

directions or the axial lines of the ash-precipitation areas of the following eight eruptions :—

- (i) Aug. 1783 (The Temmei disaster).
- (ii) Jan. 22nd, 1900.
- (iii) Feb. 7th, „
- (iv) „ 14th, „
- (v) „ 19th, „
- (vi) Dec. 7th, 1909.
- (vii) Dec. 2nd, 1910.
- (viii) May 8th, 1911.

According to Fig. 32, the directions toward which the ashes were carried varied from ENE to ESE, being mostly towards the ESE. It must hereby be noted that the eruptions (ii) to (vii) occurred in the winter months of December, January, or February, but the final and most violent phase of the great eruption of 1783 occurred in the summer epoch of the end of July and the beginning of August, when the surface wind must have been southerly. Thus it seems that the prevailing wind in the higher atmospheric region over the central Japan seems in the normal state always to be WNW or W.

The velocity with which the ashes were carried away from the Asama-yama varied from 17 to 35 m/s, as follows :—

Dec. 7th, 1909.....	22 metres per sec.
Jan. 3rd, 1911.....	17 „ „
„ 6th, „	35 „ „

CHAPTER V. REPETITION OF THE SOUNDS AND THE ZONE OF SILENCE.

31. Observations on detonations. As stated in Chapter VI, the detonation on the occasion of the explosion of Dec. 2nd, 1910, which was distinctly perceived in Tokyo, consisted of three dif-

ferent sets with the successive time intervals of 1^m44^s and 0^m04^s , the second sound being the strongest and the 3rd a little weaker. An examination of the reports from the different meteorological observatories, district offices, etc., shows that the three sounds were perceived at several places, the 3rd being sometimes described as the loudest; while at the other places only the first and the 2nd sounds, or altogether one single sound, were heard. Similar peculiarities in the sound propagation are also indicated in the reports respecting the explosion of Dec. 7th, 1909. In Tables XVIII and XIX, I give a comparative list of the observations relating to these two strong explosions, based respectively on the reports from the different meteorological observatories and those from the other sources.

TABLE XVIII. OBSERVATIONS ON THE DETONATIONS OF THE ASAMAYAMA ERUPTIONS OF DEC. 7TH, 1909, AND OF DEC. 2ND, 1910. [REPORTS FROM THE METEOROLOGICAL OBSERVATORIES.]

Meteorological Observatory.	Explosion of Dec. 2nd, 1910. [P.M.]	Explosion of Dec. 7th, 1909. [P.M.]
Maebashi.	(1) 8.20; moderately strong sound. (2) 8.21; a louder sound, causing houses to be shaken for $1\frac{1}{2}$ min.	{ 7.47; strong detonation, shaking houses violently.
Kofu.	No sound heard.	7.50; a moderately strong detonation like that of discharge of large gun, proceeding from N to S.
Kumagai.	(1) — (2) 8.25.21; loud rolling sound. (3) Sound lasting 10 sec., with 2 max. and min.	{ 7.49.49; two very loud rolling detonations lasted 30 sec., almost cracking window panes.
Utsunomiya.	(1) 8.25.38; slight movements. (2) 8.26.21; detonation heard toward the SW. (3) After 4 sec., a slightly weaker detonation.	(1) — (2) 7.51.29; detonation heard toward the W. (3) After 4 or 5 sec., a lower and weaker sound, shaking houses for 5 or 6 sec.

Meteorological Observatory.	Explosion of Dec. 2nd, 1910. [P.M.]	Explosion of Dec. 7th, 1909. [P.M.]
Tokyo.	(1) 8.25.54; slight rumbling sound. (2) 8.27.38; sound like discharge of gun. (3) After 4 sec., a slightly weaker sound.	{ Loud sound heard (exact observation wanting).
Tsukuba.	(1) 8.26.30; slight shakings. (2) 8.27.50; detonation. (3) After 2 sec., a larger rolling detonation. —	(1) 7.50.00; slight sound. (2) 7.53.00; loud detonation. — (4) 8.00.00; slight sound.
Yokohama.	(1) 8.27; a sort of shaking. (2) 8.29; detonation and shaking. (3) After a few sec., a slightly weaker detonation. —	(1) — { (2) 7.53; shakings proceeding from the N. (3) After 7 sec., shakings again. (4) After 5 min., another shaking.
Yokosuka.	(1) — (2) 8.29.02; sound like distant thunders heard toward the NW.	{ (1) 7.52.50; sound heard toward the NE. (2) After 1 ^m 10 ^s ; sound again heard toward the same direction.
Mito.	(1) 8.27.55; slight sound. (2) After 1 ^m 10 ^s , a far louder detonation.	(1) 7.53.10; shakings. (2) After 1 min., detonation heard toward the SW.
Fukushima.	No sound heard.	(1) 7.56.30; slight sound. (2) After 2 min., shakings and sound like distant thunders heard toward the SW.
Kanayama.	Do.	(1) 7.58.59; sound. (2) After 2 ^m 10 ^s , a stronger sound.

