follows :—

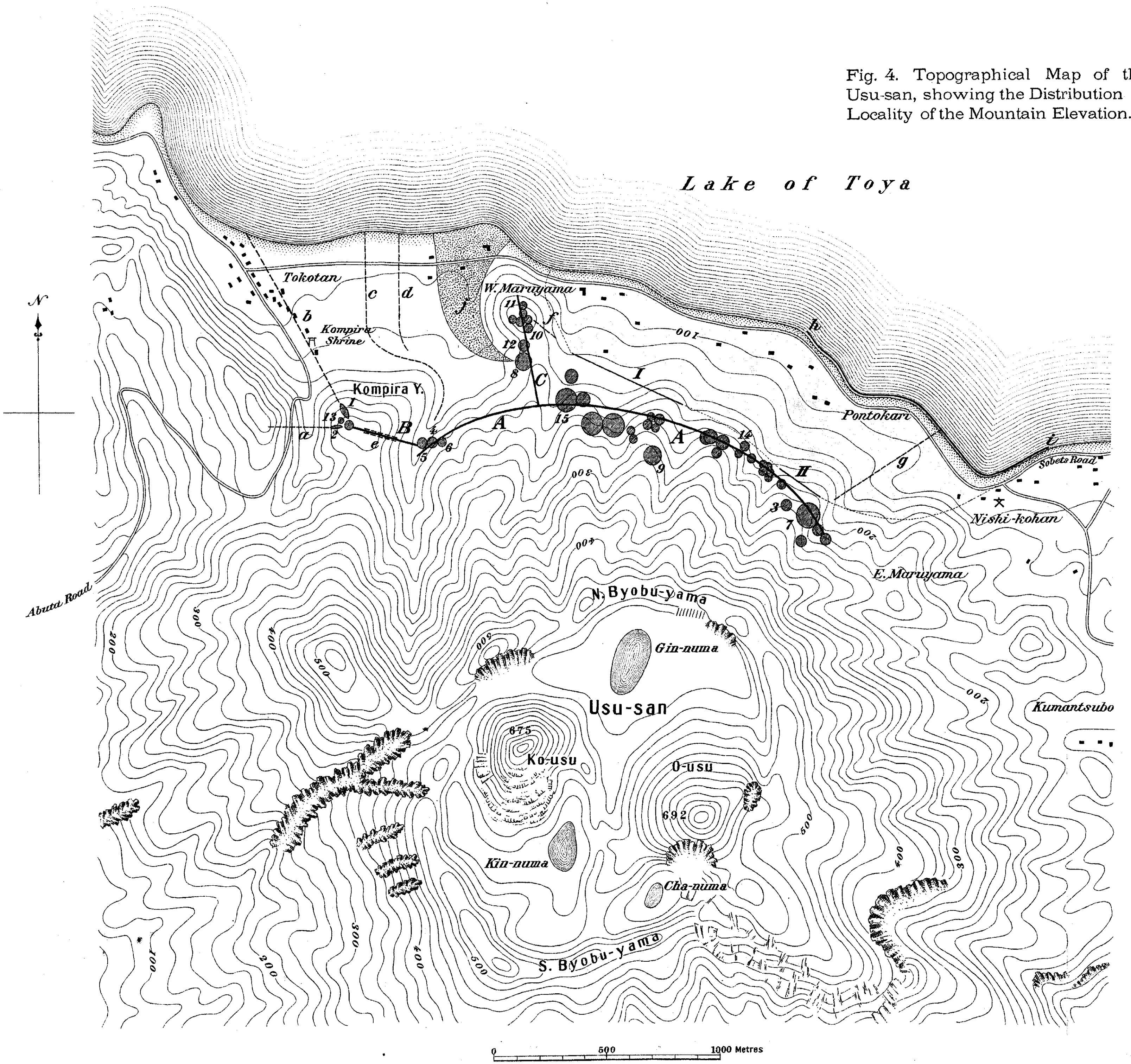
No.	Date of Formation (1910).		Locality.
1	July 25th ;	10.00 pm.	Kompira-yama.
2	26th ;	2.12 ,,	Kompira-yama.
3	27th ;	2.30 am.	Kumantsubo.
4	,, ;	5.30 pm.	Kara-sawa.
5	,, ;	6.00 ,,	Kara-sawa.
6	,, ;	6.30 ,,	Kara-sawa.
7	28th ;	11.00 am.	Kumantsubo.
8	,, ;	5.00 pm.	W. Maru-yama.
9	30th ;	5.00 ,,	Taka-ana.
10, 11	Aug. 2nd ;	3.00 am.	W. Maru-yama.
12	,, 7th ;	early morning	W. Maru-yama.
13	,, 8th ;	2.30 pm.	Kompira-yama.
14	Sept. 3rd.	——	
15	Oct. 2nd.	——	

The formations of these different craterlets, 1 to 15, are in order of time, but by no means always consecutive, as the dates of the remaining 30 are not included in the above list.

From the map (Fig. 4), it will be observed that the different craterlets, distributed over an extension of 4 km, are arranged in the following definite ways: *firstly*, along an E-W arcual zone AA, which may be regarded as being on the average identical with the 200-metres contour line of the North Byobu-yama, at a mean distance of about 800 metres from the lake coast; *secondly*, along two zones B and C, which form respectively the axes of the Kompira-yama and of the West Maru-yama, and are more or less radial to the arc AA. These two systems are naturally the forms in which the zones of explosion centres, or volcanic weak lines, can be manifested. As the heights of these hills are respectively 240 and 180 metres, we may conclude that the different explosion centres along the three zones A, B, and C, all occurred approximately at the same elevation above sea-level. It is also noteworthy that the principal explosion zone AA ends on the east at the flank of the East Maru-yama, while its western continuation, the zone B, extends to the Kompira-yama; these two hills thus constituting the limits, between which the outbursts were confined. Further, it is quite remarkable that, although the West Maru-yama was a seat of very active explosive energy, yet no eruption did occur on the flat tracts extending to its east and its west along the coast of the lake. (See §13.)

The principal order of the formation of the different craterlets was as follows:—The first two explosions, took place at the western side of the Kompira-yama, namely, at the western end of the zone of disturbance, while the 3rd explosion (No. 3) took place near the eastern end of the latter. The next explosion group, Nos. 4, 5, and 6, happened again towards the west, at the eastern

Fig. 4. Topographical Map of the Northern Flank of the Usu-san, showing the Distribution of the 45 Craterlets and the Locality of the Mountain Elevation.



Signs

....New Craterlets.
....Elevation Region.
....Mud Stream.
文 ....W. Koban School.
⛩ ....Kompira Temple.
▪ ....Building.

AA, B,C, ... Explosion Zones.
a,b,c,d,e,f,g, ... Fissures radiating from the craterlets.
I,II....Dislocation Lines produced by the elevation of the lake side tract.
h i....Elevated portion of the lake coast.

flank of the Kompira-yama, while there followed the formation of the craterlet No. 7 in the contrary direction, at the eastern end. Then, the craterlet No. 8 was formed at the southern base of the West Maru-yama, followed by No. 9 nearly at the centre of the zone. Thereafter several explosions took place from the top of the West Maru-yama, the explosive energy being then transferred again to the zone AA, at No. 15 and other craterlets. There was thus, in the occurrence of the different explosions, a certain sort of alternations of position, from west to east, which began at the extreme ends, and, after a certain repetitions, finally confined in October (1910) the outbursts to the neighbourhood of the middle of the main zone.

