CHAPTER XI. ON THE PROPAGATION OF STRONG ASAMA-YAMA EARTHQUAKES.

98. *Characteristics of strong Asama-yama earthquakes.* The strong non-eruptive volcanic earthquakes originating under, or close to, the Asama-yama are often characterized by the small extent of the area of sensible movement and a disproportionately large magnitude of the unfelt component of motion. The following are the dates of the recent seismic disturbances of this nature :—

I { (1) May 26th, 1908; 9.18 a.m.
(2) July 16th, 1912; 7.45 a.m.
(3) Jan. 22nd, 1910; 3.03 p.m.

II { (5) Aug. 17th, 1912; 11.21 a.m.
(4) April 2nd, 1911; 10.30 p.m.

Of these earthquakes, the first two originated at the Asama-yama itself, while each of the remaining three had the centre close to the volcano.

99. *Area of disturbance.* The extension of the areas of sensible motion of the different earthquakes, illustrated in figs. 54 to 59 was as follows.

(1) *Strong Asama-yama earthquake of May 26th*, 1908. (Fig. 54.) The area of strong motion was an ellipse with the volcano at the centre, and of the major and minor diameters respectively of 57 and 34 km. The area of slight, or sensible, motion including the preceding one, was an ellipse with the diameters of 130 and 90 km. Outside this area, the earthquake motion was felt also at the following two isolated localities: (a), the neighbourhood of Niigata 175 km. to the N.N.E. of the Asama-yama; (b), the

district including Tokyo, Yokohama, and a portion of the eastern Sagami, about 145 km. to the S.E. of the mountain.

(2) *Strong Asama-yama earthquake of July 16th*, 1912. (Fig. 55.) At the Yuno-taira observatory the earthquake was felt very severely, causing overthrow of bottles and other articles. It was followed in the course of the next 12 hours by 48 sensible and 162 unfelt after-shocks. On the top of the Asama-yama itself the motion was sufficiently intense to produce cracks around the crater rim, while at the vicinity of the Hōinbo water fall 2 km. below the observatory and at other places large rock fragments rolled down the mountain flank, felling trees and damaging the path ways.

A land slip of an area measuring about 300 feet took place from the lower part of the slope of the Kiba-yama opposite the observatory. There took place also a thundering avalanche of rock fragments down the steep inner slope of the Kurofu-yama at a place called Tomi-no-kuchi ("mouth of winnowing machine" so named from the resemblance of its form), 270 m. above, and 550 m. to the W.N.W. of the Yuno-taira observatory. The lava flow (Oni-Oshidashi) of 1783 on the N. side of the mountain crumbled down at several places, causing much noise and tremors of the ground perceived at the Wakasare cottage. At Naganohara, about 20 km. to the N.E. of the Asama-yama, the shock was strongly felt, almost causing overthrow of articles from shelves. Judging from the propagation of the seismic motion and from the tromometric record obtained in Tokyo, this earthquake was almost exactly similar in intensity and magnitude to the shock (1) on May 26th, 1908. The strong motion area was an ellipse of the diameters of 40 and 18 km respectively. The area of slight and sensible motion had the maximum radius of about 64 km. Out-

side this limit the motion was felt also at the two following localities: (a), at Niigata, 175 km. to the N.N.E. from the Asama-yama; (b), Yokohama and Numazu, about 150 km. to the S.E. of the volcano.

(3) *Earthquake of Jan. 22nd, 1910.* (Fig. 56.) The earthquake motion was sensible within the area of a small ellipse of the diameters of only 63 and 47 km. respectively, and also at the isolated locality of Yokohama about 155 km. to the S.E. of the origin of disturbance. The earthquake origin was at about 146 km. to the N. 54° W. of Tokyo, and situated about 10 km. to the N.W. of the Asama-yama crater.

(4) *Severe Ueda earthquake of Aug. 17th, 1912.* (Fig. 57.) The earthquake, whose origin was situated 26 km. to the west of the Asama-yama crater, or 160 km. to the N. 58° W. of Tokyo, (§ 90), namely, at $\varphi = 36°26.'9$ N., $\lambda = 138°14.'8$ E., a little to the N. of Ueda, was felt severely at the latter town and the vicinity, where some damage was caused to buildings, embankments, roads, *ishigaki* (dry-masonry stone retaining wall), etc. There was fortunately no casualty except one woman wounded by bottles thrown down from a shelf. The earthquake must be regarded as being related to the strong Asama-yama shock (2) which had happened only one month previously, on July 16th of the same year. The motion was sensible within an ellipse of the diameters of about 100 and 80 km. Outside this area the shock was felt at Nikko and Tsukuba at the distances of 125 and 170 km. to the E. slightly N. and the E. slightly S. of the centre respectively.

(5) *Earthquake of April 2nd, 1911.* (Fig. 58.) The earthquake was felt within an ellipse of the diameters of 86 and 62 km., and also at the two isolated places of Tsukuba and Mito, to

the E. slightly S. of the disturbance origin, 155 and 186 km. from the latter respectively. The origin of disturbance was at about 151 km. to the N. 54° W. of Tokyo, and situated about 15 km. to the N.W. of the Asama-yama crater.

