

CHAPTER VI. PROPAGATION VELOCITY OF DETONATIONS AND EARTHQUAKES.

35. The detonations and earthquakes, which originate at the Asama-yama, furnish interesting subjects of study in connection with the propagation of sound and earthquake waves. In the three strong explosions of Dec. 7th, 1909; Dec. 2nd, 1910; and of May 8th, 1911, the detonations were heard at a number of the meteorological stations, enabling us to make rough calculations of the sound velocity. Again, for the first and the third of these eruptions, the approximate propagation velocity of the earthquake motion, which either preceded or accompanied the volcanic outburst, has been deduced from the seismographical observations at Tokyo, Osaka, and Nagano. As the times of occurrence of the disturbances were not observed at the Asama-yama itself, the velocity calculation is in each case made according to the "difference method," which consists in dividing the difference of the radial distances of the two (or more) places by the difference of the times of arrival at the latter of the sound, or earthquake, waves, as described in the following §§.

36. *Explosion of Dec. 7th, 1909.* The exact time observation in Tokyo of this strong detonation is unfortunately wanting. The different horizontal pendulum tromometers in the Seismological Institute recorded, however, a well marked "sound-tremor," about 40 seconds in duration, which began at 7^h 51^m 38^s pm ($=t_2$), and which was preceded for about 7 seconds by extremely minute movements. (See Fig. 38.) The time observations at the different meteorological stations were as follows :—

TABLE XXI. TIMES OF ARRIVAL OF THE THREE SOUNDS AT THE DIFFERENT STATIONS. EXPLOSION OF DEC. 7TH, 1909.

Group.	Stations.	Distance from the Asama-yama.	Time of Arrival.		
			1st Sound.	2nd Sound.	3rd Sound.
i	Maebashi.	50 km.	— — —	7 ^h 47 ^m — ^s pm.	—
	Kofu.	82	— — —	7 50 —	—
	Kumagai.	83	— — —	7 49 49	(1st and 2nd sounds lasted together 30s.)
	Utsunomiya.	121	— — —	7 51 29	(A weaker sound followed the 2nd after 4 or 5sec.)
ii	Tsukuba.	145	7 ^h 50 ^m 00 ^s	7 53 00	—
	Yokohama.	147	— — —	7 53 —	7 ^h 53 ^m 07 ^s
	Yokosuka.	161	7 52 50	7 54 00	— — —
	Mito.	175	7 53 10	7 54 10	— — —
iii	Fukushima.	228	7 56 30	7 58 30	— — —
	Kanayama.	259	7 58 59	8 01 09	— — —

Assuming the identifications of the three sounds indicated in the above table to be correct, and comparing the times of occurrence of the 2nd, or principal, one with that of the sound-tremor in Tokyo, we get the following results :—

Group.	Number of Stations.	Distance Difference. (Referred to Tokyo).	Time Difference. (Referred to Tokyo.)	Sound Velocity.
i	4	53 km.	2 ^m 03 ^s	431 m/s
ii	4	20	1 22	244
iii	2	107	8 12	218
Mean.	—	—	— —	314

The results respecting the sound velocity are thus found to be much discordant, due doubtless to inaccuracy in the time deter-

minations; the mean value is, however, fairly reasonable and equal to 314 m/s. The air temperature at the time of the explosion at Tokyo, Yokohama, Mito, and the other stations were from $4^{\circ}.2$ to $5^{\circ}.8$ C, the average being 5° C.

37. Asama-yama earthquakes at the time of explosion of Dec. 7th, 1909. The seismic disturbance at the time of the explosion of Dec. 7th, 1909, was clearly registered by the seismographs at the Seismological Institute (Tokyo), the max. EW motion being 0.1 mm, and the time of commencement being 7.43.55 pm. (See Fig. 38.) The shock, which evidently originated at the Asama-yama itself, was distinctly or even severely felt at the base of the mountain, and made itself instrumentally sensible even in Osaka at the radial distance of 330 km. The following table gives the times of occurrence and the durations of the preliminary tremor in Tokyo, Osaka, and Nagano, the instruments in the 1st place being the horizontal tromometers of 120 and 500 times magnification, and those at the two last places being horizontal pendulums respectively of 20 and 30 times magnifications.