9. *Character of eruption.* All the different craterlets were formed in the thick layer of soft earth, there being, in fact, no exposure of solid rocks in the whole base district of the North Byobu-yama. As may be expected from this circumstance and also from the formation of numerous craterlets, none of the explosions was of very gigantic magnitude. On the contrary, several, if not most, of these proceeded on quietly, and were accompanied neither by a loud detonation nor a sensible earthquake shocks; the eruption in such a case, consisting of a continuous or paroxysmal ejection of ashes, mixed in some instances, with stones. There was no outflow of molten lava, and it was only on the occasion of the first explosion that volcanic fires were said to have been seen. The majority of the craterlets had very short duration of activity and threw out smoke only for a few hours or for one day or so; being then reduced to complete rest. A few of the craterlets, however, preserved their activity for several days and became gradually enlarged up to diameters of over 200 metres. These two classes of explosion centres are indicated in Fig. 4

respectively by small and large red circles. When the eruption phenomena were at their height, the sight presented by the scene of disturbance was magnificent, there being sometimes smoke columns issuing simultaneously from six or seven different sources. (See Fig. 9.)

One of the most active explosion centres was the Kumantsubo craterlet, No. 7 in the list in the preceding §, which was formed close to the flank of the East Maru-yama, and which made intermittent displays of its explosive energy during several days. Each of the violent paroxysmal outbursts threw in quick succession masses of dense smoke to considerable heights with such force and velocity that these appeared, as it were, like so many monstrous black spear heads darted vertically against heavens. When the projection of these "spears," one of which is shown at the left-hand side of Fig. 8, had been continued for a sufficient length of time, the piled up heaps of smokes began to fall down as shown in Fig. 7, like vast masses of dishevelled hair. The numerous stones or rock fragments thrown out by these outbursts looked like a dispersing group of small birds, and the course of some of them could be distinctly followed with glasses or even with naked eyes. Among these there were several, each of which dragged behind a short thread or tail of white steam, indicating the comparatively great depth of their origin. On Aug. 3rd, I have observed a number of the stones which took 10 to 11 seconds in falling from their limit of ascent down to the level of the craterlet mouth : the corresponding vertical rise must therefore be about 500 metres, their initial velocity of projection being 100 metres per sec. Horizontally the stones did not fall out of a radial distance of about 300 metres. The smoke "spear heads," which rose to a maximum height also of about 500 metres, seemed to be shot up about twice as quickly as the stones. The life history of the Kumàntsubo craterlet, which seems to have reached its maximum activity 5 or 6 days after its first formation, is as follows :—

July 28th. First explosion at 11 am.
Aug. 2nd .... Very active, violent explosions occurring in succession.
,, 3rd .... Do.
,, 5th .... Considerably reduced in activity, there being, in the course of the after-noon, only one strong explosion.
,, 6th .... In the after-noon, a great explosion occurred first at 4.06 pm., continuing more or less active till 6 pm. The "spear heads" rose from at least 5 different points in the craterlet.
,, 7th .... There were only explosions of moderate force, which happened at $7.^h 04^m$ am, and at $2.^h 49.^m 59^s$ to $2.^h 54.^m 44^s$ pm.
,, 8th .... Very inactive, there being only insignificant emission of smoke.
,, 9th .... Do.
,, 10th .... Only small quantity of white vapour came forth.

The violent explosions from the Kumantsubo craterlet on Aug. 3rd occurred, for instance, as follows: from $0.^h 28.^m 06^s$ to $0.^h 31.^m 21^s$ pm.; from $0.^h 36.^m 29^s$ to $0.^h 39.^m 46^s$ pm.; from $0.^h 50.^m 21^s$ to $0.^h 52.^m 00^s$ pm., etc. The following is the detail of one of such outbursts, also on Aug. 3rd :

$3.^h 07.^m 46^s$ pm. .... End of a strong explosion.
10. 01—$10.^m 51^s$ Perfectly smokeless.
10. 51 .... White vapour appeared.
12. 01 .... Some black smoke, immediately replaced by white vapour.
15. 51 ...... Some black smoke, soon reduced to white vapour.
20. 51 .... Do.
23. 21 .... Do.
26. 06 .... Reduced to complete rest.
30. 51 .... Slight amount of white vapour.
35. 56 .... Commencement of a violent explosion, which continued till

40.^{m}31^{s} pm. .... End of violent outburst.
42. 11 .... Smoke completely disappeared.

The craterlets of the smaller type are exemplified by those formed on the top of the West Maru-yama, where there were no less than 6 explosion holes, neighbouring closely with each other. One of these is illustrated in Fig. 11. The craterlet No. 8, formed at the south base of the same hill, was quite characteristic and threw out, after each of its stronger outbursts, a mud stream, which descended along the gently sloping ground at the west of the hill into the lake; the accumulated mud finally covering a triangular area, 800 metres in length and 450 metres in base. (See Fig. 12.) This was much larger than the others which issued forth from some of the craterlets to the east of the West Maru-yama. On Aug. 1st, I had the opportunity to witness several of the mud flows from the craterlet in question, each time hot steaming mud rushing down in folding waves with an enormous velocity of 25 to 30 miles per hour.

10. ***Increase of lake water.*** The rainfall in the vicinity of the Usu-san was, during July and August, 1910, was comparatively insignificant; the amounts of precipitation (at Abuta) in these two months were 14.6 mm. and 73.2 mm., while there were (at Sobets) in September and October 125.5 mm., and 85.7 mm. of precipitation respectively. In spite of this fact, the water of the Toya Lake rose unusually high, i.e., more than 1 foot above its usual level, about the time of commencement of the Usu-san eruption, in the latter part of July; remaining in nearly the same condition during the following month of August. (See also §12). The consequent increase of water in the Sobets River, the only outlet of the lake, amounted to 2 feet.

11. ***Elevation of lake coast.*** The present author discovered accidentally on Aug. 6th (1910), that the eastern part of the southern coast of the lake, about 1 mile in length (Fig. 4), had risen nearly 1 metre out of the water, so that the latter retreated by a horizontal distance of 6.5 metres. At the foot of the East Maru-yama, the recession of water, which in the course of the next 24 hours was increased by 6 feet, was continued at successively decreasing rates, bringing at the end of August, the total amount to about 21.2 metres, which corresponded to the relative rise of the coast by about 1.4 metres. These facts were at once seen to indicate the actual elevation of the coast as the lake water was at that time markedly abundant (§10), and, more especially, as the heights of water at other points of the lake coast were practically constant and indicated no corresponding change at all. To observe accurately the rate of the elevation, the level of the water was, since Aug. 10th, daily measured by means of a graduated level-gauge erected at the front of the West-Kohan elementary school, which is at the east end of the elevation zone. Simultaneously the height of the lake level was, by similar means, also daily read at Takinoue and Tokotan, which are situated respectively at the SW and SE corner of the lake. (See Fig. 2.) The variations of the level at the two latter places were alike each other.

