The Omachi (Shinano) Earthquakes of 1918.* I.

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(*With Plates* I–X.)

1. INTRODUCTION. The two severe earthquakes on Nov. 11, 1918, which shook the town of Omachi and the vicinity, in the province of Shinano, may be classed as small local destructive shocks, and furnish a very interesting material of study in connection with the great Zenkoji catastrophe of 1847 and other former seismic disturbances belonging to the earthquake zones of the Shinano-gawa valley and of the Hime-kawa and Tenryu-gawa valley.

The present author, who was at the time engaged in the field study of the Shirane (Kusatsu) volcano, has been telegraphically requested by Mr. T. Akaboshi, Governor of the Nagano prefecture, to proceed at once to the shaken districts and make investigations of the earthquake shocks still occurring continuously. The author arrived at the scene of disaster on Nov. 14th at noon, and on the strength of the tromometer registers obtained at the Nagano meteorological observatory and a precursory observation of the seismic damage at Omachi and the vicinity, published on the same day a preliminary note, giving an assurance of the non-recurrence of further destructive shocks to the panic stricken people who did not dare to remain in their houses and suffered much from exposure to cold weather.

The author made the field study of the seismic effects during the 7 days till the 20th (Nov.), and again during the 8 days between Nov. 28th and Dec. 5th. A continuous registration of the after-shocks was carried on by means of a portable horizontal pendulum tromometer of 100 times magnification temporarily set up in the compound of the Omachi district office, between Nov. 27th and Dec. 5th, 1918.

The following §§ give a general account of the seismic activity in 1918 of Omachi and vicinity, together with a comparison of the bench mark heights, before and after the earthquakes, along the precise leveling line extending from Matsumoto to Omachi, and thence to Itoigawa on the Japan Sea coast.

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* Translation, with additions, of my report on the Omachi earthquakes published in the Japanese Reports of the Imp. Earthq. Inv. Comm. (Shinsai Yobo Chosakai Hokoku), No. **94**.

2. AFTER SHOCKS AND REPETITION OF GREAT DESTRUCTIVE EARTHQUAKES. A great earthquake is always followed by numerous secondary shakings, which decrease very quickly at first, but which may, according to the magnitude of the initial disturbance, continue for several months or several years, sometimes even for more than 10 years. The after-shocks, whose number may amount to several hundred or several thousand, gradually bring back the disturbed region to equilibrium condition, and are much smaller and weaker than the main earthquake, their principal origins being in the immediate neighbourhood of that of the latter. Now a great destructive earthquake is equivalent to the removal of a long continued excess of stress in the earth's crust of the region concerned. Further, the seismic focus has a depth less than a certain limit, say, 20 ri (=80 km.), while its length may extend over the horizontal distance of more than 100 km. or even 100 miles. Hence it may be assumed that great destructive earthquakes do not happen from one and the same point or local tract. It is, of course, possible that such shocks originate from the same earthquake zone. In such cases, however, the centres would be widely separated from one another. Thus, the great Japan earthquake of Dec. 23rd, 1854 took place off the coast of Tokaido, while the equally great earthquake on the next day, Dec. 24th, took place off the coast of Nankaido at the distance of more than 400 km. to the S.W. along the same seismic zone on the convex, or Pacific, side of the Japan arc. Again, the great Valparaiso and the Aleutian Islands earthquakes on Aug. 16th, 1906, occurred almost simultaneously from the southern and northern parts of the earthquake zone along the Pacific coast of North and South America at a mutual distance of 10,000 miles.

3. AFTER-SHOCKS AND REPETITION OF SMALL LOCAL DESTRUCTIVE EARTHQUAKES. A small destructive earthquake is one whose area of strong motion is limited and which is sufficiently strong to damage ordinary brick chimneys, stone structures, badly built brick houses, and to cause slight cracks of the ground, but which does not attain the magnitude of a great destructive earthquake, namely, one capable of completely destroying a wooden Japanese dwelling house. A small destructive shock as here defined may prove very disastrous in some other places such as Southern Italy, where houses are made of very bad building material.