TABLE XXII. SEISMOGRAPHICAL OBSERVATIONS OF THE ASAMA-YAMA EARTHQUAKE OF DEC. 7TH, 1909.

Station.	Radial Distance = x	Duration of Preliminary Tremor= y	Time of Occurrence. = t	Remark.
Tokyo, { Seism. Institute.	137 km	18.8 sec.	7 ^h 43 ^m 55 ^s pm.	Unfelt.
Osaka, Met. Obs.	330	47.0	7 44 46	„
Nagano, „	40	4.5	7 42 31 (?)	„

Calculating the distance (x) from the duration (y) of the preliminary tremor according to the formula: x km = $6.86 y$ sec. + 8.1 km, we find, for Tokyo, Osaka, and Nagano, respectively the values

of 137 ; 330 ; and 39 km, which are identical with the corresponding actual distances. Comparing the distances (x) and times (t') of occurrence in Tokyo and Osaka, we obtain :—

$$\text{Radial Distance Difference} = 330 - 137 = 193 \text{ km.}$$

$$\text{Time Difference} = 7^{\text{h}}44^{\text{m}}46^{\text{s}} - 7^{\text{h}}43^{\text{m}}55^{\text{s}} = 51 \text{ sec.}$$

$$\text{Earthquake Velocity} = \frac{193 \text{ km}}{51 \text{ sec.}} = 3.8 \text{ km/sec.}$$

Thus the velocity of the 1st preliminary tremor of the volcanic earthquake for the distance of 137 to 330 km, between Tokyo and Osaka, is found to be 3.8 km per sec., which is only slightly higher than the velocity of the surface propagation of the ordinary earthquake motion.

If the earthquake velocity between Tokyo and the Asama-yama be assumed to be 3.3 km/sec. (§ 39), then the earthquake must have happened at the mountain itself at about $7^{\text{h}}43^{\text{m}}13^{\text{s}}$ pm ($=t'_0$). The interval between the latter time of earthquake occurrence and the commencement ($t_2 = 7^{\text{h}}51^{\text{m}}38^{\text{s}}$ pm) of the sound tremor in Tokyo is $8^{\text{m}}25^{\text{s}} = 505$ seconds, which is much longer than the actual time length likely to be taken by the sound waves in travelling the distance of 137 km from the Asama-yama to Tokyo; the intervals in question required by the sound of propagation velocities, for instance, of 320, 330, and 340 m/sec., being respectively only $7^{\text{m}}8^{\text{s}}$, $6^{\text{m}}55^{\text{s}}$, and $6^{\text{m}}43^{\text{s}}$. Thus the earthquake under consideration was evidently not the effect of, but must have occurred some time before, the explosion. In fact, the diagrams (Fig. 38) seem to indicate the occurrence in succession of two earthquakes, their conspicuous single maximum movements (C and C' in the figure) being separated by an interval of $1^{\text{m}}54^{\text{s}}$. The times of occurrence in Tokyo and at the Asama-yama of the 2nd shock, which was the smaller, and which represents the effect of the explosion, were therefore respectively

about $7^{\text{h}} 43^{\text{m}} 55^{\text{s}} + 1^{\text{m}} 54^{\text{s}} = 7^{\text{h}} 45^{\text{m}} 49^{\text{s}}$ pm ($=t_1$), and $7^{\text{h}} 43^{\text{m}} 13^{\text{s}} + 1^{\text{m}} 54^{\text{s}} = 7^{\text{h}} 45^{\text{m}} 07^{\text{s}}$ pm ($=t_0$). Again, the difference between the times of the arrival in Tokyo of the seismic motion and of the sound tremor becomes $=t_2 - t_1 = 5^{\text{m}} 49^{\text{s}}$, which is not much different from the corresponding value found for the explosion of May 8th, 1911 (§38).