The amount of elevation between Aug. 6th and Nov. 10th (1910), of the lake coast at the W. Kohan school relative to the height of the water surface on Aug. 6th, deduced by comparing the daily readings of the level gauge at that place with those at Takinoue and Tokotan, is shown in the following table.

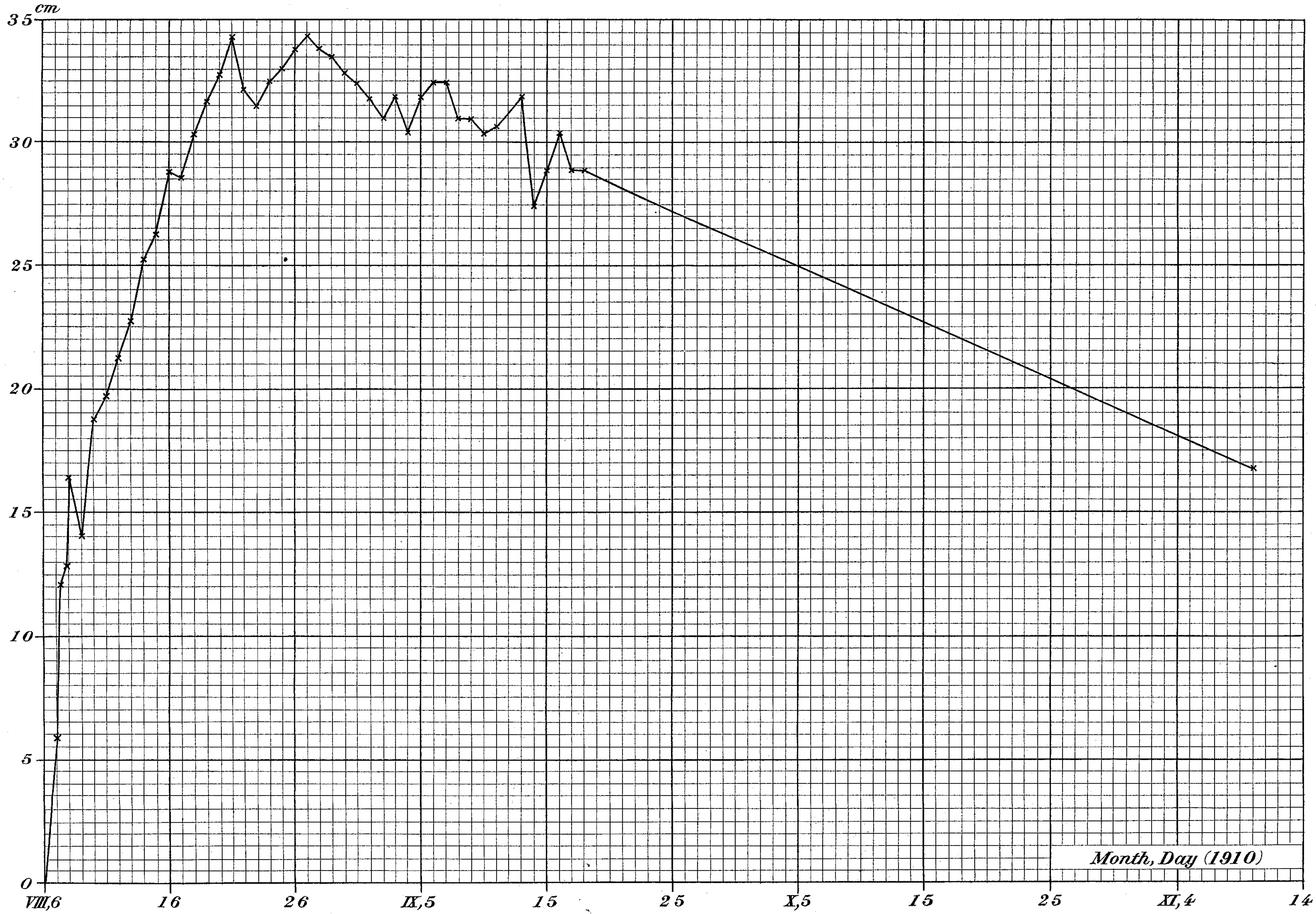
ELEVATION OF LAKE COAST IN FRONT OF WEST-KOHAN SCHOOL.
AUG. 6th TO NOV. 10th, 1910.

Date (1910).	Elevation of Lake Coast. (Integral Amount)	Date (1910).	Elevation of Lake Coast. (Integral Amount)
Aug. 6th *........	...... 0.0 cm.	Aug. 28th	...... 33.8 cm.
7th ; 0.30 pm.	5.8	29th	33.4
„ ; 6.00 „	12.1	30th	32.8
8th ; 8.00 am.	12.7	31st	32.4
„ ; Noon.	16.4	Sept. 1st	31.8
9th ; Noon.	14.0	2nd	30 9
10th	18.8	3rd	31.8
11th	19.7	4th	30.3
12th	21.2	5th	31.8
13th	22.7	6th	32.4
14th	25.2	7th	32.4
15th	26.4	8th	30.9
16th	28.8	9th	30.9
17th	28.5	10th	30.3
18th	30.3	11th	30.6
19th	31.7	12th	—
20th	32.7	13th	31.8
21st	34.3	14th	27.3
22nd	32.1	15th	28.8
23rd	31.3	16th	30.3
24th	32.4	17th	28.8
25th	33.1	18th	28.8
26th	33.8	⋮	⋮
27th	34.3	Nov. 10th	16.7

* The level-gauge readings, with the exception of those on Aug. 7th to 9th, have generally been made at about 10–11 am.

Fig. 5. Elevation of the Coast of the Lake of Toya.

Aug. 6th to Nov. 14th, 1910.

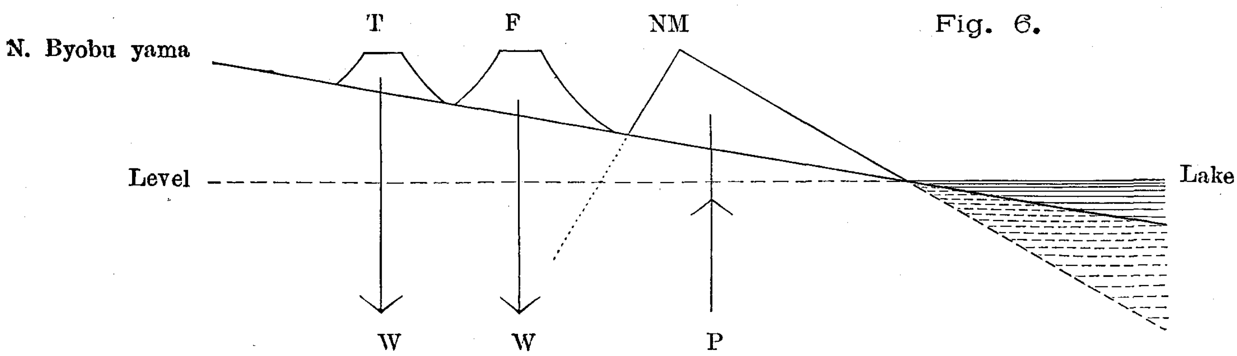


As is illustrated in Fig. 5, the elevation after Aug. 6th of the lake coast went on rapidly till the 10th, increasing the height in the course of the 4 days by 18.8 cm. During the next 11 days the elevation was continued at a little slower rate, the greatest height of 34.3 cm. being reached at on the 21st. Thereafter the elevation ceased, the height being reduced on Sept. 18th to 28.8 cm., and on Nov. 10th to 16.7 cm.; i.e., half of the amount of elevation acquired during the 15 days, from 6th to 21st, Aug., was again reduced back in the course of the next 80 days. It is hereby to be remarked that the amount of the level rise at the West-Kohan school was probably only about one-third of that at those parts of the coast where the elevation was maximum.

