THE ERUPTIONS AND EARTHQUAKES OF THE ASAMA-YAMA. IV.

[Strong Asama-yama Outbursts, Dec. 1912 to May 1914.]

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With Plates I—XXXIV.

CHAPTER I. ACTIVITY OF ASAMA-YAMA IN 1912 AND 1913.

1. *Introduction.* The recent extraordinary volcanic activity of the Asama-yama, which began in 1908, has apparently reached its maximum intensity during the last two years. In 1912, in which there was no violent *explosion* of the mountain, the non-eruptive volcanic earthquakes were very numerous; that of July 16th being especially large and violent. Again, the eruptions on Oct. 2nd and Dec. 13th–14th (Fig. 2), each of which consisted of a great number of outbursts individually not very strong, lasted respectively 8 and 31 hours, and caused remarkable elevations of the crater bottom, which became on the N and NW side practically continuous with the top of the surrounding wall. In 1913, in which the non-eruptive volcanic earthquakes were extremely few, the strong eruptions, both explosive and non-explosive (§ 3), were very numerous; there being in the course of the year, at least 16 outbursts, whose detonations were heard at considerable distances from the volcano. In 1913 there were also remarkable epochs of the continuous volcanic activity. Thus, in July between the 5th, 3½ p.m., and the 6th, 7 p.m., the tromometer at Yuno-taira registered the shakings of some 1,300 small eruptions; while, on Oct. 15th, between 4½ a.m. and 2 p.m., the tremor-recorder at Ashino-taira indicated about 250 of the similar disturbances.

One of the marked features of the eruptions in 1913 was the increase in the distance to which the red hot lava fragments were projected. The four strong explosions of June 17th, July 13th and 19th, and Aug. 12th, sent the projectiles to the immediate vicinity of, and to places beyond, the Yuno-taira seismological observatory, causing damage to the window on the crater side. On Aug. 12th, the "Volcano House", a sort of resting cottage for the mountain climbers situated at Yuno-taira about 250 m nearer the crater which had already been abandoned, fared very badly, its roof being perforated, and its inside partially burnt, by a great number of the falling stones. Such effects of the great violence of the outburst, which did not occur in 1914 so far, neither in the years preceding 1913, might be due in a part to the elevation of the crater bottom, but in the main probably to the change in the depth of the most active under-mountain centre of the volcanic activity; it being likely that there exists a particular focal depth corresponding to the maximum projection intensity of the eruption.

In 1914 the seismological and meteorological observations were carried on at Yuno-taira in the same way as in the preceding year, from May 3rd to Aug. 31st. Then, between Sept. 1st and Oct. 22nd, the tremor-recorder was taken to the temporary station at Ashino-taira, a place about 2640 m below Yuno-taira, where the trial registers had first been taken in the winter of 1911. On

Fig. 1. View of the crater of Asama-yama, from SSW, showing **lava rings** at the bottom. July 2nd, 1912. (F. Omori, phot.).

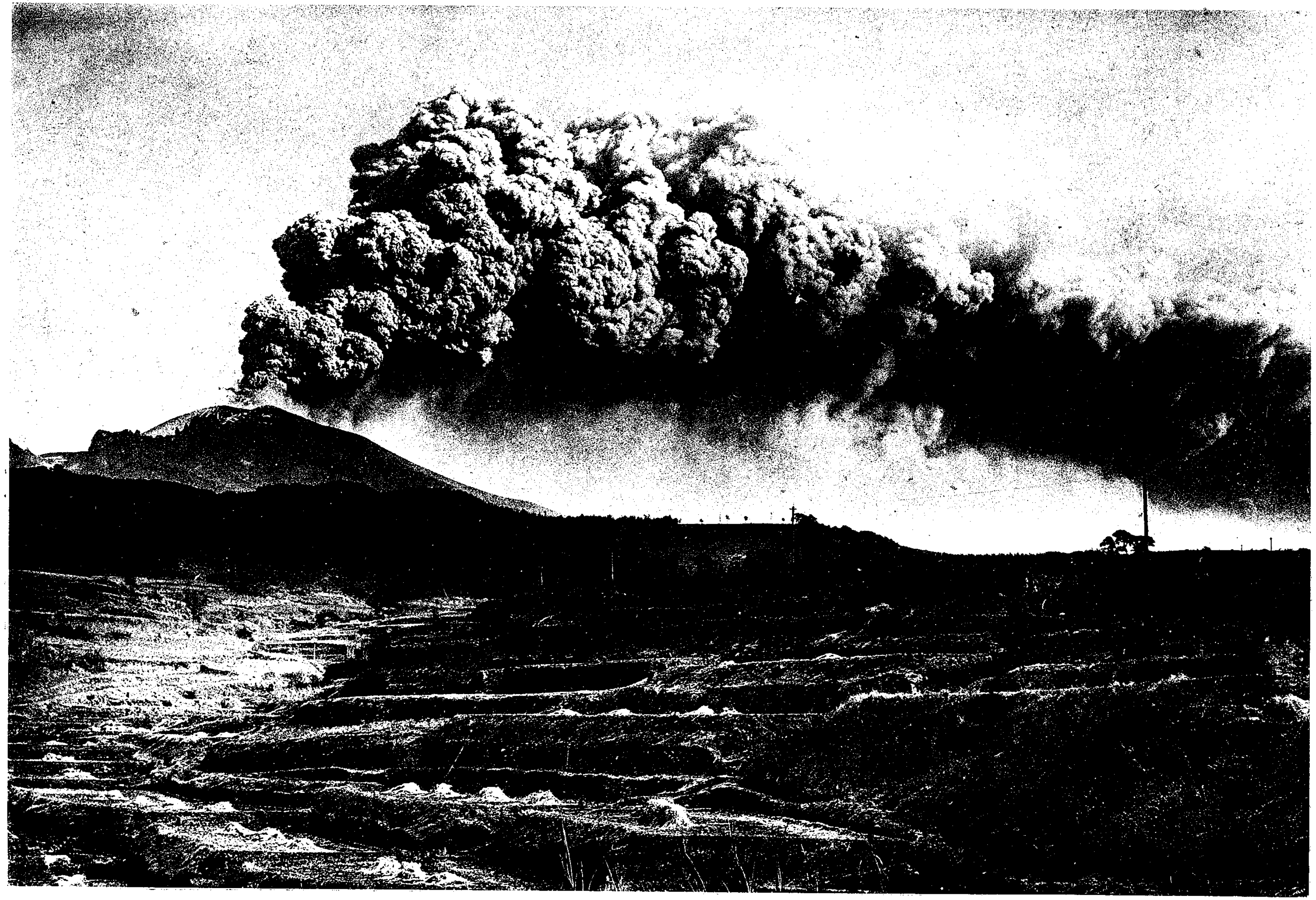


Fig. 2. Eruption of Asama-yama on Dec. 14th, 1912, seen from Komoro. (K. Uozu, phot.)