That the explosion of Dec. 7th, 1909, was announced by an earthquake about $1^{\text{m}} 54^{\text{s}}$ before, is in good accordance with the observation of Mr. C. Koborinai, of the Nagano Meteorological observatory, who was at the time at Miyota, a town at the south base of the volcano. He felt first an earthquake shock, and then after $2^{\text{m}} 30^{\text{s}}$, which interval he measured with his watch, heard the detonation. As Miyota is about 11 km distant from the crater, the sound and the seismic waves would take respectively about 33 sec. and 7 sec. to reach the town, assuming the velocities of the two kinds of shakings to be 330 m/s and 1.5 km/s; Hence the detonation must reach, according to our assumptions, the town of Miyota $1^{\text{m}} 54^{\text{s}} + (33^{\text{s}} - 7^{\text{s}}) = 2^{\text{m}} 20^{\text{s}}$ after the first earthquake, a result which agrees well with the observation of Mr. Koborinai.

In the following list are given the reports from the different places at or near the base of the Asama-yama, which possibly relate to the precursory earthquake.

TABLE XXIII. REPORTS RESPECTING THE EARTHQUAKE WHICH PRECEDED THE EXPLOSION OF DEC. 7TH, 1909.

Village or Town (County, Province.)	Distance and Direction from Crater.	Earthquake and Detonation.*
Ozasa (Azuma, Kotsuke)	^{km} 10, N10°W	{ At about 7.40 pm, a rather strong shock, with vertical movement lasting 30 sec., and causing pendulum clocks to stop. Some 5 minutes later on, loud detonation, shaking violently doors and windows.

Village or Town (County, Province.)	Distance and Direction from Crater.	Earthquake and Detonation.*
Kusatu (Azuma, Kotsuke)	^{km} 26, N 20°E	{ At about 7.46 pm, earthquake shock, with vertical movement, followed after 1 minute by detonation.
Osato { N. Saku, Shinano.	10, S 56°W	{ A slight shock lasting about 1 minute, followed after 3 minutes by loud detonation.
Kita-Oi (<i>Do.</i>)	10, S 35°W	A strong shock, followed by loud detonation.
N. Nagakura (<i>Do.</i>)	9, S 42°E	{ A slight shaking, followed after a while by detonation.
E. Nagakura (<i>Do.</i>)	12, S 67°E	Two very feeble shocks preceded the explosion.
Konuma (<i>Do.</i>)	6, S 8°W	A strong shock preceded the explosion.
Kawabe (<i>Do.</i>)	14, S 43°W	{ An earthquake followed after a while by detonation.
Shigeno { Chiisagata, Shinano.	14, S 59°W	A slight shaking, followed by explosion.

* The time observations are only approximate.

Thus at Ozasa, distant 10 km from the crater, the shock was strong enough to stop pendulum clocks.

38. Strong explosion of Dec. 2nd, 1910. The moments of arrival in Tokyo of the detonations of the explosion on the night of Dec. 2nd, 1910, were carefully noted by the present author, who was at the time quietly sitting by the desk, with a pocket chronometer in front, at his own house in the Koishikawa District, whose radial distance from the volcano is 134 km. At 8.25.54 pm, were perceived feeble sounds of a few seconds duration like those caused by the passing of a wagon; 1^m 44^s later, namely, at 8.27.38 pm, there was a loud sound like that of a gun discharge at a distance, followed after 4 seconds, or at 8.27.42 pm, by a similar but slightly stronger sound. A 100-times horizontal tremor-recorder at the Seismological Institute (radial distance=137 km) registered the sound-tremor of about 20 seconds duration at 8.27.46 pm, preceded by the trace of extremely minute movements for about 9 seconds. The small earthquake

which accompanied the explosion was not clearly indicated in the diagram, owing to the simultaneous predominance of pulsatory oscillations. The times of arrival of the sounds observed at the different meteorological stations were as follows:—

TABLE XXIV. EXPLOSION OF DEC. 2ND, 1910: TIMES OF ARRIVAL OF THE SOUNDS OBSERVED AT THE DIFFERENT PLACES.