Local destructive shocks may often occur twice, unlike large ones, from neighbouring places in the course of one day or two. For instance, in Dec. 1892, two strong earthquakes of local nature occurred off the coast of the S.W. part of the province of Noto (Hokrikdo, Japan) respectively on the 9th, at 10. 40 A.M. and on the 11th, at 1. 30 A.M., with the mutual time interval of

Fig. 1. Map showing the Shinano-gawa Valley and the Hime-kawa and Tenryu-gawa Earthquake Zones.

I.....Shinano-gawa Eq. Zone. II.....Hime-kawa and Tenryu-gawa Eq. Zone.

A .....Destructive motion area of the Sanjo (Echigo) Eqke. of 1828.

B .....Approximate position of the epicentre of the Sado and Shonai Eqke. of 1833.

C.....Destructive motion area of the great Zenkoji Eqke. of 1847.
(The inner area indicates the districts where the seismic damage was specially heavy.)

●.....Centres of the Local Destructive Earthquakes :—

1	Omachi-gumi Eqke., 1714.	6	Eqke. of 1890.
2	Iiyama Eqke., 1718.	7	„ 1897.
3	Matsushiro Eqke., 1858.	8	„ 1899.
4	Eqke. of 1886.	9	Shizuoka Eq., 1917.
5	„ 1887.	10	Omachi Eqkes., 1918.