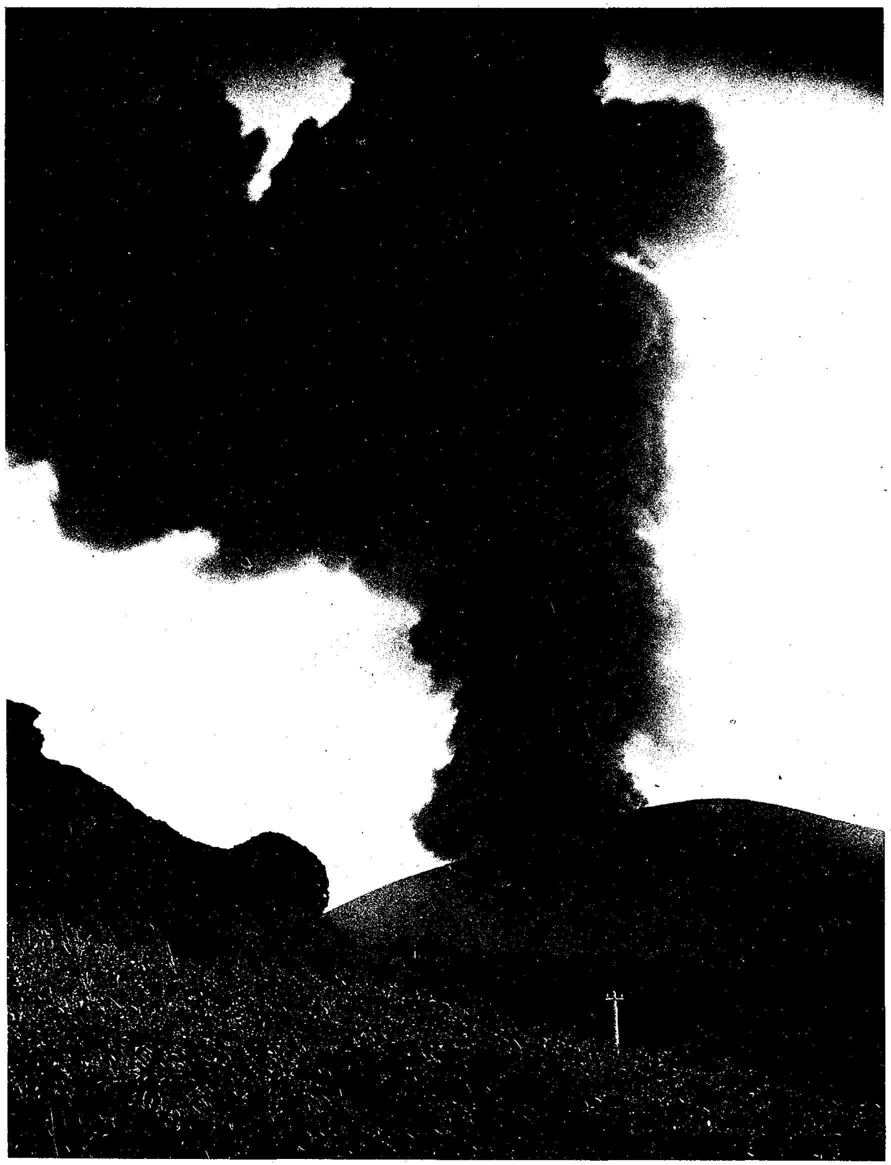


Fig. 3. A small eruption of Asama-yama on July 13th, 1913, at about 7.26 a.m., seen from Yuno-taira. (T. Kato, phot.)

Fig. 4. A strong non-detonative eruption of Asama-yama on July 1st, 1913, at 0.17.01 p.m., seen from Yuno-taira 4 minutes after the commencement. (T. Kato, phot.)

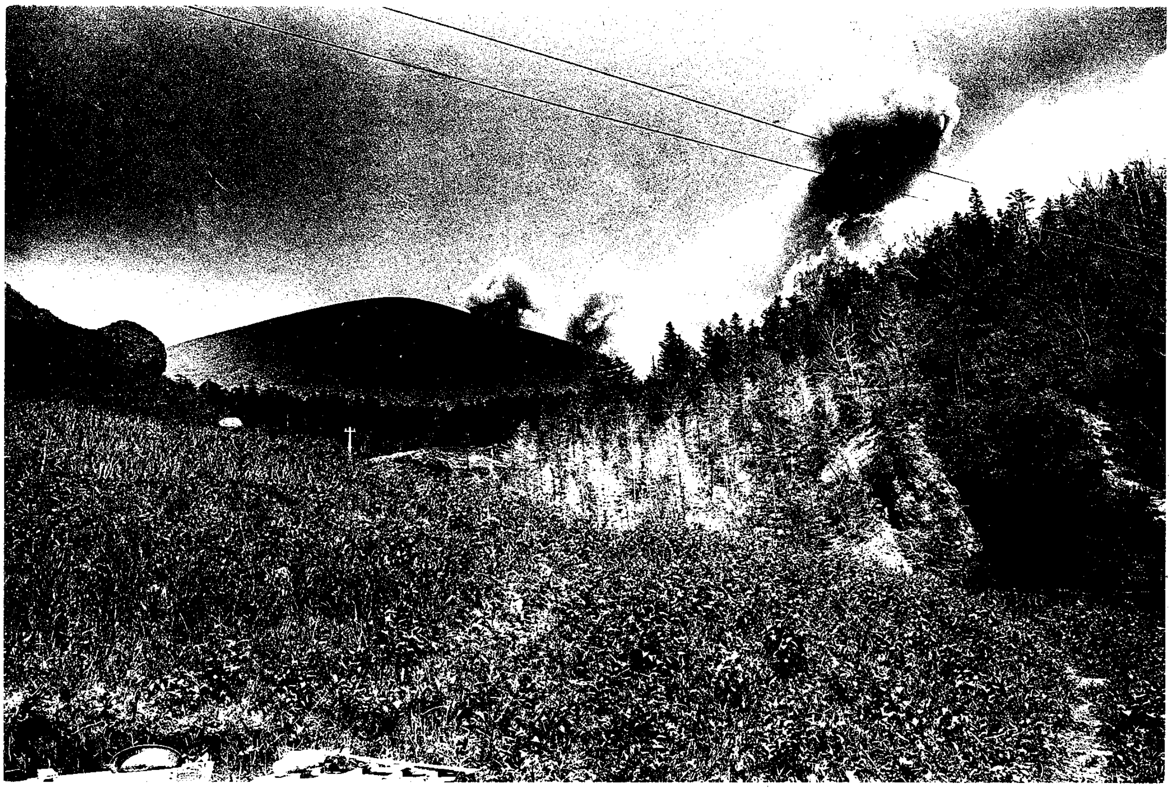


Fig. 5. Maikake-yama seen from Yuno-taira, on July 27th, 1913, at 1 30 p.m. The smoke groups were successively thrown eastwards. (F. Omori, phot.)

Fig. 6. Strong non-detonative eruption of Asama-yama on Aug. 15th, 1913, at 9.59.11 a.m., seen from Yuno-taira. The smokes were thrown eastwards. (T. Toyoda, phot.)

the other hand, the observation with another tremor-recorder of 200 times magnification was carried on, from Sept. 11th to Oct. 24th, and again from November 12th to Dec. 6th, in the office building of the Asama Pasture Ground at the distance of about 6350 m to the N 65° E of the Asama-yama crater. (See Fig. 45.)

The present paper is principally devoted to the consideration of the sound phenomena and the earthquake effects of the different strong eruptions in 1913, and those of Dec. 13th–14th, 1912, and May 5th, 1914; the full description of the diagrams of the non-eruptive volcanic earthquakes, the discussion of the areas of the seismic propagation, and other matters, being reserved for a future number of the *Bulletin*.

2. *List of Asama-yama eruptions in* 1912 *and* 1913. Table I is the continuation of a similar list for 1908–1911 (Table V, the *Bulletin*, Vol. VI, No. 1) and gives the date and time of occurrence of the 46 eruptions of the Asama-yama, which occurred in the course of the two years, 1912 and 1913, and whose detonation or emission of ashes was intense enough to be noticed in the neighbouring or distant provinces, or at least in places outside the immediate base of the mountain.

TABLE I. LIST OF THE ASAMA-YAMA ERUPTIONS, 1912—1913.

(**) ....Eruption of a long duration.
(*) ....Strong Eruption.

No.[1]	Date.	Time of Occurrence (at Asama-yama).	Remarks.
63	Jan. 28, 1912.	6.36 a.m. to 7.25 p.m.	Detonations heard at Naganohara and Maebashi. Ashes fell at Karuizawa and vicinity, and also at Kumagai and other places in Saitama Prefecture.
64	Feb. 13–14, ,,	10 p.m. (13th) to 7 a.m. (14th).	Ashes fell at Komoro and Kumagai.

1) The number is counted in continuation of Table V, the *Bulletin*, Vol. VI, p. 25.

No.	Date.	Time of Occurrence (at Asama-yama).	Remarks.
65	Feb. 22, 1912.	7.20 and 10.50 p.m.	Detonations heard at Naganohara.
66	April 9, „	0.35 p.m.	Detonation heard at Naganohara.
67	„ 15, „	7.50 p.m.	Dull detonations heard at Naganohara.
68**	Oct. 2, „	10 a.m. to 7.40 p.m.	Detonations heard at Naganohara and Maebashi, with ash-precipitation at the former.
69	„ 3–4, „	8.40 p.m. (3rd) to 10 a.m. (4th).	Dull detonations heard at Naganohara.
70	„ 7, „	2 a.m.	Detonations heard at Karuizawa, with slight ash-precipitation at Kumagai.
71	„ 9–10, „	$9\frac{1}{2}$ p.m. (9th) to $2\frac{1}{3}$ a.m. (10th).	Loud detonations heard at Naganohara.
72**	Dec. 13–14, „	Lasted 31 hours.	Ashes were carried ENE'ward to the Pacific coast. The detonations were perceived in the provinces of Kotsuke, Shimotsuke, Hitachi, Musashi, Shimosa, Sagami, Izu, Suruga, Totomi, Shinano, Iwaki, and Iwashiro.
73	Feb. 11, 1913.	2. 15. 40 p.m.	Detonation heard at Nagano, Maebashi, and Kumagai and other places in Saitama Prefecture.
74	April 18, „	11. 53. 50 p.m.	Detonation heard at Maebashi.
75	„ 21–23, „	Several outbursts.	Detonation and ash-precipitation at Naganohara and Maebashi.
76*	May 16, „	4. 41. 00 p.m.	Detonation heard at Naganohara, Maebashi, and Kumagai and other places in Saitama Prefecture.
77*	„ 27, „	5. 22. 57 a.m.	Loud detonation heard at Naganohara, Kusatsu, Komoro, and Karuizawa.
78*	„ 29, „	10. 44. 12 a.m.	Detonation heard at Komoro, Naganohara, Maebashi, Kumagai and other places in Saitama Prefecture; also at different localities in Totomi, Suruga, Mikawa, Owari, and Mino. Ash-precipitation at Naganohara and a few places in central Echigo.
79	June 13, „	11. 01. 16 p.m.	Loud detonation heard at Naganohara.
80*	„ 17, „	10. 47. 41 p.m.	A strong explosion, whose detonation was heard on the one hand in provinces of Shinano, Echigo, Kotsuke, Shimotsuke, Musashi, Shimosa and Hitachi; and on the other hand, in Noto, Etchu, Kaga, Echizen, Omi, Mino, Owari, Mikawa, Totomi, and Suruga. Ash-precipitation zone extended eastwards to the Pacific coast.
81	„ 18, „	6. 21. 03 a.m.	Detonation heard at Naganohara.