Station.	Distance from the Asama-yama.	Time of Arrival.		
		1st Sound.	2nd. or Principal Sound.	3rd Sound.
Tokyo { Koishi- Kawa	134 km	8.25.54 pm.	8.27.38 pm.	8.27.42 pm.
Tsukuba.	145	26.20	27.50	27.52
Utsunomiya.	121	25.38	26.21	26.25
Mito.	175	27.55	29.05	—
Maebashi.	50	20—	21—	—
Kumagai.	83	—	25.21	—
Yokohama.	147	(About 8.27.00)	29 (?)	{ A few seconds after the 2nd sound
Yokosuka.	161	—	29.02	—
Mera.	202	—	30.50	—

Confining our attention to the 2nd, or principal sounds, whose time-distance relation is illustrated in Fig. 39, and referring the time observations at the different district meteorological stations to that in Tokyo, we obtain the following results, for the propagation velocity of the detonation in question:—

TABLE XXV. EXPLOSION OF DEC. 2ND, 1910: VELOCITY OF SOUND.

Station.	Difference of the Radial Distances.	Difference of the Times of Arrival of the 2nd Sound.	Sound Velocity.
Tsukuba. Yokosuka.	}19 km	0 ^m 48 ^s	396 m/s

Station.	Difference of the Radial Distance.	Difference of the Times of Arrival of the 2nd Sound.	Sound Velocity.
Utsunomiya.	13	1 ^m 17 ^s	169 m/s
Mito.	41	1 27	471
Mera.	68	3 12	354
Kumagai.	51	2 17	372
Maebashi.	84	6 23 (approx.)	219
<i>Mean.</i>	—	— —	330

Owing to the inaccuracy of the time observations at the different stations, the results are widely discordant, giving, however, the mean velocity of 330 m/s. The air temperature at 8 pm, on the 2nd, was 9°.2 (in Tokyo.), and from 4°.5 to 10°.5 C in the different stations named in the above table, giving the average value of 7.3°C. Assuming the above obtained value of 330 m/s for the propagation velocity of the sound wave between Tokyo and the Asama-yama, the time of occurrence of the explosion at the volcano itself is found to be about 8.20.50 pm.

39. Explosion of May 8th, 1911. The detonation was perceived by the present author at the Seismological Institute (Hongo, Tokyo) as loud rushing sounds lasting about 10 sec., during which interval the windows were shaken considerably as by strong winds or by an earthquake of moderate intensity; the time of occurrence being 3.34.37 pm. According to the diagram furnished by the EW-component horizontal pendulum tromometer of 120 times magnification, the slight shakings of the ground occasioned by the explosion reached the observatory already at about 3.28.40 pm ($=t_1$), becoming maximum ($2a=0.02$ mm) at 3.29.10 pm ($=t_2$). This earthquake, about 2 minutes in duration, which was

somewhat confused by the presence of small pulsatory oscillations, was followed at 3.34.38 pm ($=t_3$) by the sound-tremor, consisting of extremely minute vibrations (max. $2a=0.005$ mm), which lasted about 15 sec.; the t_3 coinciding with the above-mentioned time instant when the detonation was actually perceived.

At the Nagano Meteorological Observatory, the detonation was heard at 3.29.55 pm* as sounds like distant thunders, which lasted about 5 sec., while the horizontal pendulum seismograph of 30 times magnification recorded the earthquake at 3.28.04 pm.