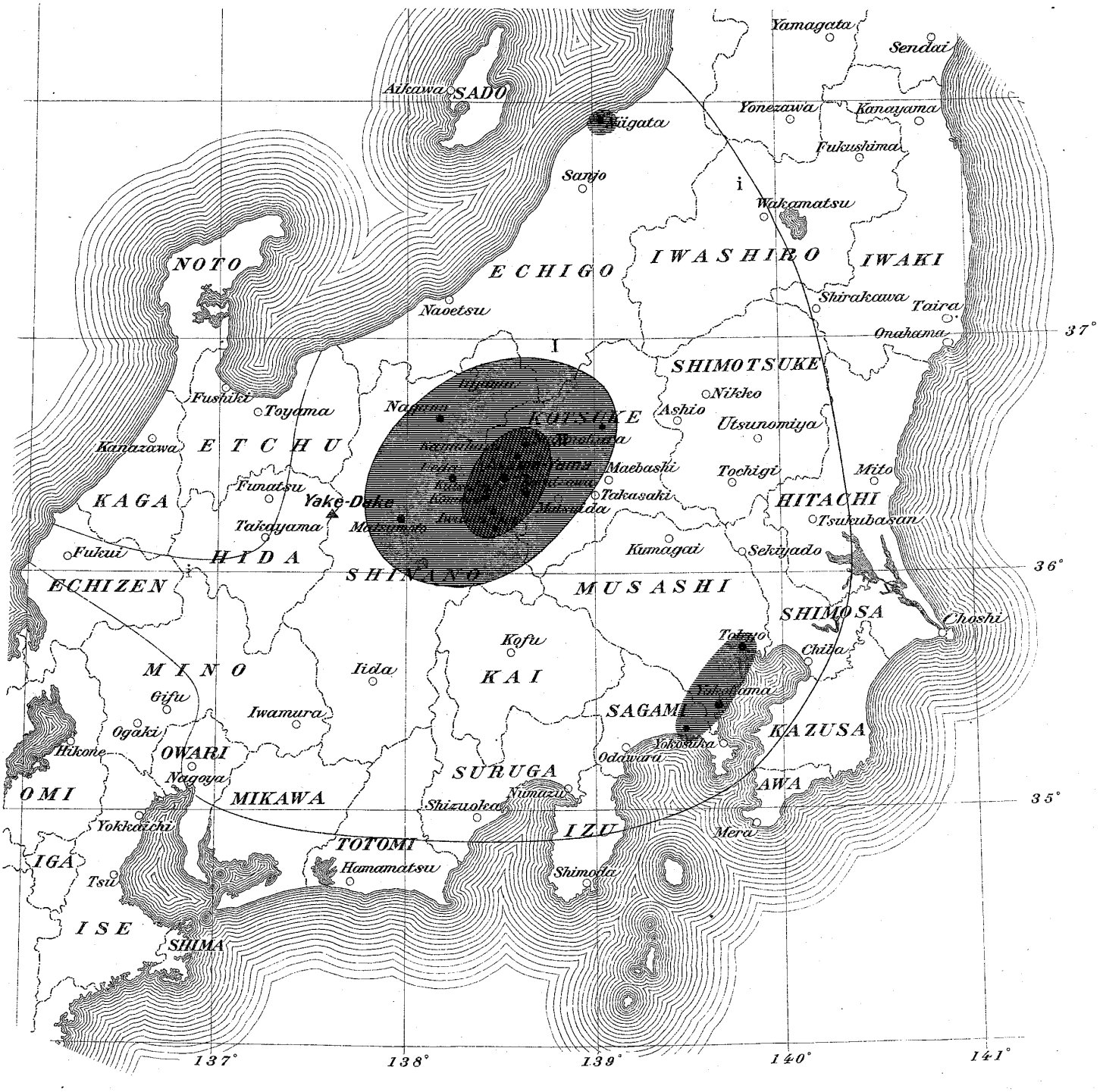
100. *Central Shinano earthquake of Jan. 22nd, 1899.* (Fig. 59.) From the preceding § it will be observed that the principal area of sensible motion for the different earthquakes of the Asama-yama region was very limited, the maximum radius being in all the cases under 70 km. By way of comparison, let us here describe the Central Shinano earthquake of Jan. 22nd, 1899, at 8.04 a.m., which was felt strongly in the counties of Suwa, Kami-Ina, and Higashi-Chikma, in the vicinity of the lake of Suwa. The area of sensible motion extended from the provinces of Shimotsuke, Musashi, and Sagami on the east to those of Bizen, Mimasaka, and Hōki on the west, through the extension of 600 km., attaining the maximum radius of 410 km. to the W.W.S. of the origin of disturbance. It follows that the distance of the propagation of the sensible motion of the earthquake in question was five or six times greater than that of the strong Asama-yama earthquakes.