No.	Date.	Time of Occurrence (at Asama-yama).	Remarks.
82*	June 20, 1913.	4h 06m 47s a.m.	Detonation heard in Kotsuke and a few places in the neighbouring provinces, the ash-precipitation zone extending toward ESE for about 90 km. The W. sound area stretched from Noto to Owari.
83	„ 24, „	11 37 34 a.m.	Sound heard at Naganohara?, ashes falling for 5 min. at 9.10 a.m.
84*	„ 26, „	8 09 40 a.m.	Detonation heard in Kotsuke and at a few places in Echigo and Shinano, the ash-precipitation zone stretching eastwards only to Maebashi. The W. sound area included parts of Mino, Owari, and Mikawa.
85*	„ „ „	11 41 59 p.m.	The sound areas were similar to those of the preceding. There was ash-precipitation at Maebashi.
86	July 1, „	0 17 01 p.m.	At Wakasare, there was some ash-precipitation.
87	„ 7, „	7 10 32 a.m.	Detonation heard at Naganohara, Maebashi, and a few other places in province of Kotsuke.
88	„ „ „	9 46 53 p.m.	Loud detonation heard at Naganohara.
89	„ 8, „	5 25 25 a.m.	*Do.*
90*	„ 13, „	4 01 19 p.m.	The principal sound area stretched in the S W from Suruga to Omi; the detonation being heard, on the other hand, only within a very limited distance of the volcano. Ashes fell at Naganohara.
91*	„ 18, „	2 08 34 a.m.	Loud detonation heard at Naganohara. The sound was also perceived toward the west at Kanazawa (Kaga), and at Gifu, Mitake, and Shiratori (Mino).
92*	„ 19, „	0 54 03 p.m.	The sound area consisted of 3 isolated portions the largest of which extended from Totomi to Omi.
93*	Aug. 12, „	7 45 08 p.m.	Detonation heard at Karuizawa, Iwamrata, and Komoro, in Shinano; at Naganohara; and a few places in Mikawa, Owari, and Kaga.
94*	„ „ „	11 20 33 p.m.	A strong explosion, whose sound area consisted of 3 portions similar to, but greater than, those in the preceding case. The ash-precipitation zone extended to Mount Tsukuba toward the E slightly S.
95	„ 15 „	9 59 11 a.m.	Powerful smoke emission, unattended by detonation.

No.	Date.	Time of Occurrence (at Asama-yama).				Remarks.
		h	m	s		
95′	Aug. 15, 1913.	3	58	46	p.m.	Powerful smoke emission, unattended by detonation.
95″	,, ,, ,,	5	08	54	p.m.	*Do.*
96*	Sept. 21, ,,	1	50	59	p.m.	The sound area, composed of 2 separate portions, was similar to those of the explosions on July 13th and June 26th, at 8 a.m.
97*	Oct. 15, ,,	10	43	13	p.m.	Detonation heard at Nagano and Iwamrata in Shinano, and Maebashi and Sannokra in Kotsuke.
98*	,, 17, ,,	3	27	47	p.m.	Detonation heard at Maebashi, Sannokra, Naganohara, and Kusatsu, in Kotsuke.
99*	,, 26, ,,	3	14	38	a.m.[1]	The sound area included parts of Echigo, Shinano, Kotsuke, Musashi, and Hitachi.
100	Nov. 3, ,,	2	25	38	p.m.[1]	Detonation heard at Naganohara and Iwamrata. There was some ash-precipitation at Yokohama and the vicinity in the morning and between 4 and 5 p.m.
101	,, ,, ,,	5	15	—	p.m.	Detonation heard at Naganohara and Iwamrata.
102	,, 4, ,,	8	35	—	a.m.	Detonation heard at Iwamrata, Naganohara, and Kusatsu.
103	,, 5, ,,	10	57	—	a.m.	Detonation heard at Iwamrata.
104	,, ,, ,,	4	20	—	p.m.	*Do.*
105	,, 6, ,,	6	04	49	a.m.[1]	Detonation heard at Naganohara and Maebashi.
106	,, ,, ,,	1	22	16	p.m.[1]	Detonation heard at Naganohara and Maebashi. Some ash-precipitation at Shiobara.
107	,, ,, ,,	7	36	16	p.m.[1]	Detonation of long duration, heard at Naganobara, Sannokra, and Takasaki, with ash-precipitation in Tone-county, prov. of Kotsuke.
108	,, 14, ,,	11	11	55	a.m.	Eruption witnessed from Asama Pasture Ground.
109*	,, 20, ,,	3	40	35	p.m.	Sounds like distant thunders heard at Maebashi. There was some precipitation of ashes (sands) at Naganohara.

1) Time of earthquake occurrence in Tokyo.

Among the outbursts tabulated above, Nos. 76, 77, 78, 80, 82, 84, 85, 90, 91, 92, 93, 94, 96, 97, 98, and 99 were strong detonative explosions, while Nos. 86, 95, 95′, 95″, and 109, were powerful non-detonative eruptions. The greatest monthly frequencies of 7, 8, and 10, occurred respectively in June, July, and November of 1913.

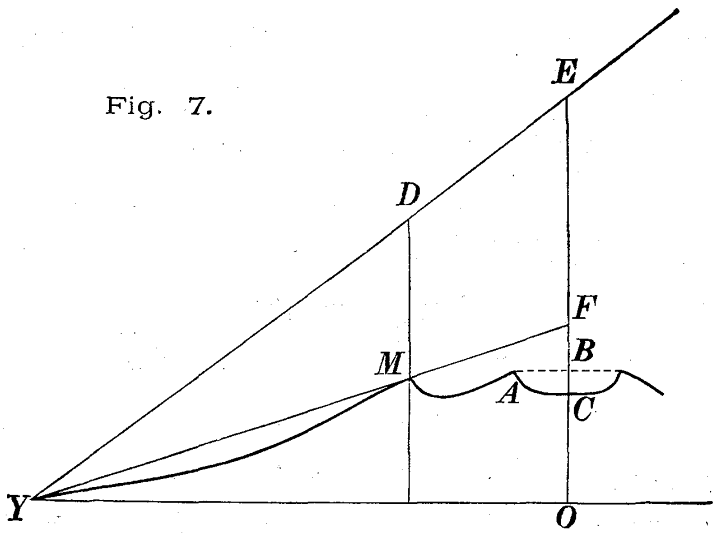
3. *Detonative and non-detonative eruptions of Asama-yama.* The eruptions of the Asama-yama may be divided into the two classes of *explosive* and *non-explosive* outbursts, these being respectively *detonative* and *non-detonative.* A strong explosion is accompanied by a loud detonation or sound shock, like heavy thunder or artillery peals, shaking houses violently and not rarely breaking window panes even at Karuizawa, Komoro, Iwamrata, etc., places situated at the radial distances of 11 to 16 km from the crater. A non-explosive eruption is, even when very strong, not accompanied by any detonation, save feeble sounds like that of a running train or rushing winds. The present author has several times witnessed moderate eruptions of this category from the crater wall itself, no explosive sound being even there perceived at all.