Comparing the times of arrival of the sound waves in Tokyo (Seismological Institute) and Nagano, which are situated respectively 137 km to S53°E, and 40 km to N48°W from the volcano, we have :—Difference of the Radial distances of Tokyo and Nagano from the Asama-yama = $137 - 40 = 97$ km; Difference of the times of arrival of the sound waves in the same two places = $3^h 34^m 38^s - 3^h 29^m 55^s = 4^m 43^s = 283$ sec.;

$$V \text{ (Sound velocity)} = \frac{97 \text{ km}}{283 \text{ sec.}} = 343 \text{ m/sec.}$$

Thus the propagation rate of the detonation is found, for the radial distance of 40 to 137 km, to be 343 m/sec. This is the value of the velocity of the ordinary sound waves in the air corresponding to a temperature of about 20°C. It may be added that at 2 and 6 pm, the air temperature at the different stations in Central Japan varied from 16°.2 (Choshi) to 23°.8 C (Kofu); in particular, the 4 pm temperatures at Tokyo, Kumagai, Mae-bashi, and Nagano, which places may be taken into consideration in connection with the above calculation of the detonation velocity,

* The time observations at Nagano respecting this explosion seem to be fairly good, as the clock-corrections on May 8th and 9th are known.

The Strong Asama-yama Earthquake of May 26th, 1908,
observed at Hongo, Tokyo. (a=Commencement).

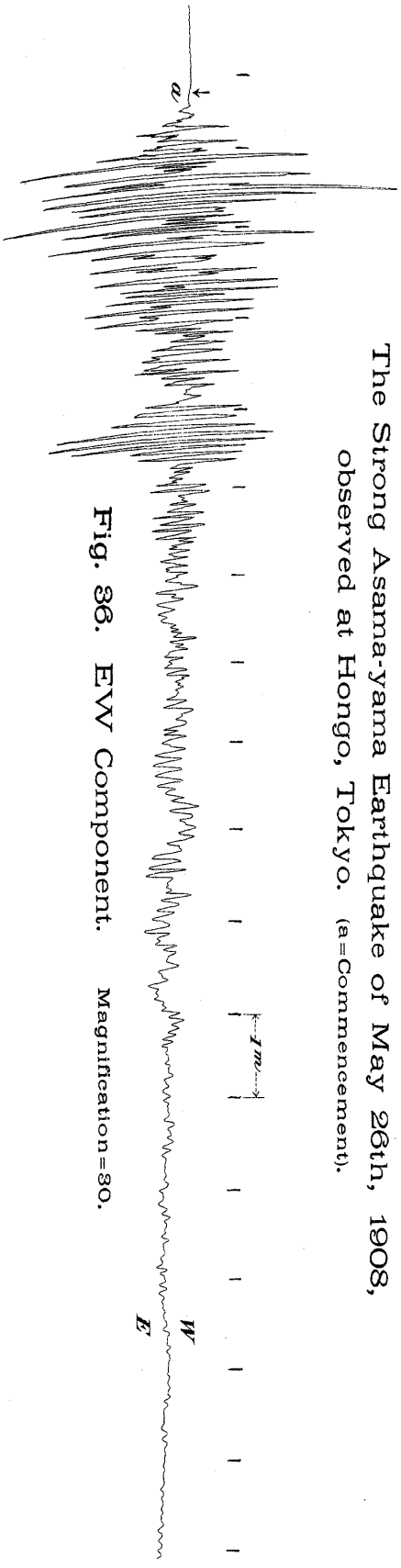


Fig. 36. EW Component. Magnification=30.