The Tokyo record of the earthquake, whose centre was situated 165 km. to the N. 72° W. of the city, or 54 km. to the S. 59° W. of the Asama-yama, shows that the amount of motion was much smaller than in the prominent seismic disturbances originating at the latter. The max. 2a was not greater than 0.6 mm. in each horizontal component. (See fig. 34.)

The following table gives, for the different earthquakes considered above, a summary of the extension of the area of sensible motion and of the elements of vibration observed in Tokyo.

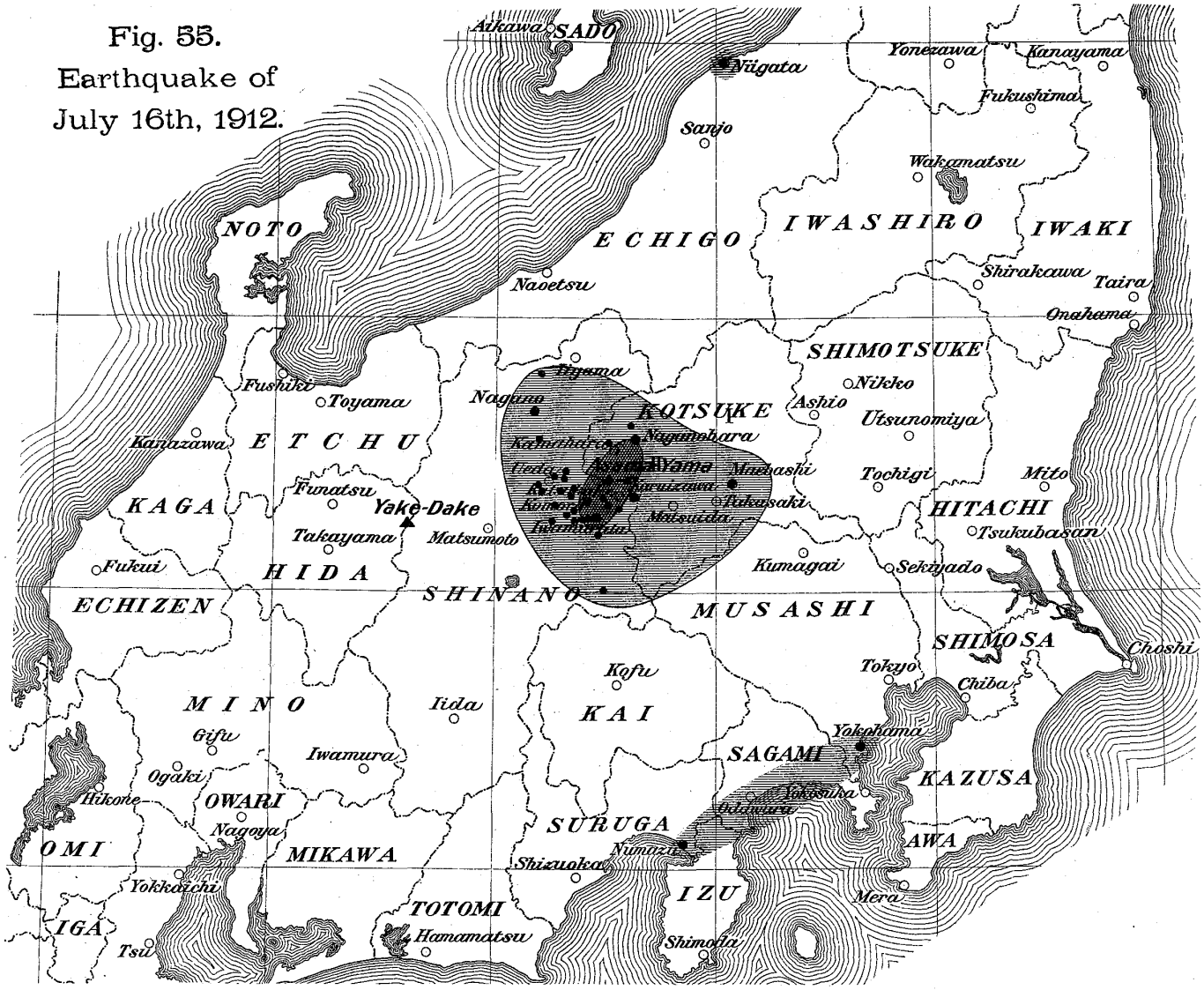
Fig. 54. The Area of Disturbance of the Strong Asama-yama Earthquake on May 26th, 1908.

Red dot indicates a place where the shock was sensible.
(II) ...Strong motion area.
(I) ... Slight „ „
(i) ....Area within which the motion was unfelt and registered by an ordinary seismograph.



Boundary of Provinces.

Fig. 55.
Earthquake of
July 16th, 1912.



(I) ....Slight motion area.
(II) ...Strong „ „

Red dot indicates a place where the shock was sensible.

