disturbance recorded by the Richard's barograph (Table XXX), arranged in order of magnitude of the latter.

Group.	Explosion.	Barometric Disturbance. (1st Displacement, or Increase).	Total Sound Area.
i	Aug. 12th (11 p.m.)	14.2 mm.	35,940 sq. km.
	July 19th	9.6	19,050
	„ 13th	7.7	18,250
	June 26th (11 p.m.)	6.0	15,750
ii	June 26th (8 a.m.)	3.4	12,610
	May 29th	3.0	19,370
	„ 16th	2.8	7,240
	June 20th	2.3	19,560

Thus, of the group (i) explosions, with the larger barometric disturbance, that on Aug. 12th had very extensive sound area. On the other hand, the explosions of the (ii) group, with the smaller barometric disturbance, had the sound areas of about the same extension as the rest of the (i) group. This seems to show that the extent of the sound area does not depend simply on the intensity of the detonation at the origin.

CHAPTER XIV. PROPAGATION VELOCITIES OF VOLCANIC DETONATION AND EARTHQUAKE MOTION.

124. *Propagation velocity* (= *V*) *of Asama-yama detonation between Yuno-taira and Tokyo.* In the two explosions of Aug. 12th, 1913, at 11.20 p.m. (§§ 62 and 117) and of May 5th, 1914, at 0.33 a.m. (§§ 63 and 117), the times of occurrence of the barometric disturbance at Yuno-taira and of the "sound shock" in Tokyo have been accurately determined; the barometric disturbance and the "sound shock" being identical with

the actual detonation (Chapters XII and XIII). We have:—

Explosion.	Commencement of Barometric Disturbance at Yuno-taira (from Barograph, § 116).	Commencement of "Sound Shock" in Tokyo.	Time Difference between Yuno-taira and Tokyo.
	h m s	h m s	m s
(i) Aug. 12th, 1913.	11 20 40.4 p.m.	11 27 07.0 p.m.(1)	6 26.6
(ii) May 5th, 1914.	0 33 10.3 a.m.	0 39 38.0 a.m.(2)	6 27.7

(1) From the tromometer record at the Seismological Institute.
(2) From the direct time observation by the present author at his house.

Thus the time intervals taken by the sound waves in travelling the space between the observatory on the volcano and the city of Tokyo were on the two occassions respectively $6^m\ 26.6^s$ and $6^m\ 27.7^s$. For (i) the difference of the radial (sound path) distances of the Yuno-taira observatory and the Seismological Institute is $135.40^{km} - 2.38^{km} = 133.02^{km}$; the propagation velocity of the detonation being 344.1 m/sec., as follows:—

$$V = \frac{133.02^{km}}{6^m\ 26.6^s} = 344.1 \text{ m/sec.}$$

For (ii), the difference of the radial distances between Yuno-taira and the author's house, is $132.08^{km} - 2.38^{km} = 129.70^{km}$; the propagation velocity being 334.5 m/sec.:

$$V = \frac{129.70^{km}}{6^m\ 27.7^s} = 334.5 \text{ m/sec.}$$

Again, for (i), the air temperature at the different places along or near the sound path, namely, at Maebashi, Kumagai, Yokohama, and Tokyo, was between 19.6°C and 28.4°C with the average of 25°C; while that for (ii) was from 7.5° to 13.1°C., with the average of 10.6°C. The values of the ordinary sound propagation corresponding to these two mean *surface* air temperatures are 347.6 and 338.8 m/sec., being respectively 3.5 and

4.3 m/s too large than the values actually found, as ought to be, the air temperature at the surface being probably about 6°C higher than the mean value along the actual sound path.

125. *Time difference between arrivals of earthquake and sound waves.* For the strong Asama-yama explosions observed in 1913 at the Asama Pasture Ground and Ashino-taira, the time differences between the arrivals of the sound shock and the earthquake motion were as follows:—

Explosion. (1913).		Asama Pasture Ground.		Ashino-taira.	
		(i) Sound-{Eqke / Comm't}	(ii) Sound-Explosion.	(i) Sound-{Eqke / Comm't}	(ii) Sound-Explosion.
Sept. 21st	(L)	17.3 sec.	16.1 sec.	14.0 sec.	12.5 sec.
	(T)	17.2	—	—	—
Oct. 15th	(L)	—	—	14.4	12.8
	(T)	17.5	—	14.3	—
„ 17th	(L)	17.2	16.0	—	—
	(T)	17.0	—	—	—
„ 22nd	(L)	—	16.5	—	—
	(T)	—	—	—	—
Mean.		**17.2**	**16.2**	**14.2**	**12.6**