12. "*New Mountain.*" As may easily be imagined, the elevation phenomena were not confined to a portion of the lake coast. On the contrary, the whole base of the North Byobu-yama between the West and the East Maru-yama's, was uplifted in a remarkable manner. This tract, about 2700 metres in length and about 600 metres in width, is bounded on the Byobu-yama side by the two dislocation lines I and II (Fig. 4), which run on the outside of, and quite close to, the explosion zone AA. Especially, the area to the north of the line I, for the length of about 1 km, was raised up into a mountain with the ash-covered trunks of the old grown up trees still standing on it. (See Fig. 14). The inside of this "New-Mountain" is made up of the steep steaming dislocation surface, about 94 metres in height, whose inclination angle varies from 30° to 60°; there were exposures of the rock fragments of different dimensions embedded in soft earth, but no massive layer of lava was visible. (See Fig. 16.) The outer side slopes down directly into the lake with an inclination angle of 30°. (See Fig. 15.) It is highly likely that the commencement of the elevation of the ground in question was at about July 21st, simultaneously with the first occurrence of the premonitary earthquakes. Still it was after Aug. 20th that the appearance of the New Mountain began to attract general attention. The process of the elevation considerably advanced already at the commencement of September, and the houses at this part of the lake coast, where the slope of the ground had been only some 5°, were, in consequence of the increasing inclination, overthrown on the 7th of that month. On Nov. 8th to 10th (1910), the height of the top ridge of the New Mountain was found by means of aneroid barometers to be 210 metres(=690 feet) above the lake level, i.e., about half of the height of the North Byobu-yama whose top edge is 400 metres above the same plane of reference; this is clearly shown in Fig. 13, which is a view taken from the small Manju-shima island in the lake about 2800 metres from the coast. As the top of the New Mountain had originally (i.e., before the commencement of the disturbances) been at a height of about 55 metres above the lake, the actual amount of elevation was 210–55=155 metres (=510 feet), giving, for the time interval of 100 days from the end of July to the commencement of November, an average rate of upheaval of 1.55 metres (=5.1 feet) per day.

An interesting fact about the New Mountain is that its height on Nov. 10th (1910) was, as stated above, 210 metres above the lake, and therefore practically identical with the heights of the two highest cones or craterlets, namely, the Fuji-yama and the Taka-Ana, each of which was about 212 metres (=700 feet) in height. It appeared as though the upward elevating force was thus just hydrostatically counterbalanced by the downward pressure due to the weight of the craterlets. From these considera-

Fig. 6.



T....Taka-Ana Craterlet.
F....Fuji-yama „
NM....“New Mountain.”
W....Downward Pressure.
P....Upward Force.

tions I concluded at the time of my second visit to the Usu-san, in Nov. (1910), that the height of the New Mountain was then already at its maximum limit. (See Fig. 6.) This supposition proved to be correct, the elevation having afterwards been a little reduced, such that in April 1911 the height of the top was, according to aneroid determinations of Mr. Ito, of the Sapporo Meteorological Observatory, about 36 metres (=120 feet) less than on the previous occasion.

The ground along the dislocation line II, which is opposite the Kumantsubo craterlet, was elevated according to the aneroid measurement on Nov. 10th, to a height of about 110 metres (=360 feet) above the lake level.

The elevation at the base of the North Byobu-yama considered in §§ 11 and 12 was in all probability continued to the bottom of the Toya Lake. This may account in a part for the abnormal increase of the lake water mentioned in §10.

13. ***Relation of seismic and volcanic disturbances to elevation phenomena.*** The O-Usu and the Ko-Usu are evidently the domes or peaks formed by the vertical lava columns which solidified while these were being squeezed out. I presume that the two peculiarly round hills, the East and the West Maru-yama's, and probably also the Kompira-yama, owe their existence to similar causes, each forming what may be termed a parasitic dome, in which the lava mass is not exposed at the surface.

Now, taking into consideration the seismic shocks and the volcanic outbursts in relation to the facts of the mountain elevation, we are lead to the hypothesis that the latter formed really the primary or fundamental telluric disturbance, while the two former classes of events were simply secondary or attendant phenomena. Thus, the volcanic energy of the Usu-san was manifested, in the present instance, by pushing upwards the underground lava masses along the zones AA, B, and C (Fig. 4), which join the three special hills with each other ; the consequence being the elevation of the ground concerned. This action would necessitate the formation of cracks and fractures below the surface, which were the causes of those premonitary earthquake shocks ; the greatest seismic frequency and intensity, between the 24th, 3 pm., and the 25th, 5 pm., July (1910), marking the epoch when the formation of the dislocations and fissures along the zones AA, B, and C was practically finished. Following this, the explosive element in the volcanic action, namely, the gases and vapours, began finally on the 25th, at night to escape out along the explosion zones thus prepared.

We can, from the above reasoning, easily understand why the seismic activity reached its maximum previous to the occurrence of the different explosions, which latter could never attain a great magnitude. Again, the formation of the New Mountain ought to be accompanied by no eruption from itself. Neither is it strange that the elevation phenomena were brought into a most marked development subsequent to the epoch of the maximum explosive activity, as the continued uplifting of the ground would be comparatively easy after the dislocation had first taken place.

Besides the notable elevations already considered, there were several minor surface convulsions. The cracks formed radially about the different craterlets as centres are indicated in Fig. 4.

14. ***Tromometer observations.*** The seismographical observations of the earthquakes and tremors originating from active volcanoes, especially at the time of their eruptions, are seismologically interesting and also practically important. As will be seen from the following account, it is necessary, for obtaining satisfactory results, to choose the site of the observatory at the immediate vicinity of the source of explosion.

In the present instance, the observation was made during the progress of the eruption with a portable horizontal tromometer (magnification=100) and a vertical motion recorder (magnification =50), as follows :—

(i) July 30th, evening, to Aug. 6th, morning; in the compound of the municipal office of Nishi-Monbets, about 8.4 km to S 23°E from centre of the Usu-san.

(ii) Aug. 6th, 4 pm., to Aug. 10th, 2 pm.; in the West-Kohan School (Sobets), at the foot of the East Maru-yama.

15. ***Observation at Nishi Monbets.*** In the course of the nearly 6 complete days from July 31st to Aug. 6th, the tromometers recorded altogether 539 earthquakes of the Usu-san origin, whose hourly numbers are given in the following table.