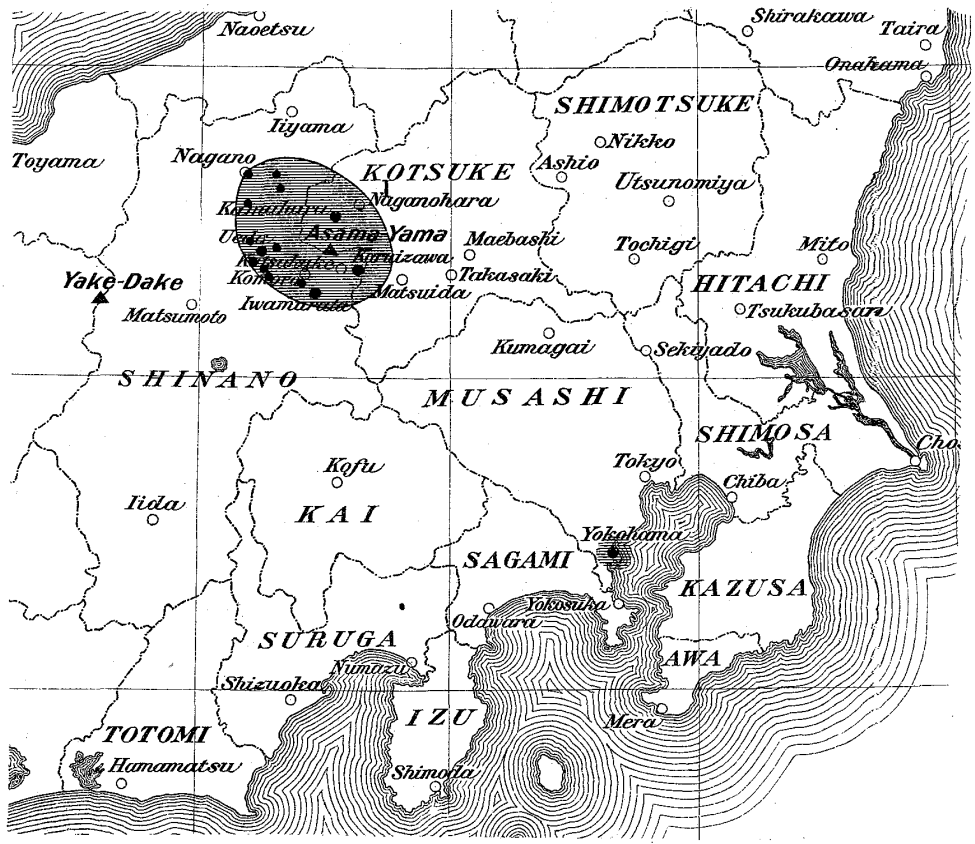
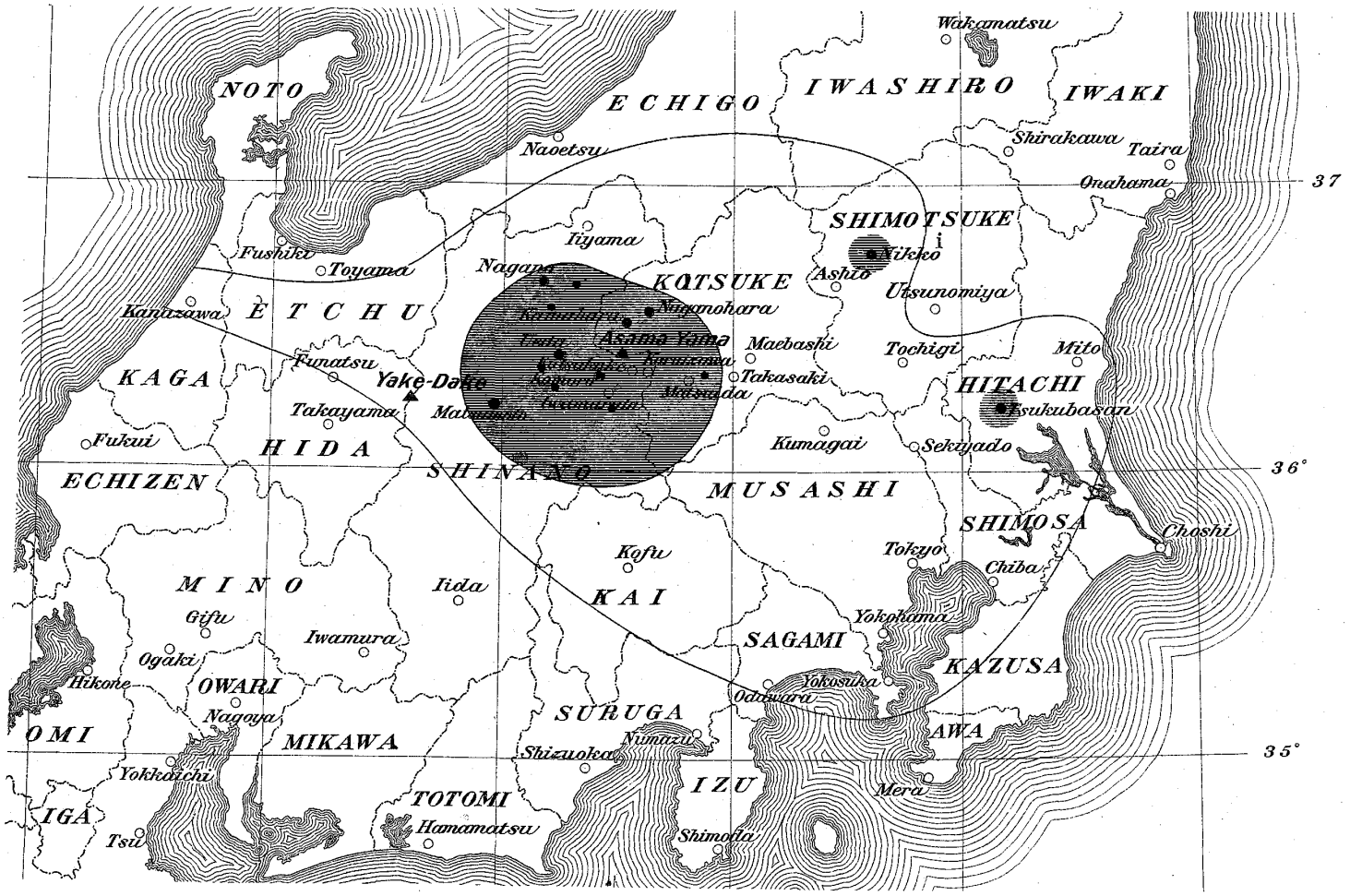