In the above table, (i) relates to the retardation time of the sound waves with respect to the commencement of the earthquake motion, and (ii) to that with respect to the moment of the explosion, namely, the end of the 1st displacement of the "initial vibration." The air temperature at the observing places at or about the time of the explosion on the 4 occasions taken into consideration varied from 5° to 16°C, giving the mean of about 12°C and 13°C respectively for the Asama Pasture Ground and for Ashino-taira. Again, for the 10 explosions observed at Yuno-

taira, for which the time differences in question have been examined in § 121, the air temperature at the observatory varied from 7.5° to 17.4° C, giving the mean value of 12° C. The mean air temperature corresponding to the sound paths between the different observing stations and the Asama-yama crater, which must be a few degrees lower than the values above obtained, may be assumed, in round number, and probably without an appreciable error, to be 10° C. We have, then, for this latter mean air temperature, the following general results :—

(For the air temperature of 10° C.)

Station.	(i) Time Difference : Sound-Earthquake Commencement.	(ii) Time Difference : Sound-Explosion.	Approximate Length of Sound Path.
Yuno-taira.	7.3 sec.	5.8 sec.	2380 m.
Ashino-taira.	14.2	12.6	4990
Asama Pasture Ground.	17.2	16.2	6490

126. ***Propagation velocity of explosive seismic waves at neighbourhood of origin.*** The distances given in the last column of the table at the end of the foregoing § are the approximate lengths of the sound paths from the crater centre to the different observing places. The mean values of the interval (ii), which gives the time difference between the arrivals of the detonation and of the earthquake vibration corresponding to the moment of the explosion, were 5.8 sec., 12.6 sec., and 16.2 sec. respectively for Yuno-taira, Ashino-taira, and the Asama Pasture Ground, very nearly in proportion to the path lengths of 2380 m, 4990 m, and 6490 m, giving the following mean relations :—

For Yuno-taira : $$2380^{m}\left(\frac{1}{V_{10^\circ}}-\frac{1}{v}\right)=5.8\ \text{sec.}$$

For Ashino-taira: $4990^{m}\left(\frac{1}{V_{10^\circ}}-\frac{1}{v}\right)=12.6$ sec.

„ Asama Pasture Ground: $6490^{m}\left(\frac{1}{V_{10^\circ}}-\frac{1}{v}\right)=16.2$ „

in which v is the propagation velocity of the "initial vibration," and V_{10° that of the detonation, or sound shock, corresponding to the air temperature of 10°C. Now, as the velocity increase with the magnitude of the detonation is anyhow limited to the very vicinity of the explosion centre, and as, more especially, the explosive violence communicated to the atmospheric mass at the mountain top ought to be directed upwards, the sound velocity of the explosions between the crater and the lower places of Yuno-taira, Ashino-taira, and the Asama Pasture Ground, may probably be assumed without much error to have the ordinary value for the corresponding air temperature.

Putting then $V_{10^\circ}=338$ m/sec. in the above equations, we obtain:

For Yuno-taira: $v=2.0$ km/sec.

„ Ashino-taira: $v=2.32$

„ Asama Pasture Ground: $v=2.17$ } Mean. 2.24 km/sec.

Thus the propagation velocity of the "initial vibration," or the vibration generated at the moment of the explosion, is about 2.0 km/sec. for Yuno-taira (radial distance=2.39 km), and about 2.2 km/sec. for Ashino-taira and the Asama Pasture Ground taken together (mean radial distance=5.7 km).

According to the approximate estimations in § 6, the initial velocity with which the lava fragments are projected from the crater seems to be some 150 m/sec. If this be also the impulsive velocity communicated to the air over the crater, then the propagation velocity of the detonation at the immediate vicinity of the origin of explosion may be some 500 m/sec.

127. ***Velocity of transverse vibration.*** Taking together the results of the observations of the Asama-yama explosions at Ashino-taira and the Asama Pasture Ground, the duration of the preliminary portion in the transverse component was on the average about 1.0 sec. longer than in the longitudinal. This may be regarded as denoting the retardation interval of the motion in the transverse corresponding to the "initial vibration" in the longitudinal component, and gives, for the two above named places, a transverse propagation velocity of about 1.6 km/sec., which is to the corresponding longitudinal velocity in the ratio of nearly 2 : 3.

128. ***Small quick vibrations.*** The small quick vibrations of T=about $\frac{1}{3}$ sec. begin to appear first some seconds after the earthquake commencement, apparently depending on the radial distances of the observing places, as follows :—

(Longitudinal Component.)