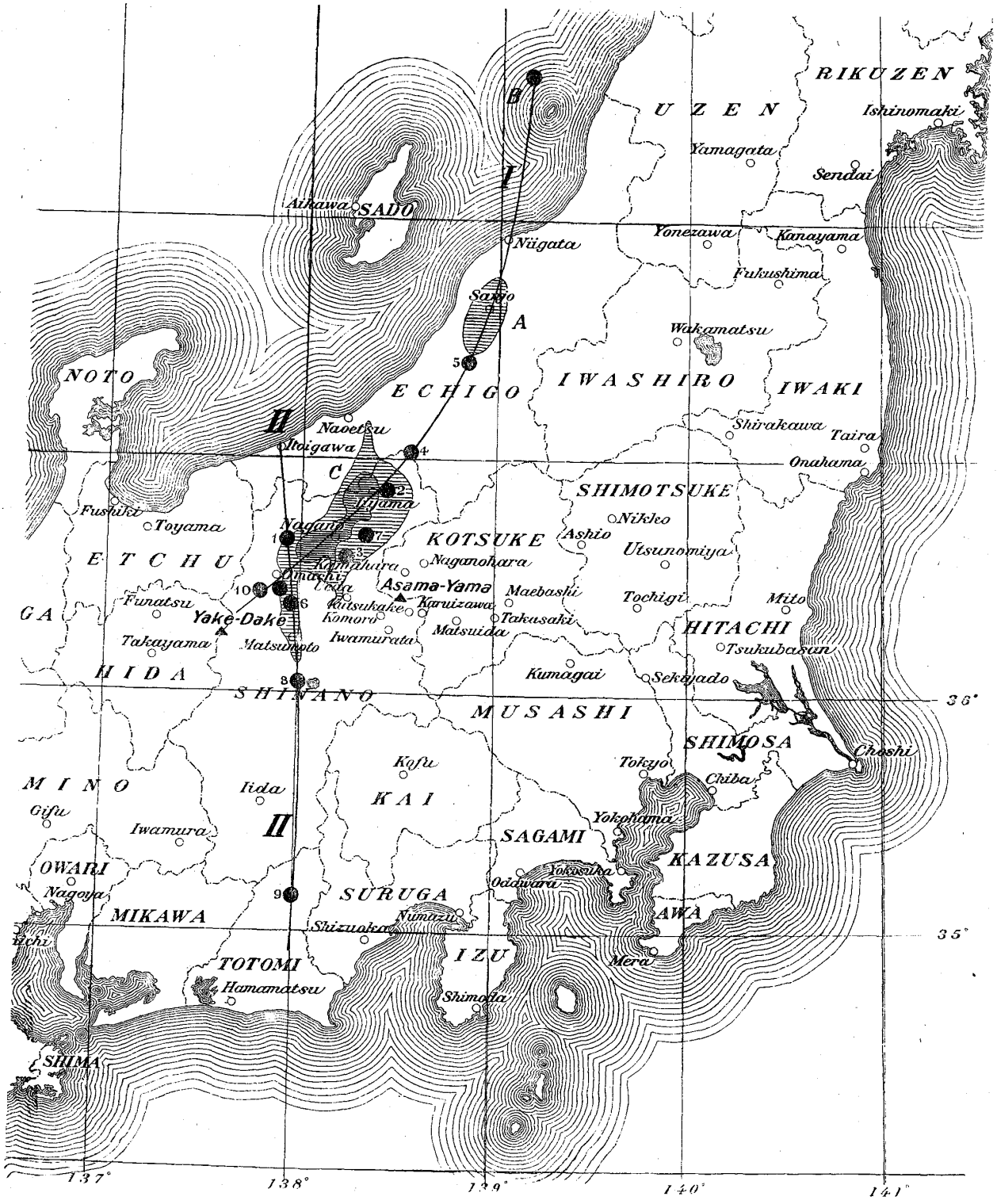
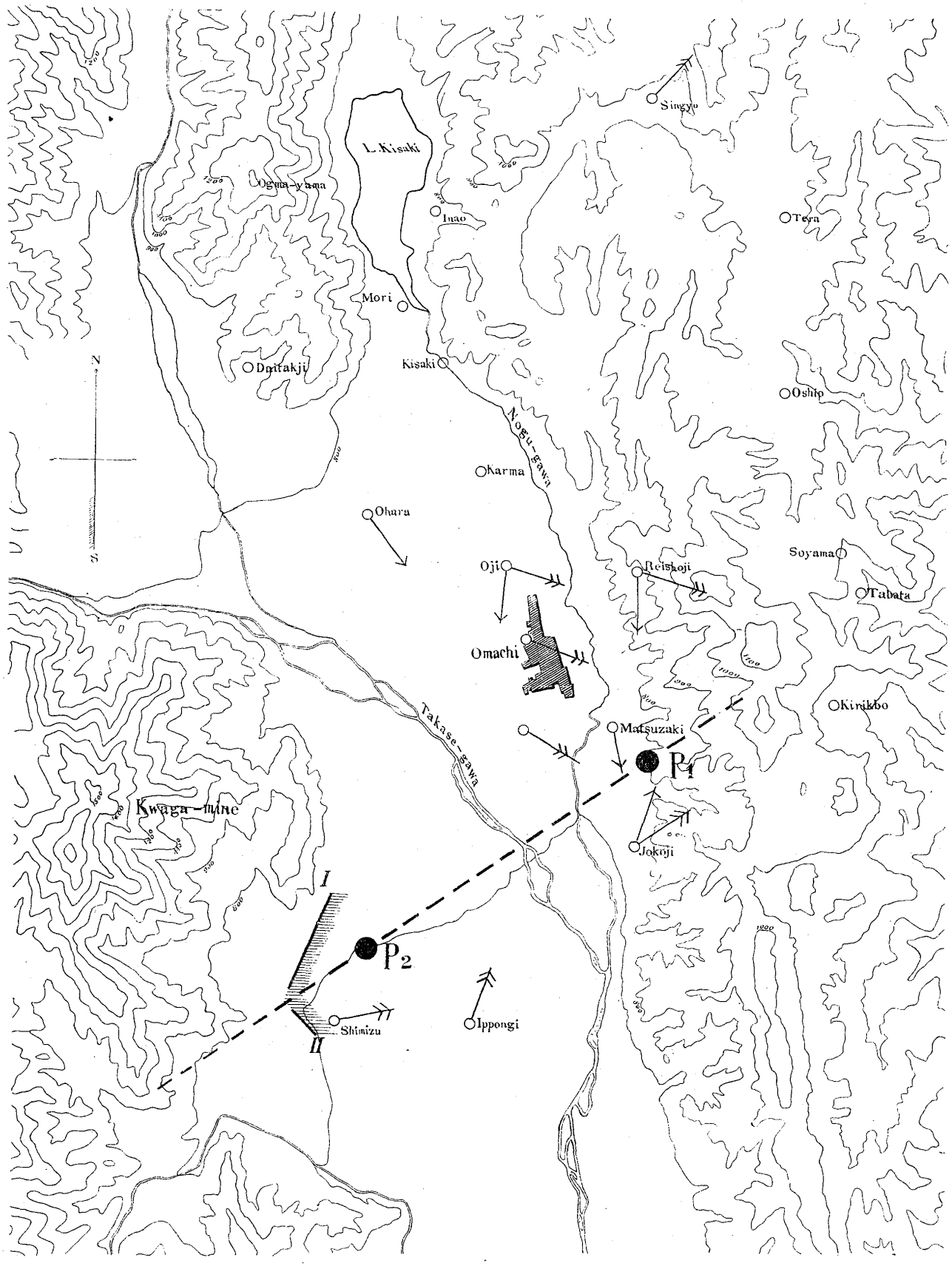