Fig. 56.
Earthquake of
Jan. 22nd, 1910.

Fig. 57. The Area of Disturbance of the Strong Ueda Earthquake of Aug. 17th, 1912.



(I)....Slight motion area.

(i)....Area within which the motion was unfelt and registered by an ordinary seismograph.

Red dot indicates a place of sensible motion.

Boundary of Provinces.

Fig. 58. Earthquake of April 2nd, 1911.

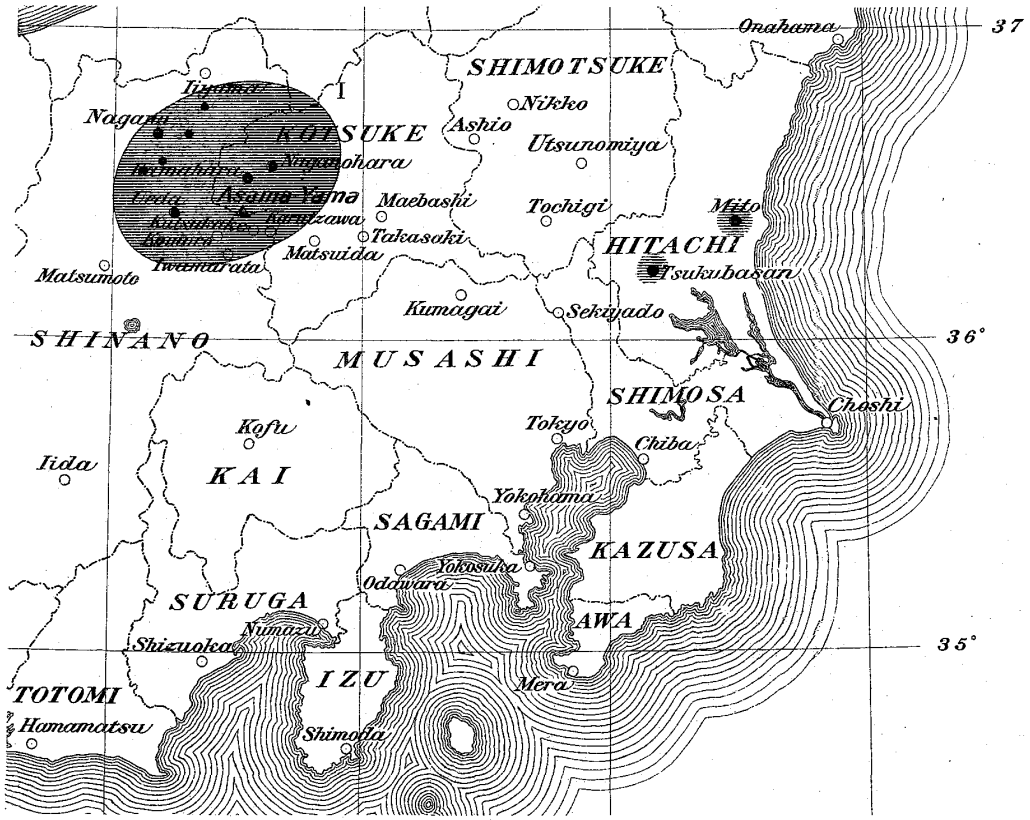
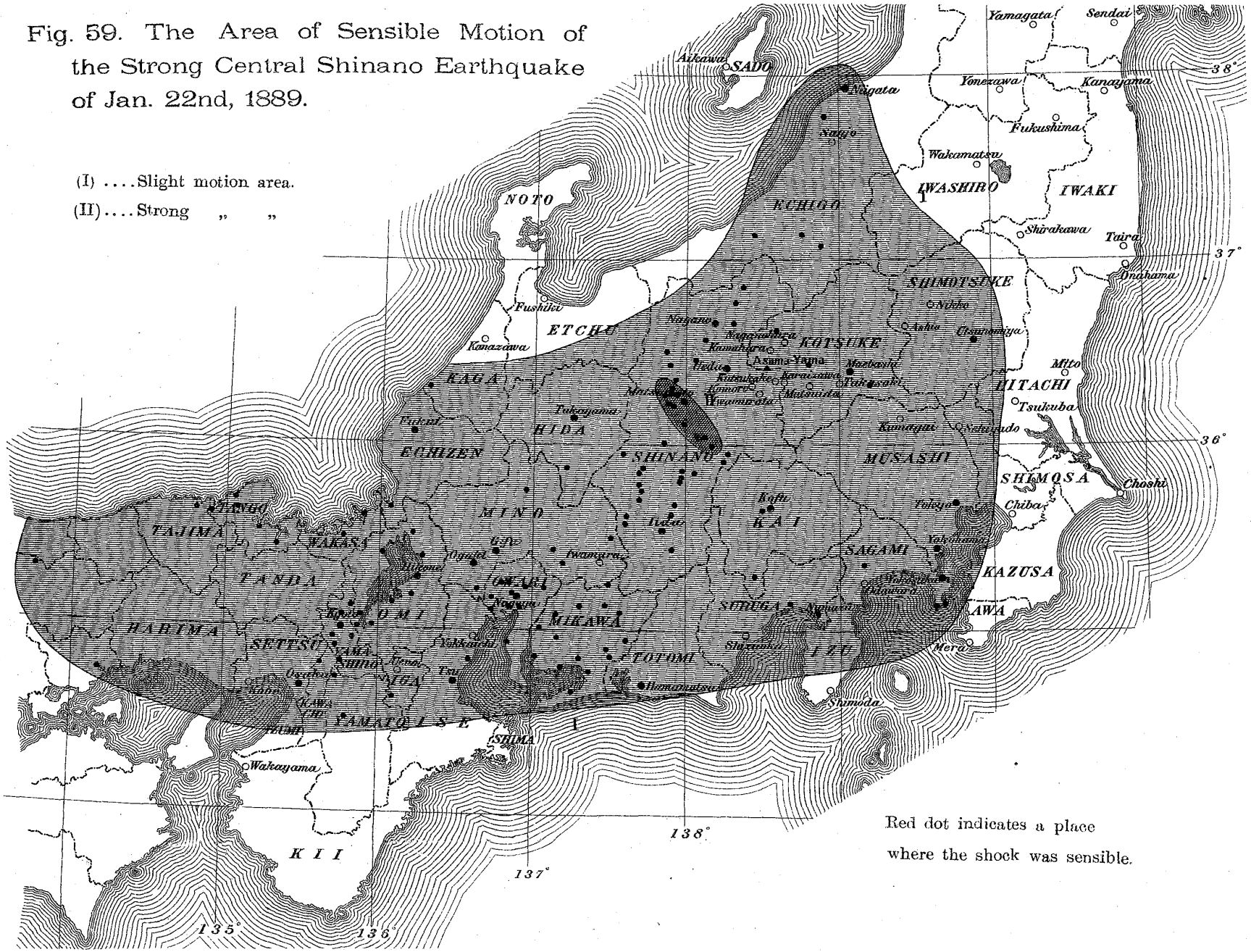