TABLE XIX. OBSERVATIONS ON THE DETONATIONS OF THE ASAMA-YAMA ERUPTIONS OF DEC. 7TH, 1909, AND OF DEC. 2ND, 1910.*
[REPORTS FROM THE DISTRICT OFFICES, ETC.]

Province.	Explosion of Dec. 2nd, 1910.	Explosion of Dec. 7th, 1909.
Kotsuke.	<p><i>One large detonation, at Naganohara.</i></p> <p><i>Two detonations at Kusatsu (Azuma); Kawayu (Tone).</i></p>	<p><i>One very loud detonation, at Omae, Naganohara, Kusatsu, Sawada, and Chujō (Azuma); Sannokura and Iizuka (Gumma); Usui, Annaka (Usui); Fujioka (Tano).</i></p> <p><i>Two detonations heard in succession, at Maebashi, Tomioka; Ise-machi (Sawa); Higashi-mura (Seta).</i></p>
Musashi. (Saitama Prefecture).	Sound heard.	<i>Two detonations, at Omiya (Chichibu).</i>
Shimotsuke.	<p><i>At Nikko and Tochigi, two detonations.</i></p> <p><i>At Yaita (Shionoya), weak shakings, followed 1 or 2 min. after by a loud detonation.</i></p> <p><i>At Hagiwara (same county), a slight sound, followed 1 min. after by one loud and two slight sounds.</i></p> <p><i>At Otahara (Nasu), weak sound, followed by a loud detonation and then by somewhat lower sound like distant thunder.</i></p> <p><i>At Maoka (Haga), shakings followed by two sounds.</i></p>	<i>Two sounds, at Nikko, Utsunomiya, Maoka.</i>
Sagami and Musashi. (Kanagawa Prefecture).	<i>Two sounds generally in the district to the east of the Sagami-gawa, except at Mizono-kuchi and Sasanoshita where three were heard.</i>	<p><i>Two sounds, at Yokohama, Yokosuka, Misaki (Miura), Kawawa (Tsuzuki).</i></p> <p><i>Three sounds, at Uruga, Minami-Shimoura (Miura), Fujisawa.</i></p>
Hitachi.	<i>Two sounds, at Shimodate and Makabe (Makabe) Moriya (Kita-Soma), Yodozaki (Inashiki); the 2nd, which was the stronger, occurring 1 or 2 min. after the 1st.</i>	<p><i>Two sounds, at Mito, Takahagi (Taga), Hokota (Kajima), Asō (Namekata), Ishioka and Yuki (Niiharu).</i></p> <p><i>Three sounds, at Tsukuba-machi, Tatsugasaki (Inashiki), Tsuchiura (Niiharu), Yatabe (Tsukuba).</i></p>
Kazusa and Shimosa.	<p><i>Two sounds, at Chiba, Sahara (Katori), Kisarazu (Kimizu), Sakura (Inba); the 1st being a little stronger than the 2nd.</i></p> <p><i>One sound, at Ōtaki (Isumi), Togane (Sanbu), Fukuoka (Sōsa).</i></p>	<p><i>Two sounds, at Chiba, Ōtaki, Hōjō (Awa).</i></p> <p><i>Three sounds at Togane, Yawata (Ichihara), Sahara, Sakura.</i></p>

* The name within the brackets is that of the county to which the town or village put before them belongs.