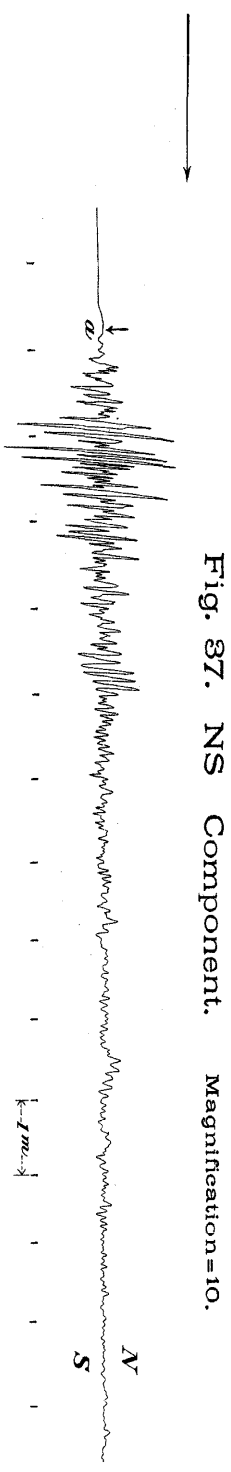
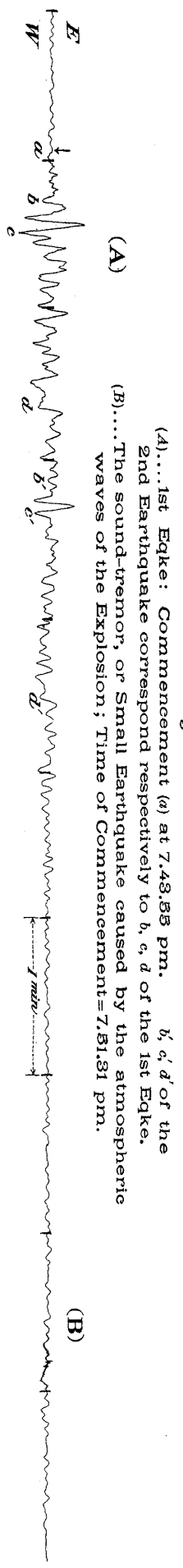


Fig. 37. NS Component. Magnification=10.

Fig. 38. The Asama-yama Earthquakes of Dec. 7th, 1909,
observed at Hongo, Tokyo. EW Component.
Magnification=120.



(A)...1st Eqke: Commencement (a) at 7.43.55 pm. b, c, d' of the
2nd Earthquake correspond respectively to b, c, d of the 1st Eqke.
(B)...The sound-tremor, or Small Earthquake caused by the atmospheric
waves of the Explosion; Time of Commencement=7.51.31 pm.

(B)

Fig. 39. Distance-Time Relation of the Detonation of the Asama-yama Eruption of Dec. 2nd, 1910.