Fig. 2. Map of the Epicentral District of the Two Destructive Omachi Earthquakes on Nov. 11, 1918.

P_1P_2.....Focal Zone of the 2nd Destructive Shock, forming the S.W. continuation of the Shinano-gawa Earthquake Zone.

P_2.....Central Point of the Zone P_1P_2. P_1.....Epicentre of the 1st Destructive Shock.



Single-feathered arrow indicates the direction of the strongest-motion of the 1st shock, and the double-feathered that of the 2nd shock.

I, II.....Small Dislocation Lines, the shade on the E. side indicating the relative depression of the ground.

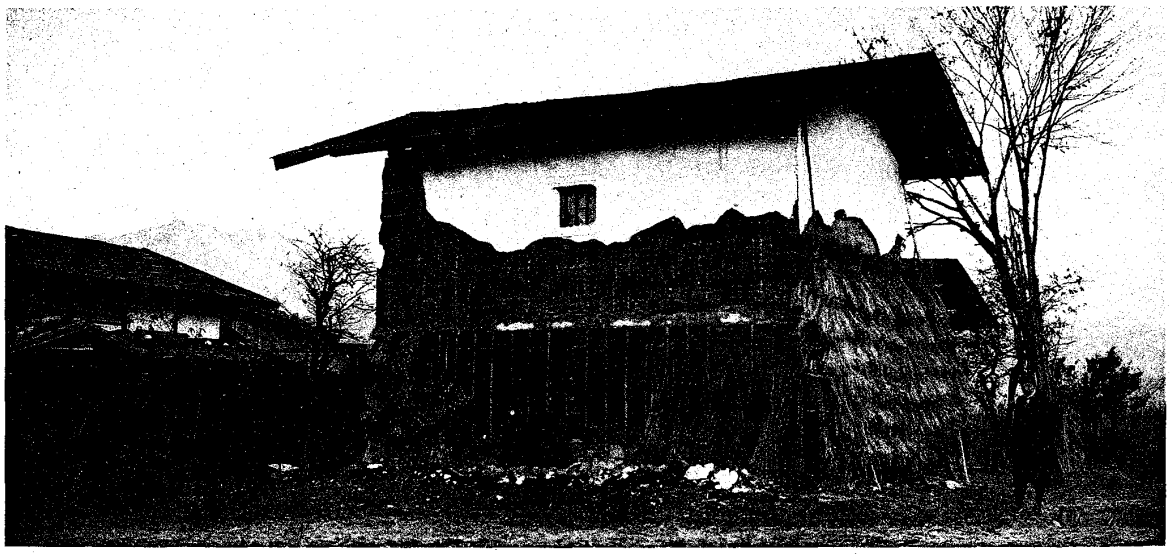


Fig. 3. A *Dozo* (Japanese Ware-house) at Shimizu, Tokiwa-mra, with its mud wall badly shaken down.

Fig. 4. A Stone-lantern overturned, at Jokoji (常光寺) Temple, Yashiro-mra. (×) .... A foot-scale indicating the amount of the displacement of the pedestal.