Fig. 59. The Area of Sensible Motion of the Strong Central Shinano Earthquake of Jan. 22nd, 1889.

(I) ....Slight motion area.

(II)....Strong „ „

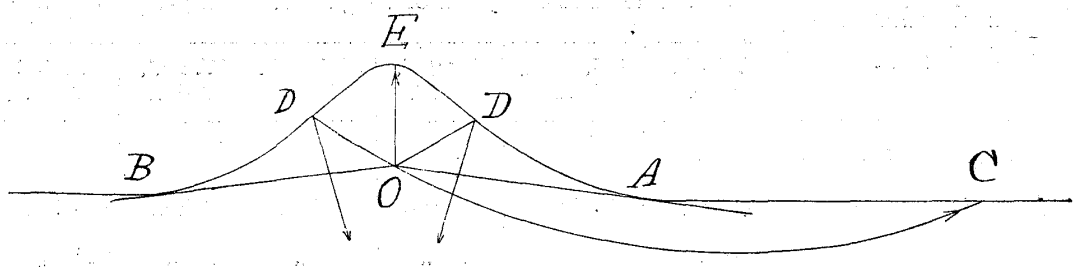


Red dot indicates a place where the shock was sensible.

Area and Elements of Motion.	Earthquake of Asama-yama or Neighbouring Origin.					Central Shinano Eqke.
	V, 26th, 1908.	VII, 16th, 1912.	I, 22nd, 1910.	VIII, 17th, 1912.	IV, 2nd, 1911.	I, 22nd, 1899.
(Earthquake Area.)						
Major Axis.	130 km.	106 km.	63 km.	100 km.	86 km.	600 km.
Minor Axis	90 „	80 „	47 „	80 „	62 „	235 „
Max. Radius.	70 „	64 „	32 „	61 „	43 „	410 „
(Earthquake Origin.)						
Distance from Tokyo.	135 „	135 „	146 „	160 „	151 „	165 „
Direction from Tokyo.	N. 56° W.	N. 56° W.	N. 54° W.	N. 58° W.	N. 54° W.	N. 72° W.
(Motion in Tokyo.)						
Max. 2a in Principal Portion.	(E.W.) 1.9 mm. (N.S.) 2.6 mm. (V.) 1.6 mm.	(E.W.) 1.8 mm. (N.S.) 2.6 mm	(E.W.) 0.87 mm. (N.S.) 1.2 mm.	(E.W.) 0.19 mm. (N.S.) 0.16 mm.	(E.W.) 0.049 mm.	(E.W.) 10.55 mm. (N.S.) 0.6 mm.
Total Duration.	—	—	$17^m\ 0^s$	—	—	$13^m\ 0^s$
Duration of Principal Portion.	(E.W.) $4^m\ 15^s$ (N.S.) $2^m\ 55^s$ (V.) $3^m\ 20^s$	(E.W.) $4^m\ 00^s$ (N.S.) $3^m\ 57^s$	(N.S.) $2^m\ 35^s$	(E.W.) $4^m\ 36^s$	$4^m\ 00^s$	$4^m\ 30^s$

101. ***Earthquake of sub-mountainous origin.*** The two Asama-yama earthquakes of May 26th, 1908. and of July 16th, 1912, which were apparently of no mean magnitude and gave prominent traces on the seismograms in Tokyo (max. 2a in the E.W. component=2.6 mm., in each case) and other distant places, were *sensible* only within areas of very limited extension. The earthquake of Jan. 22nd, 1910, whose motion registered in Tokyo was fairly large (max. 2a=1.2 mm. in the E.W. component), had also a very limited area of sensible disturbance. (See figs. 54, 55, and 56.) This peculiarity may be explained on the supposition that the depth of the foci of these strong shocks was shallow. Thus let 0 (fig. 60) be the centre of a seismic disturbance situated at a depth not exceeding some 2 km. below the summit E of the

Fig. 60.



Asama-yama, which attains the height of 2,542 m. above sea level and rises 1,600 to 2,000 m. above the plains of Karuizawa and Komoro. Then the seismic rays above the conical surface OAB drawn from the centre to touch internally the sides of the mountain, will only affect the mass of the latter, and be reflected back to the interior of the earth's crust. Consequently more than half of the seismic energy becomes unable to disturbe directly the outside surface region AC, which is thus turned into a sort of shadow ground. In other words, the intensity of the earthquake motion will rapidly decrease with the distance from the mountain and soon cease to be sensible. The seismic rays below the conical surface BOA, however, may suffer an internal reflection and emerge at a certain region C, where the motion becomes again sensible. Such is nearly what took place in the cases of the three strong Asama-yama earthquakes under consideration, the distance OC being about 150 to 175 km.

102. ***Earthquake of shallow origin.*** Let δS_0 denote the surface area at the epicentre C, subtaining a small solid angle $\delta\alpha$ at the earthquake centre 0 whose focal depth is R_0 (fig. 61). If δS be the surface area corresponding to the same amount of the solid angle at a given point P, whose radius-vector R makes an angle θ with the horizon, we have :—

$$\delta S = \frac{\delta S_0}{\sin\theta} \times \frac{R^2}{R_0^2} = \frac{\delta S_0}{\sin^3\theta}$$

If the earthquake propagation take place in a uniform medium, the reciprocal of δS may be taken as representing, so to speak, the density (=D) of the earthquake rays, or the surface distribution of the seismic energy at the point P:

$$D=\frac{\sin^3\theta}{\delta S_0}$$

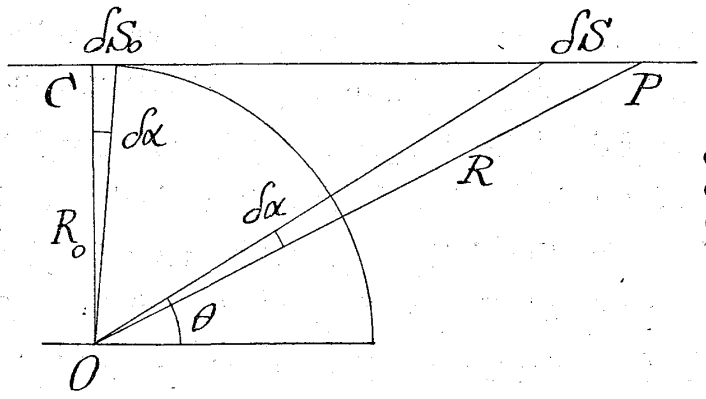


Fig. 61.

CP.....Surface.
O.....Eqke Origin.
C.....Epicentre.