HOURLY NUMBERS OF EARTHQUAKES INSTRUMENTALLY OBSERVED AT NISHI-MONBETS. JULY 31st TO AUG. 6th, 1910.

Hour \ Date	July.	August.					
	31st.	1st.	2nd.	3rd.	4th.	5th.	6th.
0^h— 1^h am.		8	4	3	2	4	4
1 — 2 ,,		5	6	1	4	3	0
2 — 3 ,,		6	5	—	2	1	1
3 — 4 ,,		9	6	—	2	1	3
4 — 5 ,,		8	4	—	3	2	2
5 — 6 ,,		7	3	—	5	2	2
6 — 7 ,,		6	7	—	2	4	
7 — 8 ,,		4	11	—	3	3	
8 — 9 ,,		8	10	6	2	1	
9 —10 ,,		8	5	3	4	2	
10 —11 ,,		5	3	3	2	2	
11 —12 ,,		7	8	2	1	1	
Sum.		**81**	**72**	**18**+	**32**	**26**	**12**+
0 — 1 pm.	—	5	5	5	0	4	
1 — 2 ,,	6	9	2	2	6	2	
2 — 3 ,,	6	5	4	3	1	1	
3 — 4 ,,	6	4	—	4	2	3	
4 — 5 ,,	9	7	7	2	2	2	
5 — 6 ,,	7	4	4	4	2	3	
6 — 7 ,,	6	6	4	4	2	1	
7 — 8 ,,	4	6	5	2	9	1	
8 — 9 ,,	14	6	7	2	3	4	
9 —10 ,,	4	5	3	2	1	2	
10 —11 ,,	8	6	4	3	4	6	
11 —12 ,,	6	7	4	4	3	2	
Sum.	**76**	**70**	**49**	**37**	**35**	**31**	
Total Sum.	**76**+	**151**	**121**	**55**+	**67**	**57**	**12**+
Mean AM.	—	6.9	6.0	3.6	2.7	2.2	2.0
Mean PM.	7.5	6.1	4.7	3.2	2.9	2.6	—

According to the above table, the instruments at Nishi Monbets registered, for instance, on Aug. 1st and 2nd together 272 earthquakes. Now, as the observation was, on the 2nd, wanting for about $1^h 40^m$ the actual total number of the shocks on these two days would be about 290, of which 10 were sensible at the above-named town. Hence the real number of the volcanic earthquakes was some 29 times more than that of those felt by people. It appears that the number of the shakings on July 24th, when the seismic frequency was at the maximum, would, had the observation been made with similar tromometers, have amounted to nearly 3800, namely, one earthquake at every 22.5 seconds, which means that the ground must have been practically in a state of continual tremblings. The time relation of the seismic frequency at Nishi-Monbets, as given in the preceding table, may with a considerable accuracy be represented by the equation :—

$$\log y = 0.8691 - 0.1152\, x \quad \ldots\ldots\ldots \quad (3)$$

in which y is the earthquake number during the 24 hours indicated by x; $x=0$ corresponding to the time interval from noon, July 31st to noon, Aug. 1st (1910).

The duration (y) of the preliminary tremor of the different earthquakes observed at Nishi-Monbets was, on the average, 1.36 sec., which corresponds to a mean radial distance (x) from the seismic origin of 10.2 km, according to the equation :—

$$x \text{ km} = 7.48 y \text{ sec.} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)^*$$

Again, the very first displacement of the preliminary tremor was directed, in the mean, toward N 15°W. The mean position of the seismic origin fixed by the central distance and the direction thus

* This formula has been deduced from the observations at the different Formosan stations, being a slight modification of that given in the " Bulletin ", Vol. II, No. 2.

obtained is exactly at the middle of the explosion zone AA, opposite the dislocation line I; this point being 2 km to the north of the centre of the crater of the Usu-san. It is to be remarked that the first displacement at the commencement of the preliminary tremor at Nishi-Monbets was directed toward the origin of disturbance, which is the characteristic of the volcanic earthquake motion.

16. ***Observation at Nishi-Kohan* (*Sobets*).** The Nishi-Kohan elementary school, where the observation was made, is at 1000 metres to N 85°E of the Kumantsubo craterlet, one of the most active centres of explosion, and 2100 metres to S 80°E of the mean origin of the seismic disturbances mentioned in the preceding §. The heavy, or "steady", masses of the EW, NS, and vertical components of the tromometers were adjusted respectively to periods of 4.0 sec., 4.5 sec., and 4.1 sec. The hourly numbers of the earthquakes observed between the 6th and the 10th, Aug., (1910) are given in the following table.

HOURLY NUMBER OF EARTHQUAKES OBSERVED WITH TROMOMETERS AT W. KOHAN SCHOOL (SOBETS). AUG. 6th to 10th, 1910.

Day. / Hour.	6	7	8	9	10
0^h— 1^h am.		5	4	2	1
1 — 2 ,,		4	0	2	0
2 — 3 ,,		2	0	1	3
3 — 4 ,,		1	1	0	1
4 — 5 ,,		5	1	1	3
5 — 6 ,,		3	0	2	2
6 — 7 ,,		1	0	1	1

Hour \ Day	6	7	8	9	10
7^h— 8^h am.		0	3	1	1
8 — 9 ,,		5	2	2	2
9 —10 ,,		3	3	0	1
10 —11 ,,		2	1	2	2
11 —12 ,,		1	3	2	3
Sum		**32**	**18**	**16**	**20**
0^h— 1^h pm.		2	2	4	5
1 — 2 ,,		3	2	1	
2 — 3 ,,		3	1	3	
3 — 4 ,,		2	3	3	
4 — 5 ,,	3	6	2	2	
5 — 6 ,,	4	2	1	4	
6 — 7 ,,	2	3	2	3	
7 — 8 ,,	2	4	0	1	
8 — 9 ,,	4	2	3	2	
9 —10 ,,	2	1	2	2	
10 —11 ,,	0	0	3	3	
11 —12 ,,	6	2	2	2	
Sum	**23**	**30**	**23**	**30**	**5**
Daily Number.	**23**+	**62**	**41**	**46**	**25**+
Mean hourly Number. AM.	—	**2.67**	**1.50**	**1.33**	**1.67**
Mean hourly Number. PM.	**2.88**	**2.50**	**1.92**	**2.50**	—

The periods of vibrations constituting the earthquake movements at W.-Kohan were three-folds as follows: $T_1=0.524$ sec., $T_2=1.03$ sec.; $T_3=1.51$ sec. Of these the first period occurred most frequently.