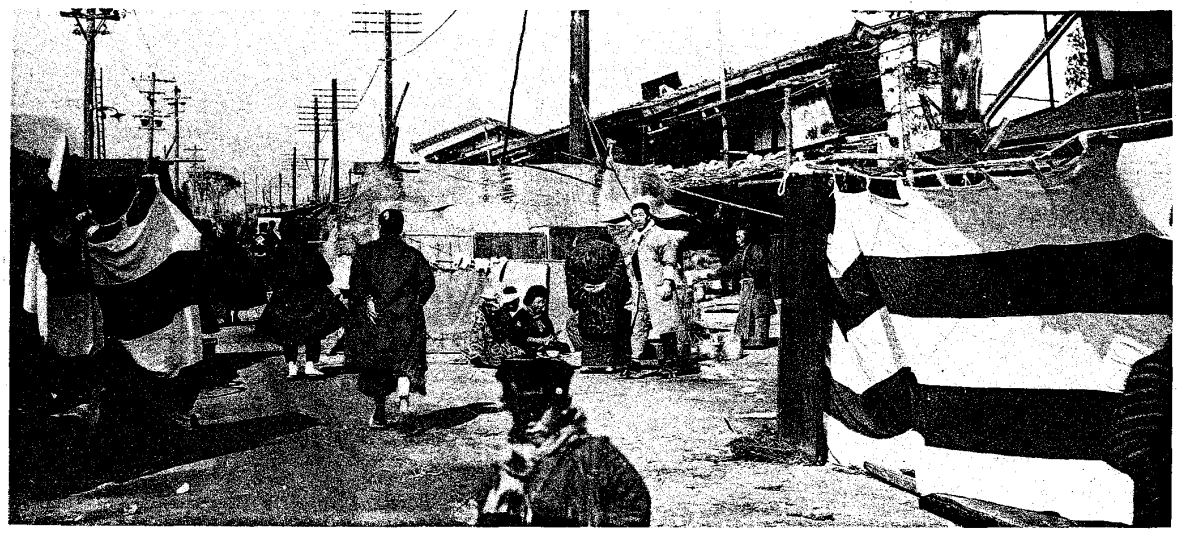


Fig. 5. Street Scene in the Town of Omachi after the Earthquakes.

38.8 hours. Again, in Aug. 1898 the Itoshima district, in the W. part of the province of Chikzen (Kyushu) was shaken by two strong shocks on the 10th, at 9. 57. 31 P.M., and on the 12th, at 8. 35. 34 A.M., with the time interval of 35.6 hours. In each of these cases, the second earthquake was a little stronger than the first, while the occurrence of the after-shocks following the latter was not sufficiently abundant. Thus, the first strong Itoshima earthquake was followed by only 3 after-shocks previous to the occurrence of the second strong earthquake, which was followed by a sufficient number of after-shocks, amounting to 34 in the course of the same day. It is likely that when a local seismic district reaches the limiting state of underground stress accumulation two small destructive earthquakes may take place from within the affected area with a mutual distance of 5 to 10 km.

4. COURSE OF OMACHI SEISMIC ACTIVITY. At the Tokiwa-mra, 6 km. to the S.W. from Omachi, a slight shock was felt on the 10th (Nov.) just after the supper time, another slight one being felt at about 10 o'clock on the same evening. In the vicinity of the Oji temple, at the northern part of the town of Omachi, sounds like those due to avalanches were perceived toward the W.S.W. at about 10 P.M., on the 10th. Similar sounds were also heard on the same day at about 4 P.M. at the village of Krumibara to the N. of Omachi. These might possibly have been the fore-shocks of the two destructive earthquakes on the 11th whose times of occurrence were, according to the tromometer observations at the Tokyo Seismological Institute, respectively 2. 58. 45 A.M. and 4. 03. 40 P.M., with the mutual time interval of 13.1 hours, the 2nd earthquake being much larger than the first. According to the tromometer records at the Nagano Meteorological Observatory, the after-shocks which followed the 1st destructive earthquake were comparatively few in number, probably in indication of the continued unstable condition of the focal district. Thus there resulted the 2nd destructive earthquake, followed by numerous after-shocks, some of which were moderately strong. This may be taken as the result of the removal of the principal underground weak points of the district under consideration, which may be assumed to be free in future from the repetition of similar seismic disturbances. The separate occurrences of the two successive destructive earthquakes have no doubt materially contributed to diminish the amount of the seismic damage which ought to have been produced had the the two shocks been combined in one occurrence.