Province.	Explosion of Dec. 2nd, 1910.	Explosion of Dec. 7th, 1909.
Iwashiro and Iwaki.	<i>Three consecutive sounds</i> heard at Wakamatsu.	<i>Two sounds</i> , at Fukushima, Fukuramura (Ase). <i>Three sounds</i> , at Onahama (Iwaki).
Izu and Suruga.	At Kami-Kawazu (Kamo), sound followed a few minutes after by a slightly smaller one. <i>One sound</i> , at Ito and Shimo-Kano (Tagata), Ōkawachi (Abe), Inatori (Kamo).	<i>Two sounds</i> , at Shimo-Kano, Ōkawachi.
Totomi.	<i>One sound</i> , at Hamamatsu.	—

32. Time differences between the successive sounds. In Table XVIII, (1), (2), and (3) denote respectively the 1st, 2nd, and 3rd sounds, which were probably one and the same at first, but which came gradually into separate existence with the increasing radial distance. The (4), noticed at a few of the stations on the occasion of the explosion of Dec. 7th, 1909, was probably an independent detonation of the Asama-yama, not connected with the sound repetition phenomena. The latter were, of course, not limited to the two strong eruptions under consideration. Thus, for instance, on the occasion of the explosion of Dec. 25th, 1910, two and four sounds were perceived respectively at Kami-Ishiki (Nishi-Yatsushiro county, Kai) and at Onahama (in Iwaki). According to Table XVIII, the successive time differences between the three sounds for the cases of the two strong explosions were as follows:—

TABLE XX. TIME DIFFERENCES BETWEEN THE 1ST, 2ND, AND 3RD SOUNDS. THE ASAMA-YAMA ERUPTIONS OF DEC. 7TH, 1909, AND OF DEC. 2ND, 1910.

Place. (Met. Observ.)	Time difference between 1st and 2nd Sounds.			Time difference between 2nd and 3rd Sounds.			Distance from Asama-yama.
	XII, 2, 1910.	XII, 7, 1909.	Mean.	XII, 2, 1910.	XII, 7, 1909.	Mean.	
Maebashi.	1 ^m 00 ^s (?)	—	1 ^m 00 ^s (?)	—	—	—	50km.
Utsunomiya.	0 43	—	0 43	4 ^s	4-5sec.	4.5sec.	121
Tokyo.	1 44	—	1 44	4	—	4	134
Tsukuba.	1 20	3 ^m 00 ^s (?)	1 20	2	—	2	145
Yokohama.	2 00 (?)	—	2 00 (?)	A few sec.	7	7	147
Yokosuka.	—	1 10	1 10	—	—	—	161
Mito.	1 10	1 00	1 05	—	—	—	175
Fukushima.	—	2 00 (?)	2 00 (?)	—	—	—	228
Kanayama.	—	2 10	2 10	—	—	—	259
<i>Mean.*</i>	1 ^m 25 ^s	4.3sec.	—

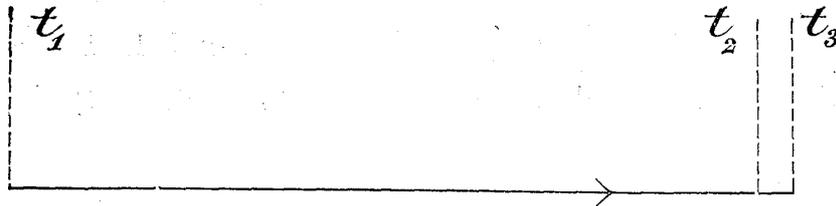
Thus the time difference between the 1st and the 2nd sounds varied between 0^m 43^s and 2^m 10^s, giving the mean value of 1^m 25^s for the corresponding mean radial distance of 161 km. It is, however, not at all clear whether the time interval in question increased with the distance from the volcano or not. Again, the time difference between the 2nd and the 3rd sounds varied from 2 to 7 sec., and gives the average value of 4.3 sec., corresponding to the mean radial distance of 138 km.* (See Fig. 33.)

33. Local distribution. The distribution of the localities where the sound was heard respectively once, twice, or thrice, as stated in Tables XVIII and XIX, is shown in Fig. 35 (Pl. XXIII), in which the line *ab* is the boundary between the 1-sound and the 2-sounds districts. It is likely that in the remoter parts of the 1-sound district, only the strongest among the two or three,

* In taking the means, those marked with (?) have been excluded.

as the case may be, was perceived. On the other hand, in the parts of this area which lies close to the volcano, the sound was heard only once each time, notwithstanding its great intensity.

Fig. 33. Diagram showing the relations of the Times of arrival of the 1st, 2nd, and 3rd Sounds.