The detonation of an explosion, which is always short in duration, is probably caused by a sudden formation or breaking open of a new vent at the crater bottom, where the lava surface was hardened into a solid layer. On the other hand, the non-explosive eruption, whose duration is generally more or less long, consists of an abundant ejection of smokes, ashes, and rock fragments, in consequence of a powerful outburst along a pre-existing crevice or channel. According to these points of view, the detonative explosions of the Asama-yama may be regarded more as of the nature of a surface disturbance which creates a great deal of air waves, and the non-detonative eruptions that of a deep-seated action involving a considerable amount of energy to be converted in a large measure to earthquake vibrations. From the tromometer diagrams obtained in Tokyo, it is clear that the Asama-yama eruptions of the latter sort cause generally much greater shakings of the ground than those of the former.

4. *Height of smoke ascent.* In the case of a strong eruption, whether detonative or non-detonative, the smokes ascend sometimes to a considerable height. Thus, on the occasion of the non-detonative eruption of Nov. 20th, 1913, which the author witnessed from Kutsukake, the eddying smoke column ascended with a small deviation from the vertical, to a height of about 7,500 m above the mountain top, or 10,000 m above sea-level, breaking through a layer of strato-cirrus, so that the round top was covered with white cloud envelope. As the ascent took about 5 minutes time, the approximate velocity of the vertical progress was on the average some 25 m per sec. Subsequently the smokes were thrown gradually eastwards to an inclination angle of about 45°. The eruption was accompanied for about 10 sec. by dull sounds, like those of distant gun reverberations, causing at the above named village slight shakings of the shojis. The ash-streamers were observed to fall down first 1 minute or so after the commencement. When first looked at, a few seconds after the perception of the feeble eruption sounds, namely, about 30 sec. after the actual occurrence of the outburst, white smokes were already issuing from a great number of points at the Tengu-no-roji on the SE base of the Maikake-yama, and at the Jigoku-zawa on the S. flank of the Asama-yama; these being no other than the small conflagrations of grass and trees caused by the precipitation of hot lava fragments.

As an instance of small non-explosive eruption, may be mentioned that of July 2nd, 1912, at $5^h\ 29^m\ 21^s$ a.m., which the author witnessed from the Yuno-taira observatory. This consisted in the emission of a large amount of black smokes, which ascended vertically to the height equivalent to the elevation of the Maikake-yama, or the space of about 1680 m (EF in the accompanying figure) in the time interval of $2^m\ 30^s$, the mountain having previously been perfectly calm. The smokes were then thrown toward the SSE. This outburst, which was accompanied

Fig. 7.



A....WSW crater edge.
C....Crater bottom.
M....Maikake-yama.
Y....Yuno-taira observatory.
$\angle MYO = \angle EYM$.
Height of *M* above *Y* = 570 m.
" *B* " = 580 m.
" *C* " = 460 m.
YO = 2300 m. *CF* = 290 m.
EF = 1680 m.

YO = Level of Yuno-taira.

by a rushing sound like that of wind blowing, gave on the tromometer record at Yuno-taira a diagram consisting of regular minute serrations. (See Fig. 60.) The approximate time interval between the 1st appearance of the smokes over the Maikake-yama and the actual commencement of the eruption was some 30 sec., the mean rate of the vertical ascension being thus some 1970 m/180 sec. = 11 m/sec. This velocity is probably little different from that of the upward current, which must always exist to a greater or smaller extent over the Asama-yama crater, a sort of huge natural furnace.

5. *Precipitation of lava fragments and ashes.* It is doubtless due to the great violence of the upward rush of the steam and gases suddenly liberated by a strong eruption that, not only the ashes and sands, but lava fragments of no insignificant dimensions are often carried along with the ascending smoke column to be dropped down after a considerable time interval at places several kilometers distant from the crater. Thus on the occasion of the eruption of Nov. 20th, 1913, which was not explosive, (§ 4), my assistant, Mr. T. Yoshida, observed at the Asama Pasture Ground the time of arrival of the sound of the eruption to be $3^h\ 41^m\ 08^s$ p.m., while it was first $7^m\ 28^s$ later, or at $3^h\ 48^m\ 36^s$ p.m., that the smoke column, gradually wafted from over the crater, reached the sky above the station in question and began to drop down lava pieces, some of which were about $2\frac{1}{2}$ cm in length and 1 cm in thickness, and weighed 5.0 to 6.6 grams; the precipitation having continued for $2^m\ 20^s$. Again, on the occasion of the smaller non-explosive eruption of Nov. 14th, 1913, (Fig. 49), the smoke column reached the zenith of the Wakasare Cottage first about 5 min. after the volcanic sound had been heard, and then there dropped down lava fragments several of which were 5 to $6\frac{1}{2}$ cm in length and $1\frac{1}{2}$ cm in thickness, and weighed 50 to 75 grams; being too hot at the moment of their fall than to be safely touched with hand. As the distances of the Asama Pasture Ground and the Wakasare Cottage from the crater are about 6350 and 5200 m, the velocities of the horizontal progress of the smoke column on the two above-mentioned cases were respectively about $13\frac{1}{2}$ and 16 m/sec. It may be remarked that the lava fragments, which are suspended in the ascending smoke column, are always more or less platy in shape. In the case of the eruption on Dec. 14th, 1912, the time of commencement and the duration of the ash-precipitation at the different places were as follows:—

Place.	Distance from Asama-yama.	Time of commencement of ash-precipitation.	Duration of the ash-precipitation.
Maebashi.	50 km	10^h 13^m a.m.	1^h 40^m
Utsunomiya.	121	11 27 ,,	50
Otsu (province of Iwaki).	204	0 50 p.m.	2 40

The average transit velocity of the ashes between the three stations of Maebashi, Utsunomiya, and Otsu, of the radial distances of 50 to 204 km, was 16.4 m/s or about 60 km per hour.

6. *Projection of lava fragments.* Several of the explosions in 1913 were quite strong, throwing out lava fragments to distances greater than in the preceding years. This implies partly an augmentation in the initial velocity, with which the lava fragments were projected out from the crater (§ 1). Let us now find out the relations existing between the projection velocity (v); the projection, or elevation, angle (α); the inclination angle (θ) of the mountain slope; the horizontal projection distance (x_0); and the angle of fall (φ), at which the projectile strikes the slope ground. Taking the coordinate origin at the source of projection, or the centre of the crater bottom, and the y-axis vertically downwards, we have, for the time t, counted from the moment of the explosion, the following equations:—

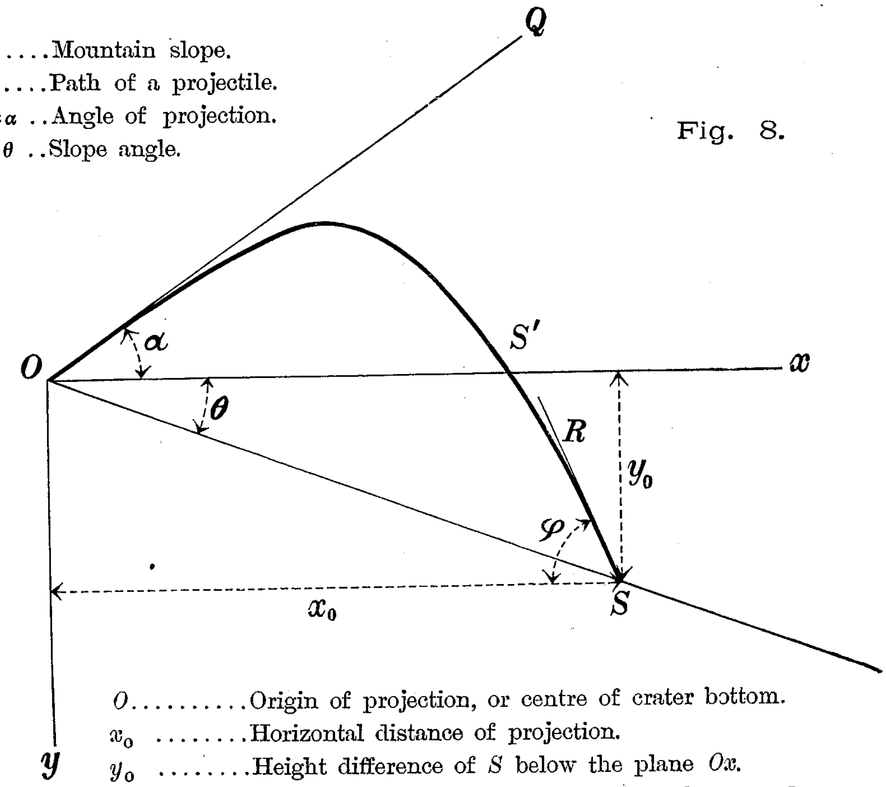
$$x = v\,t\cos\alpha;$$

$$y = -v\,t\sin\alpha + \frac{1}{2}g\,t^2;$$

in which g is the acceleration due to the gravity. For the point S, or the intersection of the path of the projection and the mountain slope OS, whose equation is $y = x\tan\theta$, we have

OS ....Mountain slope.
OS'S ......Path of a projectile.
$\angle QOx=\alpha$ ..Angle of projection.
$\angle xOS=\theta$ ..Slope angle.