Place.	Time Interval between the Appearance of the Small Quick Vibrations and	
	Earthquake Commencement.	End of 1st Displacement of "Initial Vibration."
Yuno-taira.	2.9 sec.	1.6 sec.
Ashino-taira.	5.4	3.9
Asama-Pasture Ground.	7.2	4.9

Making use of the figures in the last column of the above table and of the propagation velocities of the "initial vibration" in the longitudinal component given in § 126, we get, for the small quick vibrations in question, the following results :—

	Velocity of Small Quick Vibration.
For Yuno-taira :	0.85 km/sec.
„ Ashino-taira :	0.82
„ Asama Pasture Ground.	0.83

The velocity thus comes out nearly constant for the three observing places, with the mean value of 0.83 km per sec. The small quick movements in question may be the secondary surface vibrations.

129. ***Propagation velocity of explosive vibrations between Asama-yama and Tokyo.*** According to § 116, the differences between the time of occurrence at the Yuno-taira observatory, and the moments of arrival at the Seismological Institute of the preliminary and the maximum phases, of the earthquake motion due to the Asama-yama eruptions are respectively 42.6 and 73.6 sec. As the horizontal radial distances of these two places are 2.3 and 135.4 km, the propagation velocities between Yuno-taira and Tokyo are:—

Preliminary Tremor ..... $v_1 = 133.1 / 42.6 = 3.1$ km/sec.

End of Preliminary Tremor .... $v_2 = 133.1 / 60.5 = 2.2$
(Duration = 18 sec.)

Maximum Phase ..... $v_3 = 133.1 / 73.6 = 1.8$

The velocity (v_1) of the preliminary tremor is thus 3.1 km/sec., which is nearly equal to that of the surface propagation, or the 3rd phase of the principal portion, of the ordinary earthquake motion. It is likely that the vibrations resulting from the explosions at the crater of the Asama-yama, $2\frac{1}{2}$ km in height, are propagated to Tokyo essentially along the surface ground.* It is desirable that this result should be further verified.

130. ***Propagation velocity of earthquakes.*** The strong earthquakes, which originate from under the Asama-yama itself or the neighbouring districts, must be more or less deep-seated, and consequently we find the propagation velocity of their vibrations greater than that of the shakings caused by the explosions themselves. The velocity of propagation has been calculated in the cases

* Similar suggestion has been made in the *Bulletin*, Vol. VI, No. 1, § 39.

of the two special semi-destructive shocks in 1912, namely, the Asama-yama earthquake of July 16th and of the Ueda earthquake of Aug. 17th, from the instrumental records obtained at the Yuno-taira observatory, the Seismological Institute in Tokyo and the meteorological observatory of Osaka ($\varphi = 34° 39'$ N, $\lambda = 135° 26'$ E). The distances of the two latter places from the crater of the Asama-yama are respectively 135.4 and 341.3 km, and those from the origin of the Ueda earthquake, 156.3 and 323.1 km. The differences in the times of earthquake occurrence between Yuno-taira and Tokyo were 28 sec., and those between Tokyo and Osaka 30 and 32 sec. The durations of the preliminary tremor in Tokyo and Osaka were respectively 18.3 and 20.4 sec., and 43.0 and 49.3 sec.

(i) *Asama-yama earthquake of July 16th*, 1912. As the duration of the preliminary tremor at the Yuno-taira observatory was very short, the radial distance of the latter may be assumed to be about 3 km. The following table gives the time of commencement and the duration of the preliminary tremor at the Yuno-taira observatory, the Seismological Institute (Tokyo), and the Osaka meteorological observatory.

Station.	Radial Distance.	Time of Eqke Occurrence.	Duration of Prel. Tremor.
Yuno-taira Obs.	3 km.	7.45.35 a.m.	Very short or 0 sec.
Seismol. Institute.	135.4	7.46.03	18.3
Osaka Met. Obs.	341.3	7.46.33	49.3

The values of the propagation velocity, v_1, of the first preliminary tremor between the different stations are found as follows :—

Between Yuno-taira and Tokyo.... $v_1 = \frac{132.4^{km}}{28^{sec.}} = 4.7$ km/sec.

„ Yuno-taira „ Osaka.... $v_1 = \frac{338.3}{58} = 5.8$

„ Tokyo „ Osaka.... $v_1 = \frac{205.9}{30} = 6.9$

For the propagation velocity, v_3, of the vibration at the commencement of the principal portion, we have:—

Between Yuno-taira and Tokyo.... $v_3 = \frac{132.4^{km}}{28+18.3^{sec.}} = 2.86$ km/sec.