For an earthquake whose focus is shallow and limited in extension, the angle θ decreases quickly with the increase of the distance R, and the motion must decrease markedly in the radial propagation, becoming insensible at no great distance from the seismic origin. The area of disturbance of a normal Asama-yama shock is, however, exceptionally small. Thus the strong Ueda earthquake of Aug. 17th, 1912, (fig. 57), was a shock of small magnitude, the motion being, according to the observation in Tokyo, less than 1/10th of that of the two strong Asama-yama earthquakes in 1908 and 1912. Its area of sensible motion was, however, nearly equal to those of the two others. Again, the earthquake of April 2nd, 1911 (fig. 58), whose motion was very small and only 1/15th or so of that of the Asama-yama shock of Jan. 22nd, 1910, had an area of sensible motion a little greater than that of the latter. The re-appearance of the sensible waves at the distance of some 175 to 190 km. eastwards from the centres might be due to the mountainous nature of the districts about the latter.

103. ***On the predominance of slow oscillations.*** The seismographic diagram of a small local earthquake shock consists entirely of minute quick vibrations. In great earthquakes, on the other hand, the motion is mixed with a considerable proportion of slow oscillations. The predominance of the slow oscillations of period of about 5 or 6 sec. in the motion of those strong Asama-yama earthquakes, whose area of propagation was quite limited, must be taken as indicating the large magnitude of the disturbance at the origin, as explained in the preceding §, or may be assumed to be the result of the impulsive shock communicated to the mass of the mountain. In the latter case there may be produced in the neighbouring part of the earth's crust certain unfelt slow shakings of the nature similar to the pulsatory oscillation of the ground. Thus after the great eruption of 1914 the island of Sakura-jima and the whole northern portion of the Kagoshima bay together with the adjacent districts suffered a remarkable subsidence accompanied by horizontal displacements. Again, the district about the Usu-san made a marked elevation after the eruption of 1910. These examples show that a volcano, together with the adjacent region, may be considered as a moving system and may consequently be also thrown into a bodily swing by a strong earthquake originating under the mountain. In the neighbourhood of the Asama-yama, there are the volcanic masses of the Hanare-yama, Sajiki-yama, Kagonoto, Sumikake-yama, etc. These probably constitute a kind of solid crustal surface floating over, or supported on, the substratum of the magma.

104. ***Transverse motion and longitudinal secondary maximum vibration.*** According to the pantograph record in Tokyo (fig. 36), the principal elements of motion of the strong Asama-yama earthquake of July 16th, 1902, were as follows:—

(i) Duration of the preliminary tremor=18.1 sec. General direction of motion of the prel. tremor=S. 43° E. and N. 43° W. (*longitudinal wave*).

(ii) Movements at the commencement of the principal portion: max. 2a=6.7 mm; general direction=S. 70° E. and N. 70° W. (*longitudinal wave*).

(iii) Movements 62 sec. after the earthquake commencement: max. 2a=4.1 mm; general direction=S. 35° W. and N. 35° E. (*transverse wave*).

(iv) Secondary maximum group at $3^m\ 36^s$ after the earthquake commencement: max. 2a=4.1 mm; general direction=S. 30° E. and N. 30° W. (*longitudinal wave*).

As the Asama-yama crater is to the N. 55° W. from Tokyo (Seismological Institute), the preliminary tremor (i), the movements (ii) at the commencement of the principal portion, and the secondry maximum group (iv), all were approximately of the longitudinal wave, while the movements (iii) were of the transverse wave in nature. The occurrence of the exceptionally large secondary maximum group (iv) is quite characteristic of this and other strong Asama-yama earthquakes, the time of its occurrence being in the mean $3^m\ 35^s$ after the earthquake commencement as follows:—

	Time Interval between the eqke. commencement and the occurrence of the second max. group.
Eqke of May 26th, 1908.....	$3^m\ 35.4^s$ (E.W. Component.)
	3 37.0 (N.S. „)
„ Jnly 16th, 1912.....	3 35.9 (E.W. „)
„ Jan. 22nd, 1910.	3 34.0 (E.W. „)

The secondary maximum (iv), which forms a distinct group, seems not to be the result of a mere accumulation of the free motion of the ground produced by the initial shock, but is probably a

separate set of vibrations due to a certain cause, such as, for instance, the seismic disturbance communicated to the subterranean magma. The propagation velocities* between Yuno-taira and Tokyo corresponding to the different phases of motion of the earthquake of July 16th, 1912, varied from 4.7 km/sec. for the commencement to only 0.55 km/sec. for the secondary maximum, as follows:—

			km.		km/sec.
(i)	Commencement of the	Prel. Tremor:	V_1 = 132.4	/ 28 sec.	= 4.7
(ii)	„ „	Princ. Portion:	V_3 = „	/(28+18.3)	= 2.9
(iii)	„ „	Transv. Wave:	V_t = „	/(28+62)	= 1.5
(iv)	„ „	Secondary Max.:	V' = „	/(28+215)	= 0.55

The occurrence of the transverse maximum vibrations at the later part of the principal portion is also well illustrated in the pantograph diagrams of the strong Nagaoka (province of Echigo) earthquake on Aug. 29th, 1917, and of the after-shocks of the Ozasa earthquake, on Feb. 22nd and 23rd, 1916. (See figs. 37, 49, 50, and 51.)

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* This volume, p 205