Fig. 8.



O.........Origin of projection, or centre of crater bottom.
x_0 ....Horizontal distance of projection.
y_0 ....Height difference of S below the plane Ox.
φ ....Angle at which the projectile strikes the ground.

$$x_0=\frac{v^2}{g}\left(\sin 2\alpha+\cos 2\alpha\ \tan\theta+\tan\theta\right)\ \ldots\ldots\ldots\ldots(1)$$

$$\tan\alpha=\tan\varphi-2\tan\theta\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$v^2=\frac{gx_0}{\tan\varphi\cos^2\alpha+\sin\alpha\cos\alpha}\ \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

These equations enable us to calculate, from the knowledge of the horizontal distance (x_0) of projection and the angle (φ) of fall, the value of the initial velocity (v) of projection, and the angle (α) of elevation. Should the lava fragments be assumed to be projected with one and the same initial speed in the different directions and elevations, the angle α_0 corresponding to the maximum horizontal distance of projection is given, in virtue of (1), by the equation

$$\alpha_0=45^\circ-\theta^\circ/2\ \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

(Size is indicated in each figure by the annexed cm. scale.)

Fig. 10.

Fig. 9.

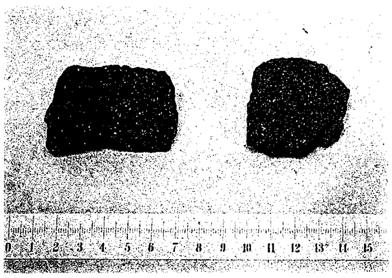


Fig. 11.

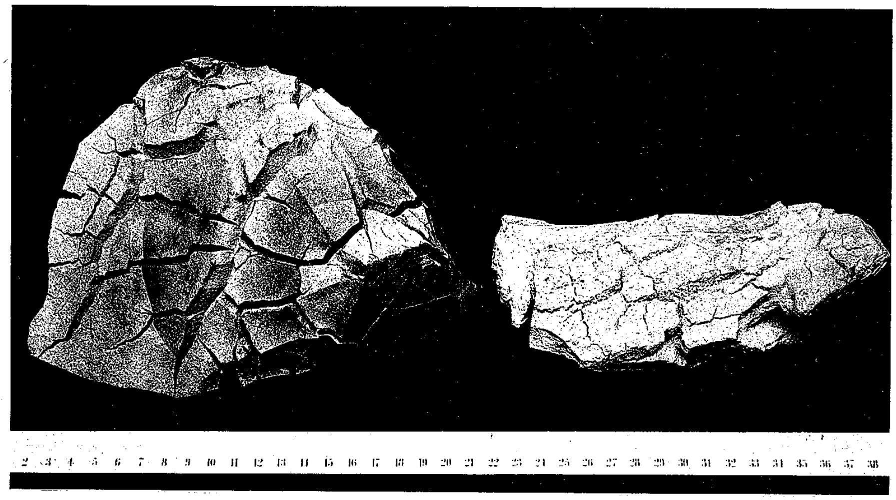


Fig. 9. Lava fragments suspended in the ascending air current and dropped down at the Wakasare Cottage. (Eruption of Noy. 14th, 1913.)

Fig. 10. A lava block projected to the Yuno-taira Observatory Ground, burying itself into the soil with the **arrow-head point** downwards. (Explosion of July 19th, 1913.)

Fig. 11. Light bluish-white **bread-crust bombs**, found at the summit of the Asama-yama, after the explosion of Dec. 13th–14th, 1912. (The right-hand side one contains small pieces of **cordierite.**)

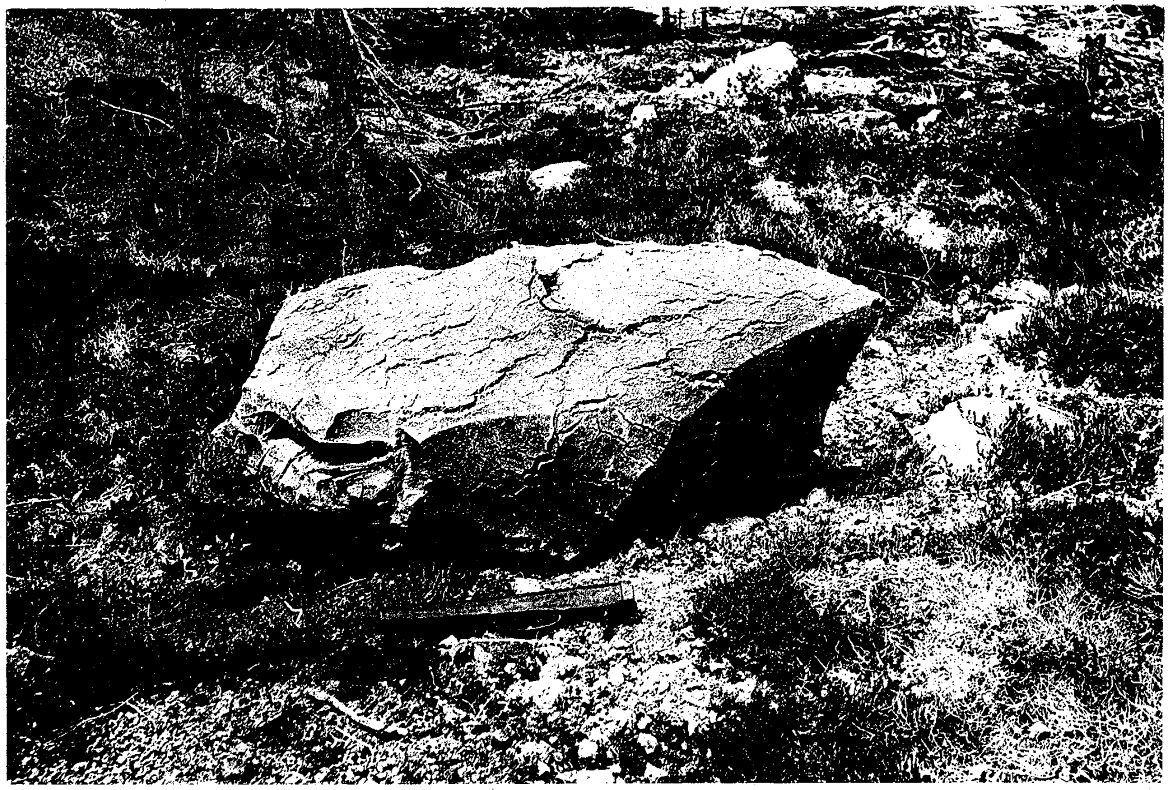


Fig. 12. A large bomb, about 3ft. in length, projected to Tengu-no-roji by the strong explosion of June 17th, 1913. (F. Omori, phot.)

Fig. 13. The "Volcano House," a resting place at Yuno-taira, perforated by numerous lava fragments projected out by the strong explosion of Aug. 12th, 1913. (F. Omori, phot.)

Fig. 14. A hole caused at Tengu-no-roji by the fall of a lava block projected by the explosion, probably of Oct. 22nd, 1911. May 20th, 1912. (F. Omori, phot.)

Fig. 15. View of the margin of the Wakasare branch of the lava stream of Temmei (1783), with Ko-Asama on the left-hand side back ground. May 20th, 1912. (F. Omori, phot.)

It follows that, if $\theta=0$, then α_0 reduces to 45°; i.e., for the case of an explosion from a centre situated on a horizontal plane, the lava fragments projected at an elevation angle of 45° will reach the furthest radial distance. Again, the time of descent, or more strictly, the time interval (τ) between the moment of the explosion and that of fall of the projectile at S, is given by the equation

$$\tau=\sqrt{\frac{2x_0}{g}\left(\tan\alpha+\tan\theta\right)} \quad\ldots\ldots\ldots\ldots\ldots(5)$$

As illustrative examples, I shall next apply the calculations to the cases of a few of the strong explosions of the Asama-yama.

Explosion of July 19th, 1913. According to the eye observation of Dr. K. Aomi, the angle φ for a lava fragment, which fell in the vicinity of the Yuno-taira observatory, at the foot of the Kiba-yama, was about 70°. As the corresponding horizontal distance from, and the height difference below, the crater bottom, are respectively about $x_0=2300$ and $y_0=580$ metres,* we find :—
Mean slope angle $\theta=14°$ Again, according to Equations (2), (5), and (3), we have :—

Angle of projection .... $\alpha=66°$
Time of descent .... $\tau=34$ sec.
Projection velocity .... $v=165$ m/sec.