A special feature in the W. Kohan tromometer diagrams is the occurrence, besides the proper volcanic earthquakes, of well defined small quick unfelt vibrations, which may be termed *micro-tremors*, and which were almost entirely wanting at Nishi-Monbets. These vibrations are perfectly different from the usual small slow movements called pulsatory oscillations, whose periods are in the mean about 4 and about 8 sec. In Fig. 19, Pl. XII, is reproduced the exact copy of a portion of the W.-Kohan horizontal tromometer record for Aug., 7th to 8th, 1910, when the micro-tremors were very active; the diagram indicating also a *jinari* and a few small shocks. On Pl. XIII, which gives photographic enlargements (resultant magnification=885) of parts of the diagram at the same station for Aug. 8th, 1910, are shown micro-tremors of a short period as well as those of slower periods; the large disturbance in the lower figure is a local earthquake. The mean values of the different kinds of periods of the micro-tremors and their (NS) ranges of motion, or double amplitudes, were as follows:—

(i) $T_1=0.53$ sec., $2a=0.086$ mm;

(ii) $T_2=1.12$ „ , $2a=0.021$ „ ;

(iii) $T_3=1.66$ „ , $2a=0.010$ „ ;

(iv) $T_4=2.14$ „ , $2a=0.013$ „ .

The first three of these periods are respectively equal to the periods of the vibrations composing the earthquake motion as before noted. The conclusion is that the micro-tremors are identical in nature with, and due to the same cause as, the earthquakes themselves. This is also evident at once from the diagrams, the micro-tremors consisting of a series of small disturbances, each of which may be regarded as an earthquake.

Further, the periods at W. Kohan are essentially similar to those occurring at Nishi-Monbets, as follows :—

	(T_1)	(T_2)	(T_3)	(T_4)
	sec.	sec.	sec.	sec.
W. Kohan (Eqkes and micro-tremors)	0.53	1.08	1.59	2.14
Nishi-Monbets (Earthquakes)	0.53	1.01	1.58	2.43
Mean	**0.53**	**1.04**	**1.58**	**2.29**

It appears that the micro-tremors, which originated at the seat of the eruption, were with the increasing distance quickly reduced in magnitude. T_1 may be regarded as the fundamental period, and the three others its multiples, giving the following approximate relations :

$$T_1=\tfrac{1}{2}\times T_2=\tfrac{1}{3}\times T_3=\tfrac{1}{4}\times T_4$$

The relations of the micro-tremors to the paroxysmal explosions from the different craterlets, were as follows :—(i) Moderate explosions from the nearest, or Kumantsubo, craterlet were generally accompanied by no marked micro-tremors ; (ii) Violent explosions from the Kumantsubo, the Taka-ana, the Fuji-yama, and other craterlets were generally accompanied by well pronounced micro-tremors, these latter often preceding such an outburst by a few minutes interval. (iii) Marked micro-tremors often occurred when the smoke ejections from the different craterlets were very insignificant or even when completely ceased. It is likely that there took place an accumulation of underground stress, when the different craterlets were prevented, on account of temporary filling up of their mouths or of some other causes, to make regular explosions ; the pent up steam and gases producing, in consequence, a series of minor earthquakes, resulting in the micro-tremors. The latter movements must have been, in all probability, very active in the days immediately preceding the first explosion.

The tromometer observations were repeated in April 1911 at the West-Kohan School (Sobets), but no micro-tremors were then registered; the volcanic district having, by that time, already settled into equilibrium condition.

17. *On prediction of volcanic eruptions.* The eruptions of the Usu-san in 1910, 1822 and 1663, of the Unsen-dake (in the province of Hizen, Kyushu) in 1792, of the Fuji-san in 1707, and some others, lasted from a few days to several months, each being preceded by numerous earthquake shocks and *jinaris.* In such a case, seismograph and tromometer observations made at the vicinity of the centre of the volcanic activity would give the people a warning of the approaching outburst. As a matter of fact, in the Usu-san eruption of 1910, the precautionary measures proved useful, no life having been lost in consequence of the explosions. I believe the problem of prediction of great volcanic eruptions is, in some cases, not very difficult.

A fuller account of the Usu-san eruption will be published in a future report.

Tokyo. May 1911.

Eruption of the Usu-san. Views taken from East. (Aug. 3, 1910).

Fig. 7. At the left-hand side is seen a great explosion from the Kumantsubo craterlet.

Fig. 8. At the left-hand side is seen a smoke "Spear-head" from Kumantsubo craterlet, to the right an explosion from the craterlet at the south base of W. Maru-yama, and at the middle another from the Taka-ana.

Eruption of the Usu-san (1910). Views taken from West.

Fig. 9. Eruptions of the Usu-san, seen from Kompira Temple: to the left two black columns from the top of W. Maru-yama ; at centre, a white column from craterlet No. 8, and, to the right, explosions from four other sources. (Aug. 2nd, 1910.)

Fig. 10. View taken from the same place, on Nov. 9th, 1910. "New Mountain" shown on the back ground to the right shoulder of W. Maru-yama.

Eruption of the Usu-san, 1910.

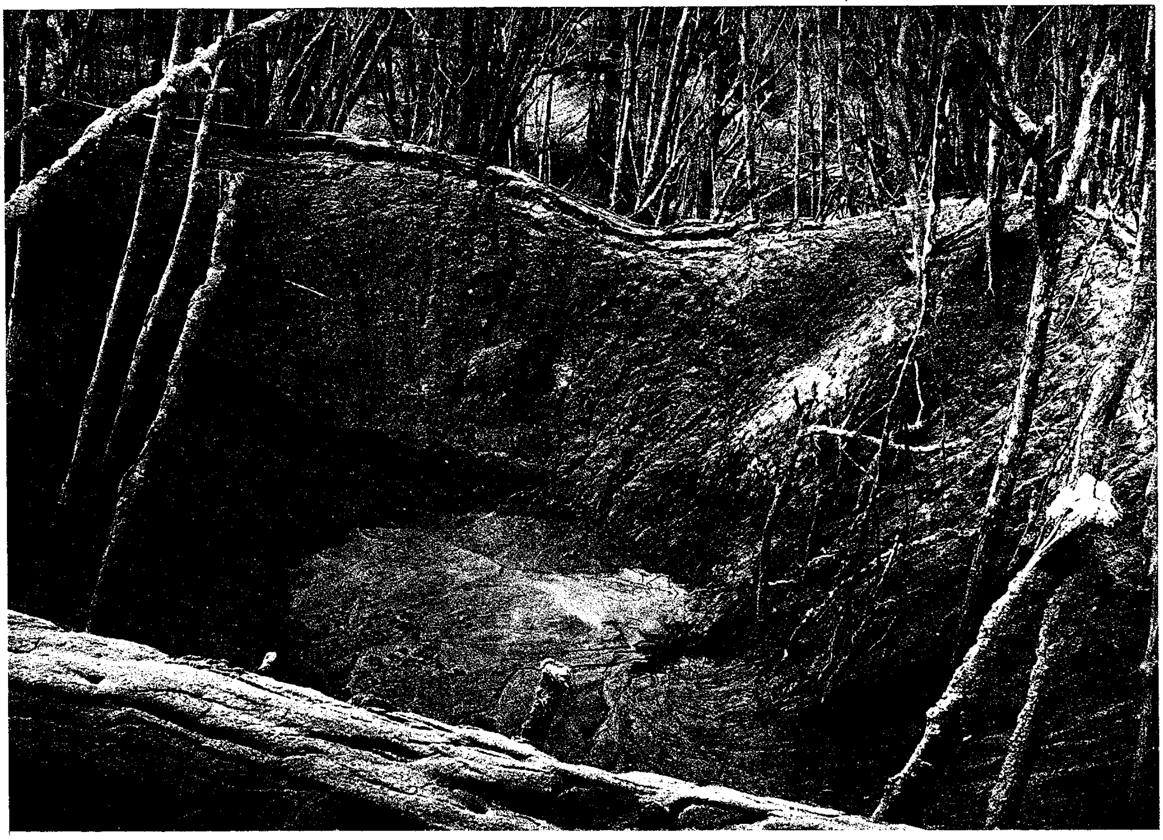


Fig. 11. One of the small craterlets (Diameter=40 metres) on the top of W. Maruyama. (Nov. 8, 1910.)