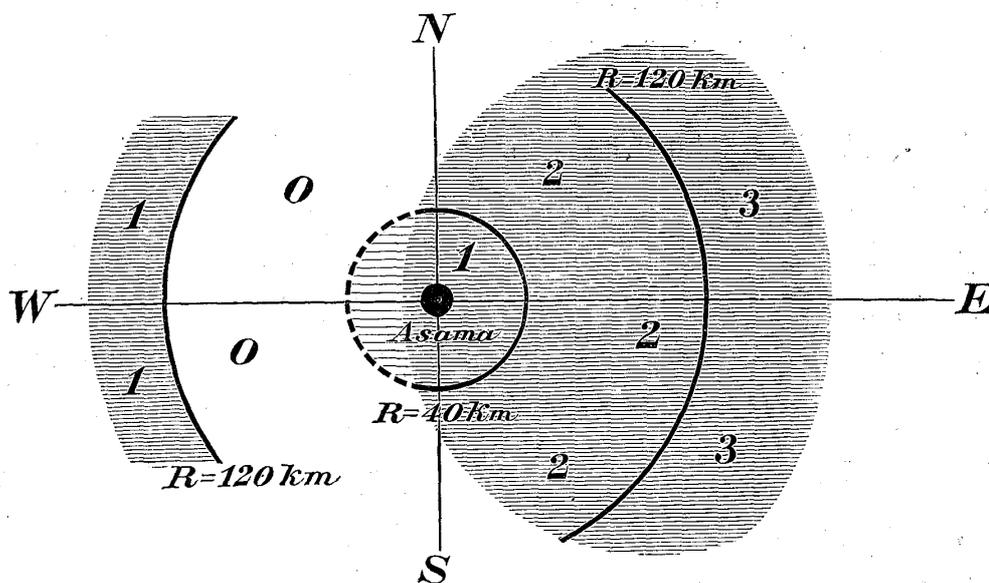
t_1 = Time of arrival of 1st Sound.	$t_2 - t_1 = 1^m 25^s$
t_2 = " " " " 2nd "	$t_3 - t_2 = 4.3^{\text{sec}}$
t_3 = " " " " 3rd "	

Especially, at Naganohara, which lies at the distance of only 19 km to the NNE from the mountain, the detonation consisted of a very loud single sound in each of the two cases in question, as well as in all the other explosions. It is likely that within short distances from the Asama-yama the detonation is really single and not repetitive; the area of the single sound being represented on the map by a part of circle, I, whose radius is about 40 km. Again, the 3-sounds districts form two areas III and III, of which the former includes parts of Iwashiro, Shimotsuke, Hitachi, and Iwaki, and the latter, parts of Hitachi, Shimosa, Kazusa, Musashi, and Sagami. As indicated by the dotted line III III, these two areas may be regarded as forming a continuous zone, whose mean radius is about 150 km, but whose nearest distance from the Asama-yama is about 120 km. The 2-sounds area lies partly between the 1-sound area and the 3-sounds area, and partly outside the latter. Fig. 34 gives the diagrammatic representation of

the relations between the radial distance and the sound repetition phenomena.

The 3-sounds area, which commences as above mentioned at the radial distance of about 120 km to the E. of the Asama-yama, may probably be regarded as corresponding to the *zone of audible sound* (§ 29), which is situated also at the distance of about 120 km to the W. of the mountain. The 2-sounds area on the E. side will, further, probably correspond to the region of sound-shadow, or silent zone, on the W. side. (See Figs. 34 and 35)

Fig. 34. Diagram showing the Locations of the different Sound Areas.



The sound areas are shaded. In the lightly shaded part of the inner circle, the sound was heard only rarely.

Inner (smaller) circle Radius= 40 km.

Outer (larger) circle Radius= 120 km.

- | | |
|---|---------------------------------------|
| (1), within the smaller circle | 1-sound area. |
| (2), between the smaller circle and the eastern }
branch of the larger circle. | 2-sounds area. |
| (3), outside the eastern branch of the larger circle..... | 3-sounds area. |
| (1), outside the western branch of the larger circle. | 1-sound area. |
| (0), the space between the smaller circle and the }
W. branch of the larger circle. | { No-sound area, or
"silent zone." |