The frequency and intensity of after-shocks of a destructive earthquake usually show periodic variations with the lengths, amongst the others, of $4\frac{1}{2}$ days and 8–9 days. In the present instance, the after-shocks of the two

destructive earthquakes on the 11th steadily decreased in frequency; with none of the *strong* intensity after the 14th. A somewhat strong after-shock took place, however, on the 20th, at 9. 48. 55 A.M., namely, 9 days 7 hours after the 1st earthquake. Again, after an interval of 4 days 19 hours, a pretty severe after-shock took place on the 25th, at 4. 56. 55 A.M. After a further interval of 5 days 23 hours, again took place a strong after-shock on Dec. 1st, at 4. 15 A.M. Then, after an interval of 13 days (equivalent to the sum of $4\frac{1}{2}$ and 9 days), occurred a fairly strong shock on Dec. 14th, at 5. 34 P.M. These show the two average intervals of approximately $4\frac{1}{2}$ and 9 days in conformity with the general time distribution of after-shocks. The occasional occurrence of comparatively strong after-shocks at Omachi was thus a matter of no extraordinary seismic behaviour. This fact was recognized by the author already at the time of his visits to the shaken districts and pointed out to the panic stricken people as one of the reassuring circumstances.

5. **EARTHQUAKE DAMAGE.** The earthquake damage was chiefly limited to the town of Omachi and the 5 neighbouring villages of Tokiwa (常盤), Yashiro (社), Taira (平), Yasaka (八阪), and Mima (美馬), in the central and southern parts of the Kita Atsumi district, province of Shinano (prefecture of Nagano), the first named 4 places having suffered most severely. There was no case of casuality, except one man wounded at each of the villages of Tokiwa, Yasaka, and Aisome, and two at Mima. According to the census of the Kita Atsumi district office, the total seismic damage, relating to the towns of Omachi and Ikeda and of Yashiro and 9 other villages, was as follows:—

Number of the dwelling houses totally destroyed.....6
" " " half destroyed 2,852
" " *dozo*, ware-houses, etc., totally destroyed.....16
" " " " damaged.....2,273
" public buildings, temples, etc., damaged.....290
Roads and river embankments, cracked .....7365 metres
Ishigaki (stone retaining walls) damaged .....334 places.

The dwelling houses totally destroyed were either old rotten buildings or converted ware-houses, none of the houses in ordinary condition of keeping having collapsed. Hereby it is to be noted that most of the Japanese style houses in Omachi and the vicinity are low, even the two-storied buildings looking like $1\frac{1}{2}$-storied ones. In this connection it may be stated that after the great Zenkoji (Nagano) earthquake of 1847, it has been prohibited in the city of Nagano to build 2-storied houses, on account of the great risk to

which the tall wooden buildings were exposed on occasion of destructive earthquakes. The maximum height of vertical posts to be allowed in the one-storied houses was fixed at 11 *shaku**, the limit having subsequently been raised to $2\frac{1}{2}$ *ken*. (=15 feet). It is probable that the low structures in the Omachi district were the result of a similar seismic precaution, as the

Table I. List of Seismic Damage in the different Towns and Villages.