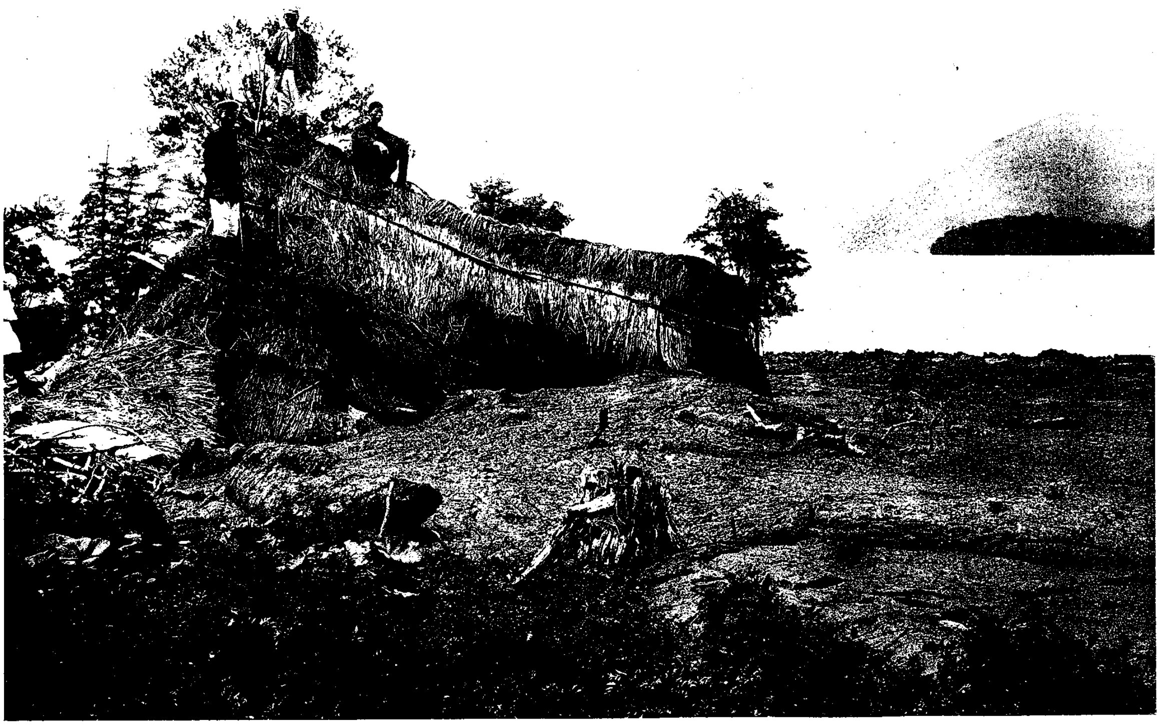


Fig. 12. A cottage swept down by the Mud Stream along the west base of W. Maruyama. (Aug. 2, 1910.)

Eruption of the Usu-san, 1910.

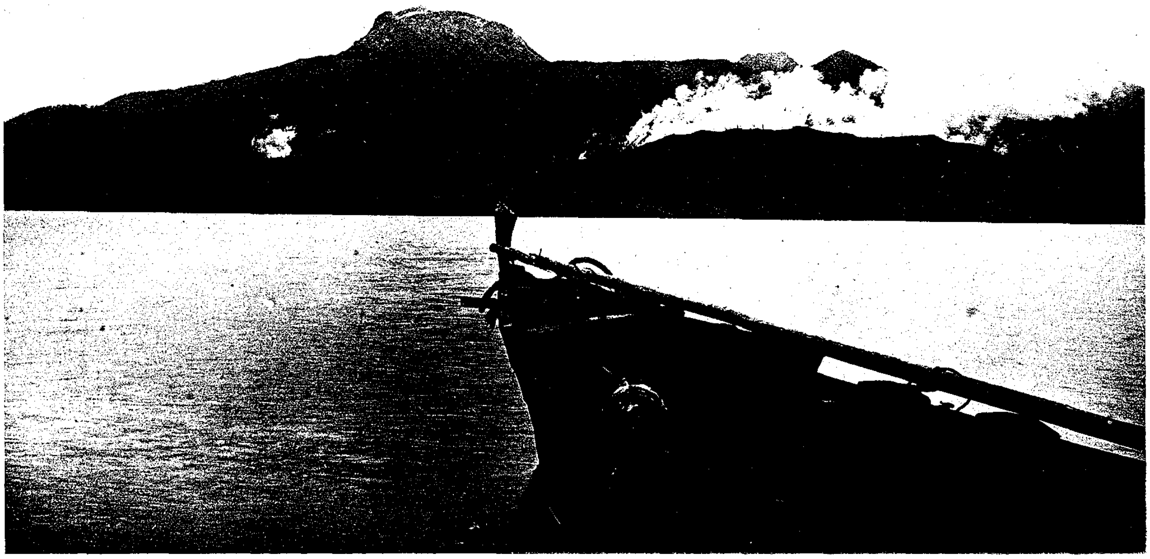


Fig. 13. The Usu-san seen from Manju Island in Toya Lake, showing the "New Mountain" to the right along the shore. The O-Usu dome is at a little to the left from centre. (Nov. 11th, 1910.)

Fig. 14. "New mountain" seen toward SW from a boat on Toya Lake. Height above the lake-level = 690 feet. (Nov. 9th, 1910.)

Fig. 15. General View of the Usu-san from NE.

The O-Usu dome rises at the left-hand side, with the E. Maru-yama at its right base. The "New mountain" is at the right end of the figure.

Fig. 16. The Craterlets Group opposite the New Mountain, seen from East.

The cone at the extreme left end is the "Taka-Ana," and that at its right-side is the "Fuji-yama". To the right hand side of the figure is shown the inside, or the dislocation plane, of the "New Mountain".

Eruption of the Usu-san (1910).

Fig. 17. The Kompira Temple, showing on the back ground the scene of the first outburst. The roof of the temple was pierced by numerous stones projected on the occasion of the explosion.