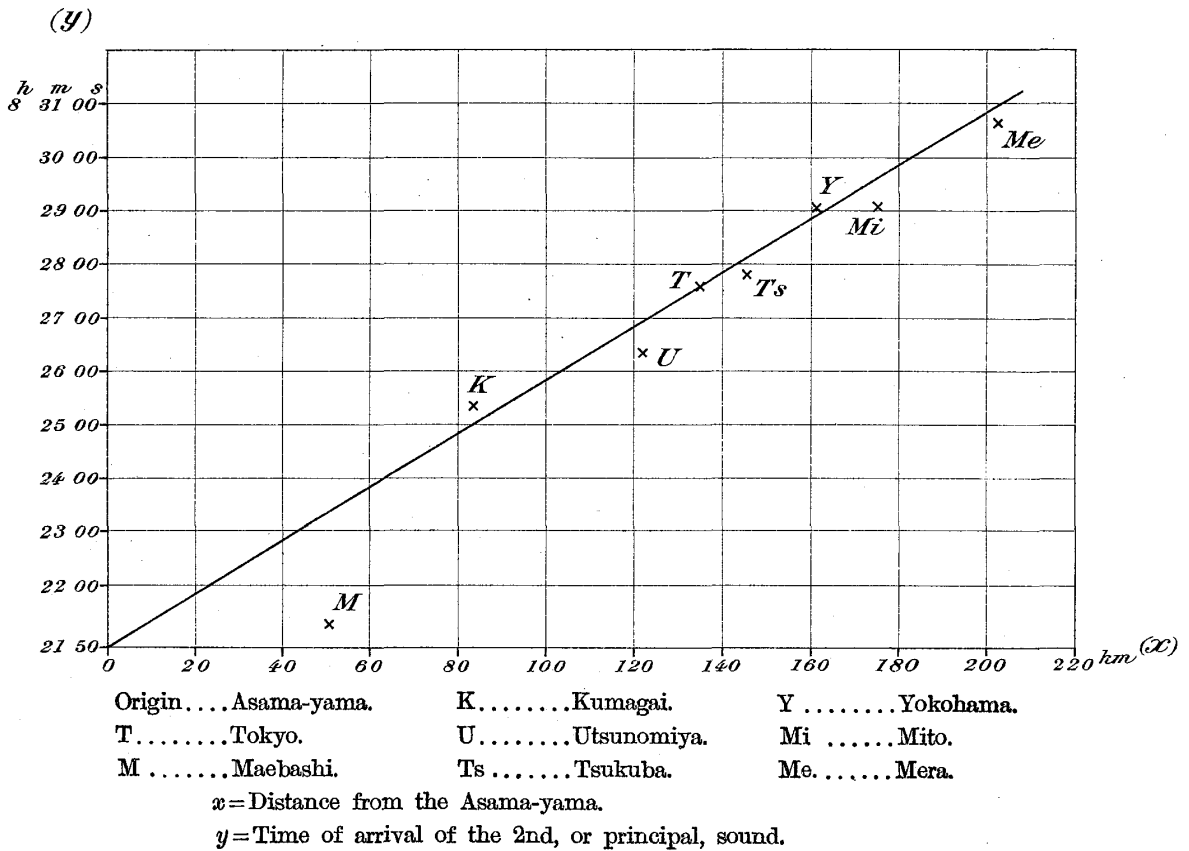
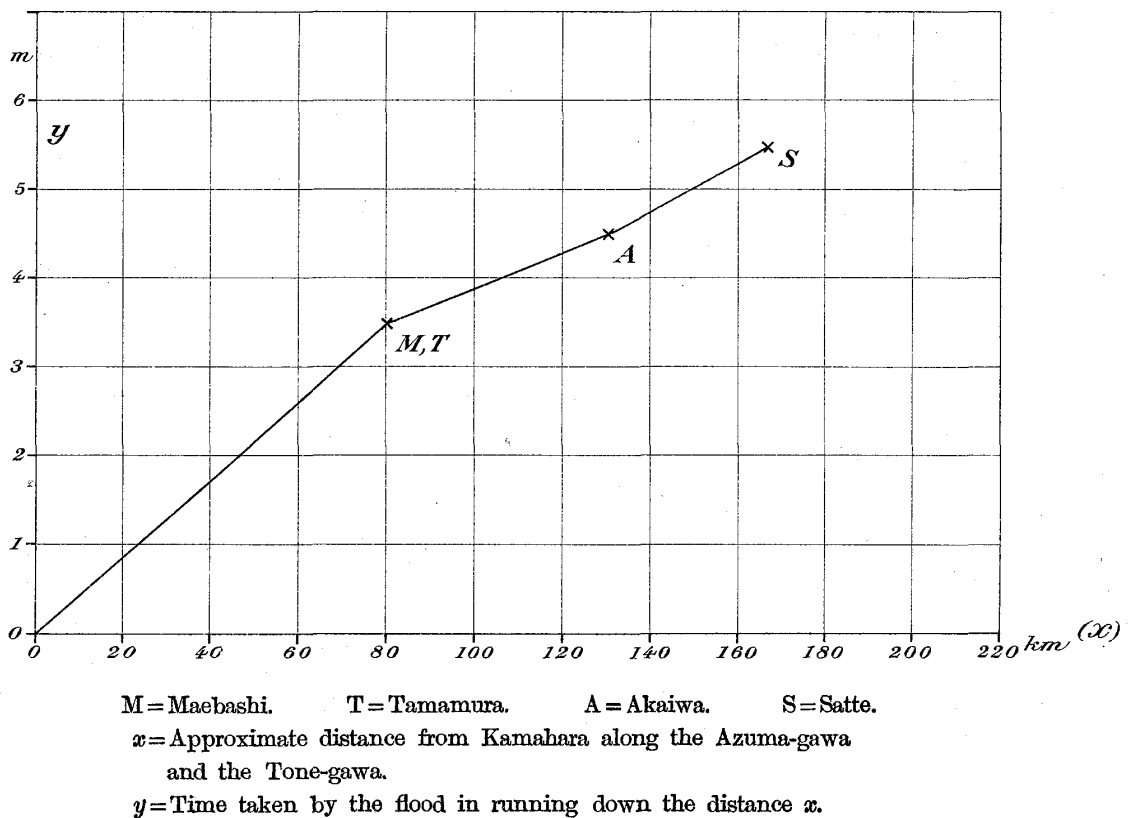