Town or Village.	Number of Dwelling Houses.			Dozo. Warehouses, etc.		Schools, Temples and Public Offices, damaged.	Number of damaged Ishigaki (stone wall).	Length† of	
	Totally destroyed.	Half destroyed.	Damaged.	Totally destroyed.	Damaged.			Roads damaged.	Rivers damaged.
								ken	ken
Omachi (大町)	—	241	867	6	692	84	228	302	2566
Yashiro (社村)	4	16	270	7	350	18	57	1242	570
Tokiwa (常盤村)	1	28	585	—	476	11	3	120	—
Matsukawa (松川村)	—	—	—	—	13	2	—	—	—
Ikeda (池田町)	—	—	7	—	42	1	—	—	—
Aisome (會染村)	—	—	3	—	14	2	4	—	—
Nanaki (七貴村)	—	2	—	—	—	8	—	—	—
Rokgo (陸郷村)	—	1	370	—	386	—	—	—	—
Hirotsu (廣津村)	—	1	1	1	3	6	2	60	—
Yasaka (八阪村)	1	9	67	2	71	7	36	226	200
Taira (平村)	—	3	309	—	188	6	2	25	8
Mima (美麻村)	—	4	68	—	33	145	—	20	—
Sum.	6	305	2574	16	2273	290	334	1507	3344

town and some of the neighbouring villages suffered not in an insignificant degree the effect of the Zenkoji (1847) and the Ansei (1854) earthquakes. The comparatively small amount of damage done to the houses in the present case was also doubtless due to the employment of thick strong wooden posts. The statistical statements of the seismic damage for the different towns and villages are given in Table I.

* 1 *shaku* = 0.997 English foot.

† Expressed in *ken* = 6 *shaku* = 6 feet very nearly.

A special feature in the Omachi earthquake damage was an enormous amount of the cracks and shaking down of the plastered mud walls of the dwelling houses and the *dozo* (wooden-frame ware-houses with thick plastered mud walls). In fact the seismic disturbances may, as far as the damage is concerned, termed as "*dozo* earthquakes." The chief fault of construction lies in the inferior quality of the wall mud, which is made up of incoherent sandy earth mixed with a small proportion of clay. For the structures in Omachi and the villages of Yashiro and Tokiwa, the clay must be imported from other places, and the high cost of transportation reduces sometimes the use of the clay to only 10 or 20% in the preparation of the wall mud. Another objectionable custom in the construction of the *dozo* walls is the employment, not of the bamboo pieces as they do in other parts of Japan, but of thick round rods of wood, sometimes 1″ or 2″ in diameter, for the internal framing of the walls. These are arranged vertically and horizontally and are tied at their crossings with straw ropes, and then plastered over to the thickness of about 6″ by the mud mixture above mentioned. Thus it follows that the mud walls are at the time of a destructive shocks very easily cracked and shaken down in large masses. On the other hand, it may be that this very circumstance, taking off the heavy weight from the buildings, actually saved the latter from being totally overthrown by the earthquake motion.

6. COMPARISON OF THE TWO DESTRUCTIVE SHOCKS ON NOV. 11TH. The two earthquakes on the 11th, at about 3 A.M. and about 4 P.M., had different meizoseismal areas. Thus at Omachi the 3 A.M. earthquake was very strongly felt, almost to the same degree as the 4 P.M. earthquake. At the temple Reishoji situated on a hill of diluvial formation about 1.5 km. to the N. E. of Omachi, the 3 A.M. shock was strong and caused the overthrow of the several *ishidoro* (stone lanterns). It was, however, at the 4. P.M. shock that the sandy cliffs fell down and blocked the road ascending to the temple. At the village of Kirikbo (切久保), 3.5 km. to the E. slightly S. of Omachi, the 3 A.M. shock caused considerable damage to the *ishigaki* of the different houses and threw out of perpendicular the elementary school, a 2-storied wooden building, which had also its wall mud shaken down, window panes broken, and the wooden stair-case deranged out of position; the 4 P.M. shock which was a little stronger, having caused no special further damage. At the temple of Yamashita Myojin in the Jokoji locality of the Yashiromra, about 2.5 km., to the S.E. of Omachi, all the ordinary *ishidoro* were overthrown by the 3 A.M. shock. In the same compound, the pedestal of a stone lantern was found displaced to the extent of 17cm., while the wooden *torii* (Shinto gate) suffered a displacement of 20 cm. off the foundation stones.