The question of the anomalous propagation of the sound wave has in recent years been theoretically discussed by several eminent authorities. Amongst the others, Prof. v. d. Borne gave a highly interesting new explanation respecting the "silent zone" (Zone des Schweigens) and the abnormal audibility region outside the latter; his theory being based on the existence of the isothermal layer and the light-gas envelop in the higher parts of the earth's atmosphere.* Prof. v. d. Borne neglects the effect of the wind velocity. On the other hand, Dr. S. Fujiwara, of the Central Meteorological Observatory, Tokyo, who worked out the problem elaborately, arrived at the conclusion that the refraction of the sound rays, giving rise to the "silent zone," may be explained by the wind motion in the atmosphere.** Now, from our examination of the sound areas of the Asama-yama explosions, it will be noticed that, in the majority of cases, the detonation was propagated eastwards or south-eastwards, indicating no "silent zone" at all, although the radial distances in these directions reached 200 to 300 km. In fact we have, eastwards from the Asama-yama, an arrangement of the 1-sound, 2-sounds, and 3-sounds regions, as already noted in detail. Further, an inspection of the sound-areas (Figs. 20, 21, and 22) of the three strong eruptions, namely, those of Dec. 7th, 1909; Dec. 2nd, 1910; and of May 8th, 1911, brings out prominently the following two facts:—*Firstly*, that in each of the two first explosions, the winds at the different places within the sound-areas were directed more or less in the sense of, but materially different

* Prof. Dr. G. v. d. Borne: *Ueber die Schallverbreitung bei Explosionskatastrophen*, Physik. Zeitschrift, 11. Jahrgang, 1910, Seite 483—488.

**Dr. S. Fujiwara: *On the anomalous propagation of sound rays in the atmosphere*, Tokyo Sugaku-Butsurigakkai Kiji (Proceedings of the Tokyo Mathematico-Physical Society), 2nd Ser., Vol. VI, No. 9, 1911. Also, in *Journal (Japanese) of the Meteorological Society of Japan*, 30th year, No. 8, 1911.

from, the principal direction of extension of the latter; while in the third explosion, the wind was actually opposite to the direction of the propagation in the eastern half of the area. *Secondly*, that, in each of these strong explosions, the sound area was approximately symmetrical to the ash-precipitation zone; the Asama-yama, which formed the origin, or W. apex, of the latter, being situated close to the (W.) boundary of the former. As, further, the extension of the ash-precipitation zone must certainly be determined by the wind movements in the higher region of the atmosphere, we arrive at the following two conclusions:—(i) *The form of the sound area does not depend on the surface winds*; (ii) *The principal direction of the extension of the sound area is the same as that of the wind prevailing in the upper strata of the air, probably at the height of 8 to 10 km above sea-level.** From these considerations it seems likely that the existence of the “silent zone” is due to the effect on the propagation of the sound wave of the wind movement in the higher atmospheric region. The invariable absence of the “silent zone” in the cases of the extension of the sound area eastwards or south-eastwards from the Asama-yama may possibly be due to the great height, and the peculiarity of the position, of the volcano, which stands on the eastern edge of the plateau and overlooks the Kanto plain spreading to the E. and the SE; in consequence, the different places situated in the latter directions would be enabled to receive the sound rays directly propagated from the source of disturbance, even should they happen to fall within the limit of the otherwise “silent zone.” Similar remark applies also to the eruption of Oct. 22nd, 1911, in which the sound area extended towards the NE along the course of the Shinano-gawa (Fig. 29). On the

* This is the height generally attained by the explosion smokes of the Asama-yama.

other hand, the regions lying westwards from the Asama-yama, where the "silent zone" seems generally to exist, (as in the two notable cases of the eruptions of Dec. 25th, 1910, and April 3rd, 1911, and also in a few other cases less conspicuous), are characterized by entirely different geographical features, being mountainous and traversed by several cross valley zones, as mentioned in Chapter I.

The eruption of May 31st, 1902, is an example of a strong explosion which occurred in very quiet weather and whose sound and ash-precipitation areas were limited to small distances around the mountain.

34. Digression on the eruptions of the Bandai-san and of the Azuma-san. In the case of the great eruption of the Bandai-san (in the province of Iwashiro) on July 15th, 1888, the ash-precipitation zone stretched to the Pacific in the ESE direction, forming the axis of the sound area, which extended from the neighbourhood of the volcano in the same direction to the southern part of the coast of the province of Iwaki. Westwards from the Bandai-san, the sound was heard in the island of Sado and also in the Takai county, province of Shinano, at the radial distance of about 150 km, but not in the intermediate region of the Shinano-gawa valley, which thus formed a "silent zone." In the eruptions of the Azuma-san, also in the province of Iwashiro, on May 19th and June 4th, 1893, the sound-areas extended to the Pacific coast respectively in the eastern and the north-eastern directions. Thus, these three eruptions, the fuller accounts of whose sound areas will be given on another occasion, indicated the existence of higher wind currents respectively in the ESE, E, and ENE directions.