Fig. 40. Time-Distance Relation of the Flood along the Azuma-gawa and the Tone-gawa produced by the great Volcanic Avalanch of Aug. 5th, 1783.



were respectively $20^{\circ}.3$; $20^{\circ}.9$; $21^{\circ}.1$; and $20^{\circ}.5$ C , giving the value of $20^{\circ}.7$ C for the mean surface air temperature.

The velocity (v) of the earthquake motion may be estimated from the Tokyo observation, as follows :—

$$\frac{1}{v} = \frac{1}{V} - \frac{t_3 - t_1}{\text{Rad. Distance}} = \frac{1}{V} - \frac{358^{\text{sec.}}}{137^{\text{km.}}}$$

Assuming for V the above found approximate value of 343 m/sec., we obtain :—

$$v = 3.31 \text{ km per sec.}$$

If these results can be trusted, the velocity of the explosion-earthquake is about 3.3 km per sec., consequently practically identical with that of the surface propagation of the ordinary earthquake motion, as is to be expected from the purely surface origin of the seismic disturbances accompanying the volcanic explosions. This conclusion requires, of course, verifications.

The time of occurrence at the Asama-yama itself of the explosion under consideration was probably about 3.27.58 pm.

40. Summary. The results of the calculations of the sound velocity obtained in the foregoing §§ are tabulated below :—

Explosion of	Limits of the Radial Distance taken in the calculation.	Mean Surface Temperature.*	Sound Velocity.
Dec. 7th, 1909.	50 ^{km} —259 ^{km}	5 ^o .0 C	314 m/s
Dec. 2nd, 1910.	50—202	7 ^o .3	330
May. 8th, 1911.	40—137	20 ^o .7	343

* Mean of the temperatures observed at the different meteorological stations at the time of each explosion.

These results, which are only gross approximations, indicate that the velocity of the detonations generated by the explosions of the Asama-yama varied from 314 to 343 m/s, for the radial distances between some 40 and 260 km, and for the mean *surface* temperatures of $5^{\circ}.0$ to $20^{\circ}.7$ C.

The velocity of the earthquake motion was 3.31 km/s for the radial distances of 40 to 137 km between Nagano and Tokyo, and 3.8 km/s for the radial distances of 137 to 330 km between Tokyo and Osaka, tending to indicate that the propagation rate of volcanic earthquakes is generally low.

CHAPTER VII. ERUPTIONS OF THE YAKE-DAKE.

41. *Recent Activity of Yake-dake (Iwo-san).* The Yake-dake, whose proper name is Iwo-san (Sulphur Mountain) is 2053 metres in height, and is situated at a distance of 85 km to the SW from the Asama-yama, on the boundary of the provinces of Shinano and Hida, and between the two much higher mountains of the Norikura-dake (3166 m) and Yariga-take (3092 m). This volcano, whose present activity began in Dec. 1907, had, according to Dr. Tetsunosuke Kato, been quiet for many centuries after its eruption in 1585, such that the crater became densely covered with trees. Since about 20 years ago, however, the volcanic energy gradually revived, till the old crater bottom was partly destroyed by the recent convulsions. On the occasions of these latter, the precipitation of ashes took place very often at Matsumoto, which is 32 km to the due E. of the volcano, and the different towns and villages situated on the plateau stretching N-S to the west of that city. The ashes reached, on several occasions, as far as Nagano, 70 km to the NE; Ueda, 65 km to the ENE; and