„ Yuno-taira „ Osaka.... $v_3 = \frac{338.3}{58+49.3} = 3.15$

„ Tokyo „ Osaka.... $v_3 = \frac{205.9}{30+31.0} = 3.38$

(ii) *Ueda earthquake of Aug. 17th, 1912.* The time of occurrence and the duration of the preliminary tremor of this earthquake, whose origin was at $\varphi = 36°\ 26'$N, $\lambda = 138°\ 15'\ 35''$ E, or about 25 km to the N 77° W of the Asama-yama crater, at the Yunotaira observatory (Asama-yama), the Seismological Institute of Tokyo, and the meteorological observatory of Osaka, were as shown in the following table.

Station.	Radial Distance.	Time of Eqke Occurrence.	Duration of Prel. Tremor.
Yuno-taira.	23 km	11h 21m 25s pm.	4.2 sec.
Tokyo (Seism. Institute).	156.3	11 21 53	20.4
Osaka.	323.1	11 22 24.8	43.0

The values of the propagation velocity, v_1, of the first preliminary tremor between the different stations are found to be about 5 km/sec., as follows:—

$$\text{Between Yuno-taira and Tokyo} \ldots v_1 = \frac{133^{km}}{28^{sec.}} = 4.8 \text{ km/sec.}$$

$$\text{„ Yuno-taira „ Osaka} \ldots v_1 = \frac{300^{km}}{60^{sec.}} = 5.0 \text{ „}$$

$$\text{„ Tokyo „ Osaka} \ldots v_1 = \frac{167^{km}}{32^{sec.}} = 5.2 \text{ „}$$

For the calculation of the propagation velocity, v_3, of the vibration at the commencement of the principal portion, we have:

$$\text{Between Yuno-taira and Tokyo} \ldots v_3 = \frac{133^{km}}{28+16.2} = 3.01 \text{ km/sec.}$$

$$\text{„ Yuno-taira „ Osaka} \ldots v_3 = \frac{300^{km}}{60+38.8} = 3.04 \text{ „}$$

$$\text{„ Tokyo „ Osaka} \ldots v_3 = \frac{167^{km}}{32+22.6} = 3.06 \text{ „}$$

Summary. The results obtained above are collected in the following table :—

(Velocities v_1 and v_3 in km/sec.)

Radial Distance.	v_1 (Commencement of Earthquake).			v_3 (Commencement of Principal Portion).		
	Eqke i.	Eqke ii.	Mean.	Eqke i.	Eqke ii.	Mean.
Asama-yama to Tokyo.	4.7	4.8	4.7	2.86	3.01	2.94
Asama-yama to Osaka.	5.8	5.0	5.4	3.15	3.04	3.10
Tokyo to Osaka.	6.9	5.2	6.0	3.38	3.06	3.22

Thus the mean values of the velocity (v_1) of the preliminary tremor of the earthquakes were 4.7 and 5.4 km/sec. for the radial distances of about 135 and 341 km from the Asama-yama respectively to Tokyo and Osaka. The velocity calculated by the "difference method" between the two latter places was 6.0 km/sec. The velocity (v_3), which corresponds to the commencement of the principal portion, and which characterizes the surface propagation,

did not much vary, being 2.9 and 3.1 km/sec. for the distances respectively to Tokyo and Osaka, and 3.2 km/sec. between the two latter places.

CHAPTER XV. CONDITION OF ASAMA-YAMA, 1912 TO 1914.

131. ***Strong Asama-yama earthquakes in relation to eruptions.*** The recent extraordinary activity of the Asama-yama may be considered to have began with the strong non-eruptive earthquake of May 26th, 1908. Yet the energetic explosions of the volcano took place first from Dec. 7th of the next year (1909), followed by several others in 1910 and 1911. After the strong explosion of Oct. 22nd, 1911, the eruptive activity was greatly reduced, there having been no important outburst of the Asama-yama during the summer of 1912. At the same time, however, the seismic activity of the volcano became very pronounced, and, amongst the others, the earthquake on July 16th (1912), at 7.45.35 a.m., was markedly strong, being, according to the tromometer observations in Tokyo, of the same magnitude with, and identical almost vibration for vibration to, the shock on May 26th, 1908. The period of the greatest explosive activity of the Asama-yama began with the outburst of May 16th, the next year (1913). From these circumstances, it seems that the opening of a period of great eruptive activity of the volcano is announced by strong seismic disturbances 10 months or $1\frac{1}{2}$ years beforehand. Such an assumption is by no means unreasonable: for instance, the premonitary earthquake shocks of the Kirishima-yama explosion of Nov. 8th, 1913, had began already 6 months before the latter date. In other words, the explosions, which are themselves mere surface phenomena, must be the results of the