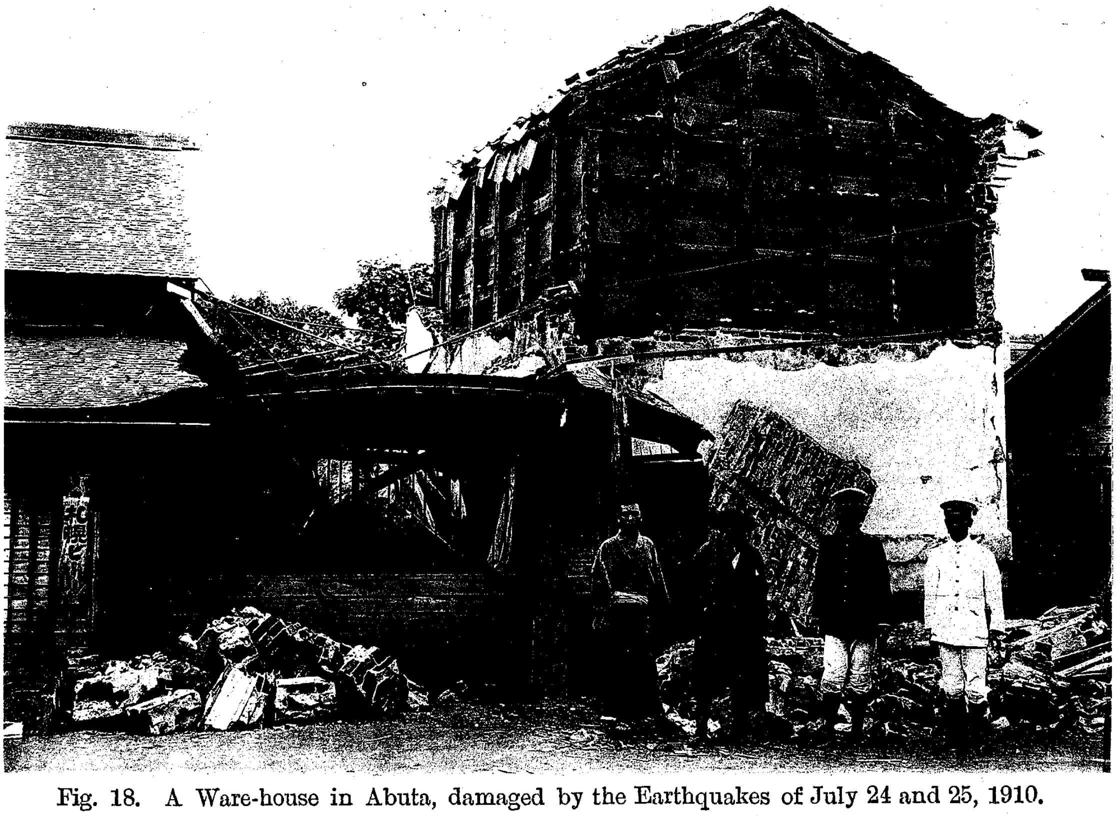
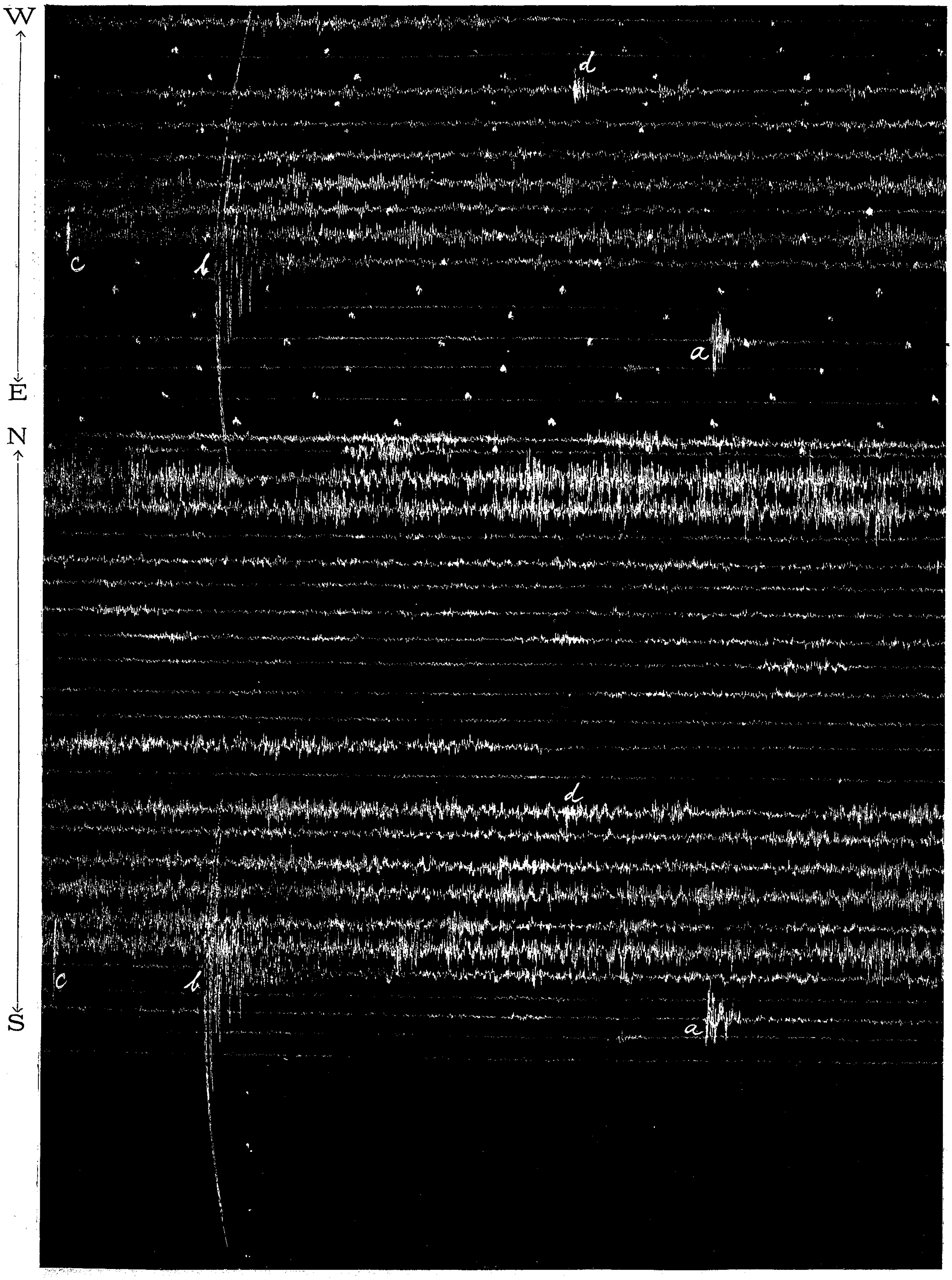


Fig. 18. A Ware-house in Abuta, damaged by the Earthquakes of July 24 and 25, 1910.

Fig. 19. Part of the Horizontal Tremor Recorder Diagram for 7th to 8th, Aug., 1910; observed at the W.-Kohan School (Sobets).



(EW)....E-W Component. (NE).... N-S Component.
Magnification = 100. Time Scale: 1 minute = 24.6. mm.
a,b,d,.... Usu-san eqkes. c....*Jinari*, or earth-sound.
The Micro-tremors are very markedly shown.

Fig. 20. Parts of the Horizontal Tremor Recorder Diagram for Aug. 8th, 1910; observed at the West-Kohan School (Sobets).

N.S Component. Magnification = 885.

Time Scale: 1 minute = 247 mm.