According to these calculations, the moment of impact of the lava fragment in question was 34 sec. after the commencement of the explosion, or some 26 sec. after the arrival of the detonation at Yuno-taira. There were, of course, cases of earlier descent of lava fragments. Thus, according to the account of the observatory servant, who was sitting by the fire-side at the time of the explosion, the building was struck, as he got out of doors, by the earth splashes caused by the fragments, which fell a short

* In 1913, the crater bottom was quite shallow.

distance to the east, probably some 10 sec. after the arrival of the detonation.

Explosion of June 17th, 1913. On this occasion a lava fragment of no insignificant magnitude (probably 1 foot or so in dimension) was hurled to a place 768 metres below the Yuno-taira observatory, or about 2930 metres ($=x_0$) horizontally distant from the origin of the explosion, forming there by the force of impact a conical hole on the ground about 3 m in diameter and $1\frac{1}{2}$ m in depth. We may reasonably assume the lava block in question to have been thrown out from the crater at the elevation angle (α_0), which corresponded to the maximum horizontal projection distance, and we obtain from Equation (4), taking θ to be 14°, the value of about 38° for α_0, as follows:—

$$\alpha_0=45°-\frac{\theta°}{2}=38°$$

we further find:—

Angle of impact ....$\varphi=52°$
Time of descent....................$\tau=24.8$ sec.
Projection velocity....................$v=150$ m/sec.

Explosion of Aug. 12th, 1913. On this occasion, the "Volcano House" at Yuno-taira, a low flat wooden building,

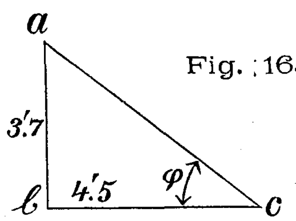


Fig. 16.
($\varphi=40°$)

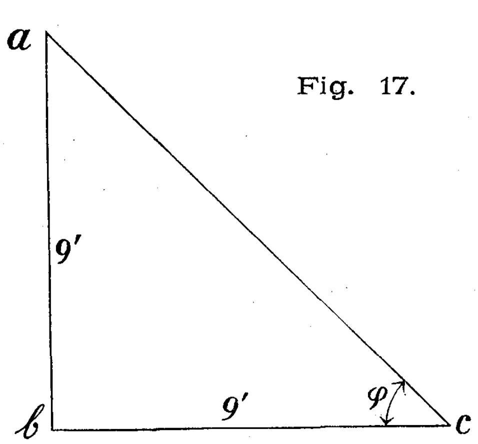
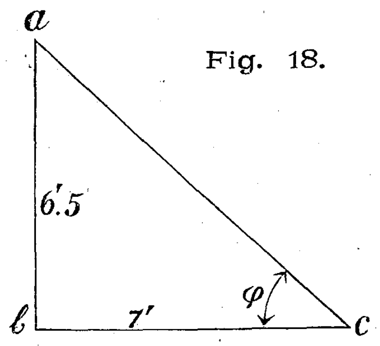


Fig. 17.
($\varphi=45°$)

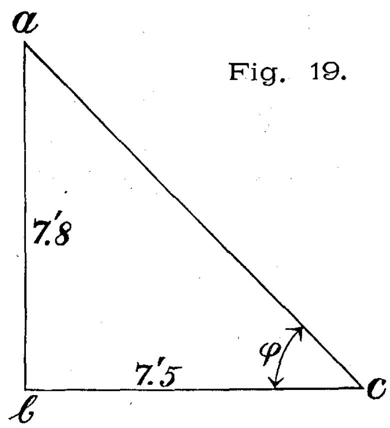
Fig. 18.



($\varphi=43°$)

(a) ....Point where a lava fragment pierced the roof.
(c) ....Point of impact on the floor or ceiling.

Fig. 19.



($\varphi=47°$)

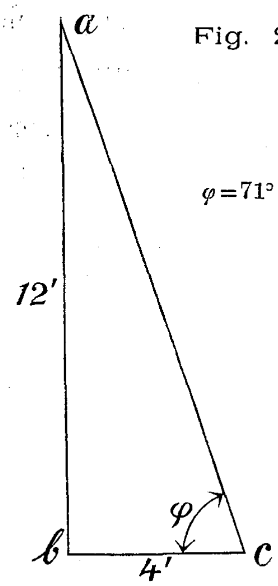
11 m long and 6 m wide, had its thatched roof pierced by no less than 27 small lava fragments. One of these, of about the size of a man's fist, made a hole about 10 inches in diameter on the roof (at a, Fig. 16), and scorching the bamboo ceiling (at c), finally dropped down to the floor. Another lava block $6'' \times 6'' \times 3''$ in dimensions, made a hole about $10''$ in size on the roof of the bath room (Fig. 17) and then strack the ground. A third broke through the roof of a neighbouring room (Fig. 18), and then strack the side wall. A fourth, about $6''$ in size, made a hole $12'' \times 6''$ in dimensions, on the roof of the stable (Fig. 19), and then strack the ground. The angles of impact in these 4 cases were respectively 40°, 45°, 43°, and 47°, giving the average of 44°. The different buildings were scorched more or less at many points. As the "Volcano House" is about 500 m below, and at 2080 m horizontal distance from, the crater centre, we find :—

$$\text{For } \varphi=44° \ldots \begin{cases} \alpha=24° \\ v=131 \text{ m/sec.} \\ \tau=17 \text{ sec.} \end{cases}$$

In the case of the eruption under consideration, a curious phenomenon was that there were in the neighbourhood of the observatory several narrow canal-like scratchings of the ground, apparently the effect of the rebounding out of the lava blocks projected at low angles. The largest of these was about 8′ in length, 2′½ in width, and 10″ in depth; the soil and grass being forcibly torn and thrown to distances of 10 m or more. In the case of a small scratching, the length was 1′½ and the width 4″. There were of course numerous instances, in which the lava fragments buried themselves into the soft ground. Thus, a hard angular block about 6″ in length, which fell at a distance of only a few metres from the observatory, was found embedded some 10″ obliquely in the soil. Another, about 5″ in size penetrated to a depth of 6″ at an inclination angle of 30°.

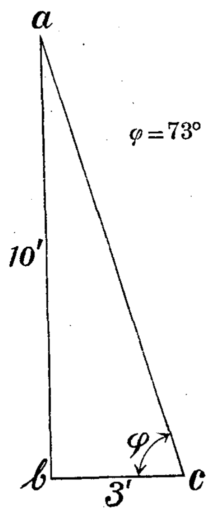
Lava fragments projected to Tengu-no-roji. On occasions of the different strong explosions, lava fragments, of maximum dimension of about 1 m (Fig. 12), were in a great number projected to the Tengu-no-roji (Devils' Throughfare), a picturesque

Fig. 20.



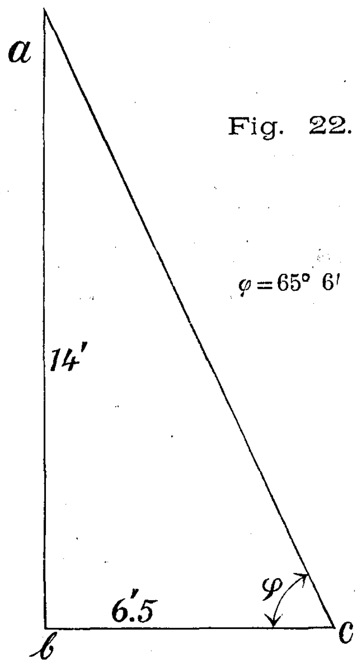
Lava block was an angular piece 1′ in length.

Fig. 21.



Lava block, 1′ cube, made a hole at c, 3′ in diam. and 1′ in depth.

Fig. 22.



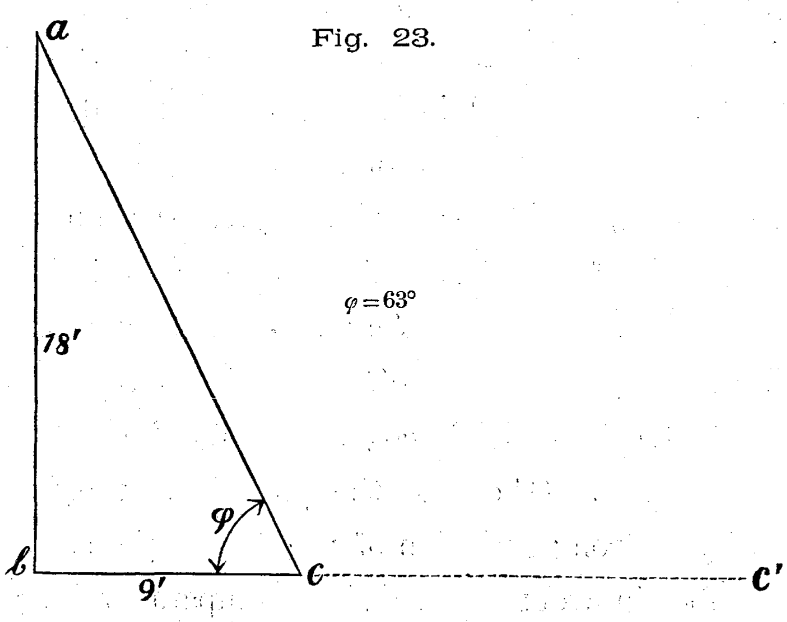
Lava block, embedded at c, formed a hole 4′ in diameter and 2′ in depth.

flat enclosure of hard ground at the SW foot of the Maikake-yama. The following determinations of the angle φ were made on July 28th, 1913, from the observations of the height of the point (a), where a falling lava fragment smashed a tree trank (ab), and the horizontal distance between the latter and the place of impact (c) on the ground (bc). The values of the angle of impact (φ) in the three cases figured above (Figs. 20, 21, and 22), which probably relate to the explosion of June 17th, 1913, were respectively 71° 34′; 73° 18′; and 65° 6′, giving the average of 70°. As the place under consideration is at a radial distance of about 1900 m from the crater centre and 470 m below the level of the latter, we find:—

$$\alpha = 66°$$
$$v = 150 \text{ m/sec.}$$
$$\tau = 31 \text{ sec.}$$

Explosion of Oct. 22nd, 1911. At a place called Sai-no-kawara on the plateau (Yuno-taira proper) above the "Volcano House" of Yuno-taira, at a radial distance of about 2000 m to the WSW from the crater centre, and 490 m below the level of the latter, there were found a few large lava blocks, which were projected on the occasion of the explosion in question. One

Fig. 23.



of these smashed a large *Larix leptolepis* tree (*ab*, Fig. 23) at the height of 18 feet (at *a*), and strack the ground with the angle of $\varphi=63°$ (at *c*), forming a hole 12′ in length, 6′ in breadth, and 4′ in depth. The stone block, which was about 4′ long and 3′ thick, jamped out and rebounded to a further forward distance of 15 feet (to *c′*). The results of the calculations are :—

$$\alpha=56°$$
$$v=134 \text{ m/sec.}$$
$$\tau=26 \text{ sec.}$$

Summary. The estimated values of the initial projection velocity on the occasions of the different explosions are as follows :—

July 19th, 1913	$v=165$ m/sec.
June 17th, „	152
„ „ „	150
Aug. 12th, „	131
Oct. 22nd, 1911	134

Thus the projection velocity seems to be *roughly* about 150 m/sec., or, say, from 100 to 200 m per sec., there being no reason to assign any high degree of accuracy to the results of the calculations, in which the air resistance has been entirely neglected. Now, the muzzle velocities of 12 inch and 6 inch naval guns attain respectively the maximum values of about 860 and 900 m per sec., that is to say, some 5 or 6 times greater than the assumed projection velocity of the strong Asama-yama explosions. That the latter can not throw out lava fragments with extremely high velocities is likely enough, as the effect of the outbursts is simply to scatter off the superficial coverings of the molten material filling the crater shaft. Of course, the quantity of the total lava mass thrown out by a strong explosion of the Asama-yama may be some 50 metres cube in volume, and is incomparably larger than that of the projectiles from heavy artillery pieces. The energy of such an explosion will roughly, so far as the projection of lava masses (m) of density ρ (=2) is concerned, be, assuming the initial velocity (v) to be 150 m per sec.,

$$=\frac{1}{2}mv^2=\frac{1}{2}\times 50^3\times 10^3\times 2\times 150^2=10^{13}\times 3 \text{ kilogrammetres,}$$

or about 200 times larger than that of the eruption of the Azuma-san of May 19th, 1893.* In the small explosions, the velocity is smaller, and the courses of the projected lava fragments, which have often tails of steam or gases, can distinctly be followed with the eye from the northern base of the mountain, as was the case, for instance, on Dec. 25th, 1911. Again, it is by no means rare that large lava masses thrown out by the strong explosions were observed even from the towns of Komoro and Kutsukake at the radial distances of 9 to 13 km. (See Fig. 2.)

The lava fragments projected vertically upwards with the initial velocity of, say, 150 metres per sec. will reach to a distance of some 1,100 metres above the crater.

It is to be remarked that the lava masses projected to a more or less considerable radial distance were hard fragments, often with arrow-head like point with which they penetrated into the ground. (See Fig. 10.)

7. *Holes caused by the falling lava fragments.* The hard lava fragments projected out on the occasions of the different strong eruptions of the Asama-yama produced holes as they fell on the ground with considerable force. These were most abundant on the plane grounds of the Yuno-taira and the Tengu-no-roji, and other places within about 2,200 metres horizontal distance from the crater centre. The farthest horizontal distance of projec-

* F. Omori: *The eruption of Azuma-san.* Seismological Journal of Japan, Vol. XIX, 1894.

tion of about 2,930 metres was reached on the occasion of the explosion of June 17th, 1913, when a hole 3 metres in diameter was formed on the slope of Nagasaka, between Yuno-taira and Ashino-taira. The greatest of the holes, which were circular or elliptical, had the diameter of about 8 m, the depth being, however, comparatively small and less than 1.7 m, as the ground is, at the places under consideration, hard and mixed with rock fragments. In the following table, I give the dimensions of a few holes found at Yuno-taira and Tengu-no roji:—

Place.	No.	Diameters.	Depth.	Remarks.
Tengu-no-roji.	1	15ft × 18ft	4ft	Relating probably to the explosion of of Oct. 22, 1912.
	2	6 × 6	1½	The stone block was of the size: 2 × 2 × 2′.
	3	6 × 4	1½	
	4	18 × 18	5	Relating probably to explosion of June 17, 1913. The stone block, which jumped out and rebounded several times, was of the size: 2 × 2 × 4′. (See Fig. 12.)
	5	21 × 21	4	
	6	10 × 10	4	The dimension of the stone block was about 2′.
	7	9 × 9	2	(See Fig. 25.)
Yuno-taira.	8	12 × 12	5	(See Fig. 24.)
	9	15 × 12	4	Relating probably to the explosion of Aug. 12, 1913.
	10	12 × 10	4	Relating probably to the explosion of Aug. 12, 1913. The stone block was of the size: 3 × 3 × 1½′.

As will be seen from the above table, the major diameter of the holes was on the average about 4 times larger than the depth, a relation which is contrary to that for holes produced on soft soil. (See below.) Again, the size (length) of the stone block was

Fig. 24.

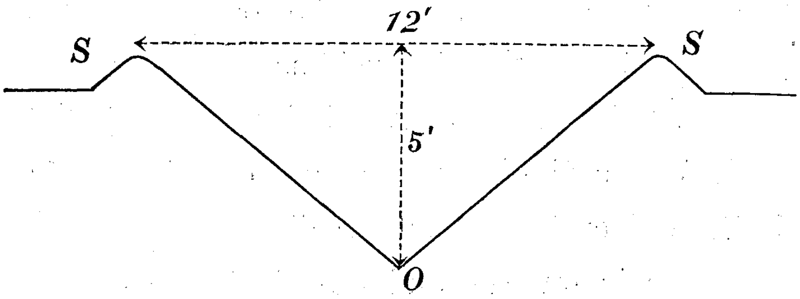
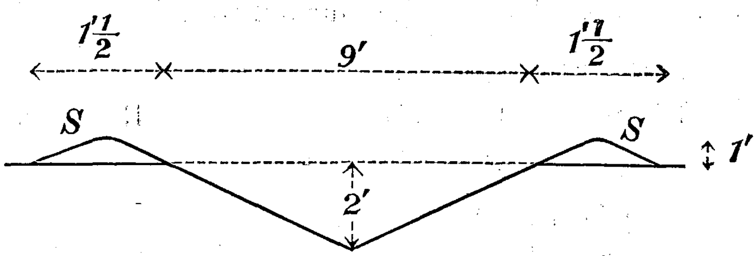


Fig. 25.



only about ¼ of the major diameter of the hole it produced. In very many cases, the holes at the Asama-yama were each a perfect inverted cone, as indicated in Figs. 24 and 25, being usually furnished with a ridge along the circumference, or part of it, (S in the figures). If the ground had been covered with grasses, the latter were found at the ridge, whose maximum height was 3 feet, turned upside-down and struck or splashed forcibly outwards, due to the force of the impact of the falling lava mass, often exploding with great violence, such that its fragments and the smashed plants were, in the case of No. 9 found shot off to the distance of about 35 feet from the centre of hole. A lava block, about 1 ft. in size, which fell on soft soil at a distance of 110 feet from the observatory, splashed earth to the doors of the building.

7′. Digression: holes in the case of Azuma-san eruption. The formation of the holes, which is a phenomenon almost common to all explosive eruptions, has been brought into notice by the late Professors S. Sekiya and Y. Kikuchi in their reports on the

Bandai-san outburst of 1888. On the occassion of the eruption of the Azuma-san*, in the Fukushima prefecture, on June 4th, 1893, numerous holes were produced by the projected rock fragments, which fell on the marshy plain, called the Numa-no-taira, the site of the old crater. As the soil was soft, the holes remained perfectly clear in outline, and the depth was generally a little larger than the major diameter of the opening, as will be seen from the following list of the measurements :—

No.	Diameters.	Depth.	Remarks.
1	65 cm	90 cm	
2	25	23	
3	$7\frac{1}{2}$	15	
4	22	40	
5	20	90	
6	40	40	Stone block, 12 × 12 × 6 cm, buried edgewise. (Fig. 26).
7	24 × 17	> 14	(See Fig. 27.)
8	200	270	Stone block was about 60 cm in size. (Fig. 28.)

Fig. 26.

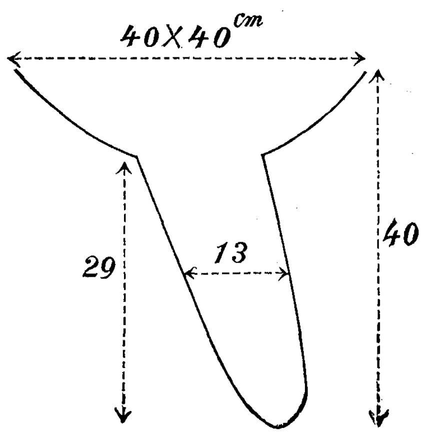
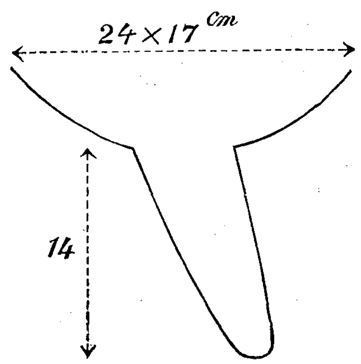
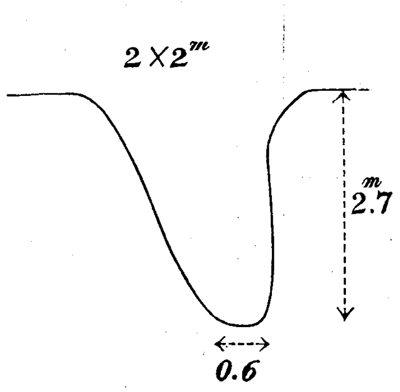


Fig. 27.



* An account of the eruption is given in the Seismological Journal of Japan, Vol. XX, 1894.

Fig. 28.



As indicated in Figs. 26, 27, and 28, the hole, whose axis was more or less inclined away from the direction of the crater, was generally of a compound form, being made up of the wide and shallow depression and a narrow deepening. The hole No. 8 (Fig. 28) was like a large paraboloid. The size of the stone block was in these cases only about one-third of the diameter of the mouth opening.

8. *Specific gravity of Asama-yama lava.* The following table gives the list of values of the specific gravity of a few specimens of the Asama-yama lava, relating mostly to the eruptions in 1913. It will be noted that the specific gravity of the massive lava pieces (i and ii) was about 2.5; while that of the bread-crust bombs and scoriae pieces found near the mountain summit was, on the average, about 1.1, being not much different from that of the ashes. The specific gravity of the pumice was about 1.2.

Specimen.		Specific Gravity.	
(i)	Massive lava pieces *projected* to the vicinity of Yuno-taira observatory, or to Tengu-no-roji.	2.42	
		2.51	
		2.58	
		2.29	mean, 2.47
(ii)	Lava fragments *dropped down* at Wakasare from among the smoke columns.	2.82	
		2.36	
		2.29	
(iii)	Bread-crust bombs found at the summit.	0.90	
		1.04	
		0.82	
		1.36	mean, 1.07

Specimen.	Specific Gravity.
(iv) Large scoriae pieces.	0.97 1.31
(v) Pumice which were *dropped* down at Wakasare.	0.86 0.83 0.60
(vi) Ashes, which fell at Wakasare. (vi) ,, ,, ,, ,, Kumagai.	1.32 1.05

9. *Emission of smoke.* In the ordinary, or non-eruptive, times, the large smoke masses of white or gray colour come out from the crater in detatched clusters often at more or less regular intervals. Such can be seen more distinctly when winds are blowing strongly over the mountain, as was the case on July 27th, 1913, when successive pieces of cotton-ball like smokes were swiftly carried eastwards. (See the illustration, Fig. 5.) The following is a part of the list of the times of appearance of the smoke masses over the summit, observed on the above-mentioned day from the Yuno-taira observatory:—

h m s	h m s	h m s	h m s
11 05 24 a.m.	11 10 50 a.m.	11 16 20 a.m.	11 22 21 a.m.
05 50	11 13	16 51	23 08
06 10	11 34	17 45	24 15
06 35*	12 28	18 00	24 55
06 51*	12 44	18 13	25 36
07 35	13 21*	18 50*	25 54
08 08	13 54	18 56*	25 30
08 22	14 14	19 31	27 07*
08 54*	15 13	20 07	28 06
09 52	15 41	20 26*	28 20
10 15*	15 57	21 19	28 36

11h 29m 24s a.m.	11h 32m 19s a.m.	11h 36m 28s a.m.	11h 40m 24s a.m.
29 52	33 04	37 04	40 40
30 48	33 36	37 44	41 33
31 06	34 14	38 30	
31 36	34 44	39 11	
31 58	35 40*	40 06	

* Comparatively larger ones.

The time interval between the successive emissions of the smoke masses, which varied between 13 and 62 sec., was most frequently included between 16 and 23 sec., and, to a less extent, between 35 and 38 sec., and betweeh 53 and 59 sec., giving the average values respectively of 19, 36, and 56 sec. Of these three values, the 1st may be taken as the fundamental interval, and the two latter as its multiples.

As a case of the occurrences at close intervals of the small non-explosive eruptions, which were strong enough to be registered by the tromometers at the Yuno-taira observatory, we may take the 135 outbursts observed on Oct. 2nd, 1912, between $0^h\ 0^m$ and $1^h\ 04^m\ 39^s$ a.m. According to Table II, the *Bulletin*, Vol. VI, No. 2, the successive time differences, which varied between 10 and 82 sec., were as follows :—

Interval.	Frequency.	Interval.	Frequency.	Interval.	Frequency.	Interval.	Frequency.
10 sec.	1	18 sec.	3	26 sec.	4	34 sec.	0
11	3	19	7	27	8	35	3
12	4	20	5	28	5	36	1
13	1	21	7	29	3	37	1
14	4	22	6	30	4	38	1
15	7	23	3	31	3	39	3
16	4	24	4	32	4	40	1
17	9	25	2	33	1	41	2

Interval.	Frequency.	Interval.	Frequency.	Interval.	Frequency.	Interval.	Frequency.
42 sec.	0	46 sec.	2	58 sec.	1	73 sec.	1
43	2	47	3	61	1	81	2
44	3	53	2	65	1	82	1
45	1	57	2	70	2		

From the above table, it will be noticed that the interval in question was in the 100 out of the total number of the 135 were included between 11 and 32 sec., while it was specially frequent between 15 and 22 sec. This last feature is similar to the preponderance of the value of about 19 sec. in the cases of the smoke emissions in the ordinary times, before considered.

On July 27th, 1913, the smokes were carried by the strong winds along the south-eastern slope to the mountain base, and constituted in the evening hours a light yellowish misty layer extending over the plains below, which caused some ash-precipitation at Miyoda, Komoro, and neighbouring places. It is evident that the strong explosions send the smokes into a considerable height, thence to be generally carried eastwards by the upper air current, differing in this respect from the small eruptions or the ordinary non-explosive smoke emissions, which cause ash-precipitation in the immediate neighbourhood of the mountain in obedience to the surface winds.

CHAPTER II. SOUND AREA AND ASH-PRECIPITATION ZONE.

10. The sound areas and the ash-precipitation zones of the 11 typical explosions in the three years 1909 to 1911 have been described in the preceding volume of the *Bulletin*. I now proceed