These latter effects seem to be due to the 4 P.M. shock. At the Matsuzaki locality of the Yashiro-mra, adjoining the S.E. part of the town of Omachi, the 3 A.M. shock caused the crack of walls and the overthrow of the *ishidoro*; it being chiefly, however, the 4 P.M. earthquake which caused damage to the *ishigaki*. At the Nakabayashi locality of the same village, where the soil is low and moist, the motion was very violent, as may be judged from the following facts :— a large manure tub, 3 feet in diameter and 3 feet in depth, buried in the ground was thrown by the shocks 1.5 feet vertically out of the latter. Subsequently it subsided 0.5 foot by itself. At the village of Mikka-machi, 2 km. to the N. slightly E. of Omachi, the 3 A.M. shock was very strong and caused much cracking of the *dozo* walls, which were in most cases finally shaken down by the 4 P.M. shock. Again the two ware-houses, somewhat thrown out of the vertical by the 3 A.M. shock, were thrown down by the 4 P.M. shock.

At the Osaki, Shimizu, and Ippongi localities of the Tokiwa-mra, about 6 km. to the S.W. of Omachi, the 3 A.M. shock was only slightly felt and it caused no damage, such that no peaple ran out of the doors, and even very unstable tomb stones and stone-lanterns were not overthrown. On the other hand, the 4 P.M. shock was very strong at these places, causing, amongst the others, at Shimizu the displacement of the pedestals of the tomb stones to the maximum horizontal amount of 3′ 2.″5.

From the above accounts it will be quite evident that the two destructive earthquakes on Nov. 11th had different foci. The first (3 A.M.) shock was strongly felt, with production of marked damage, only within an area, 4 km. in diameter, including the town of Omachi and the adjacent places to its N., E., and S. E. The second (4 P.M.) shock was of a much greater magnitude and was felt most strongly in the Tokiwa-mra localities; its intensity of motion in the meizoseismal area of the first earthquake being also higher than on that occasion.

7. POSITIONS OF THE EARTHQUAKE ORIGINS DEDUCED FROM TOKYO OBSERVATIONS. The two Omachi earthquakes under consideration have been felt slightly in Tokyo. The results of the tromometer observations at the Seismological Institute were as follows :—*

1st Earthquake.

Time of Occurrence=2. 58. 48 A.M.

Duration of Preliminary Tremor=25.8 sec.

* The radial distance from the observing place (=x km.) has been calculated from the duration of the preliminary tremor (=y sec.) by the formula : x km.=7.42 y sec.

Radial Distance = 191 km.
1st Displacement of the earthquake motion = 0.12 mm. directed originward.
Mean Direction of motion in Prel. Tremor = N.63°.9W.
Maximum Motion = 3.3 mm.

2nd Earthquake.

Time of Occurrence = 4. 03. 40 P.M.
Duration of Preliminary Tremor = 2[illegible].8 sec.
Radial Distance = 199 km.
1st Displacement of the earthquake motion = 0.55 mm. directed originward.
Mean Direction of motion in Prel. Tremor = N. 66°.6W.
Maximum Motion = 11.8 mm.

Thus the origin of the 1st earthquake was situated 191 km. to the N.63.°9W. of Tokyo, and that of the 2nd at 199 km. to the N.66°.6W. of Tokyo. These positions are close to Omachi, the 2nd origin being located about 8 km. to the S.W. of the 1st origin. (See fig. 11.)

8. POSITIONS OF THE EARTHQUAKE ORIGINS DEDUCED FROM NAGANO OBSERVATIONS. The portable type horizontal pendulum tromometer, of pointer magnification = 75, at the meteorological observatory of Nagano, where the earthquakes were felt as *strong* motion,* has given satisfactory registers. (See Pls. VI and VII.)

On account of the short distance the Nagano records fix the positions of the centres of disturbances with accuracy. The results of the observations were as follows :—

1st Earthquake.

Time of Occurrence = 2. 58. 13 A.M.
Duration of Preliminary Tremor = 4.7 sec.
Radial Distance = 35 km.
1st Displacemeut = 0.17 mm., directed originward.
Mean Direction of motion in Prel. Tremor = S.60°.4W.

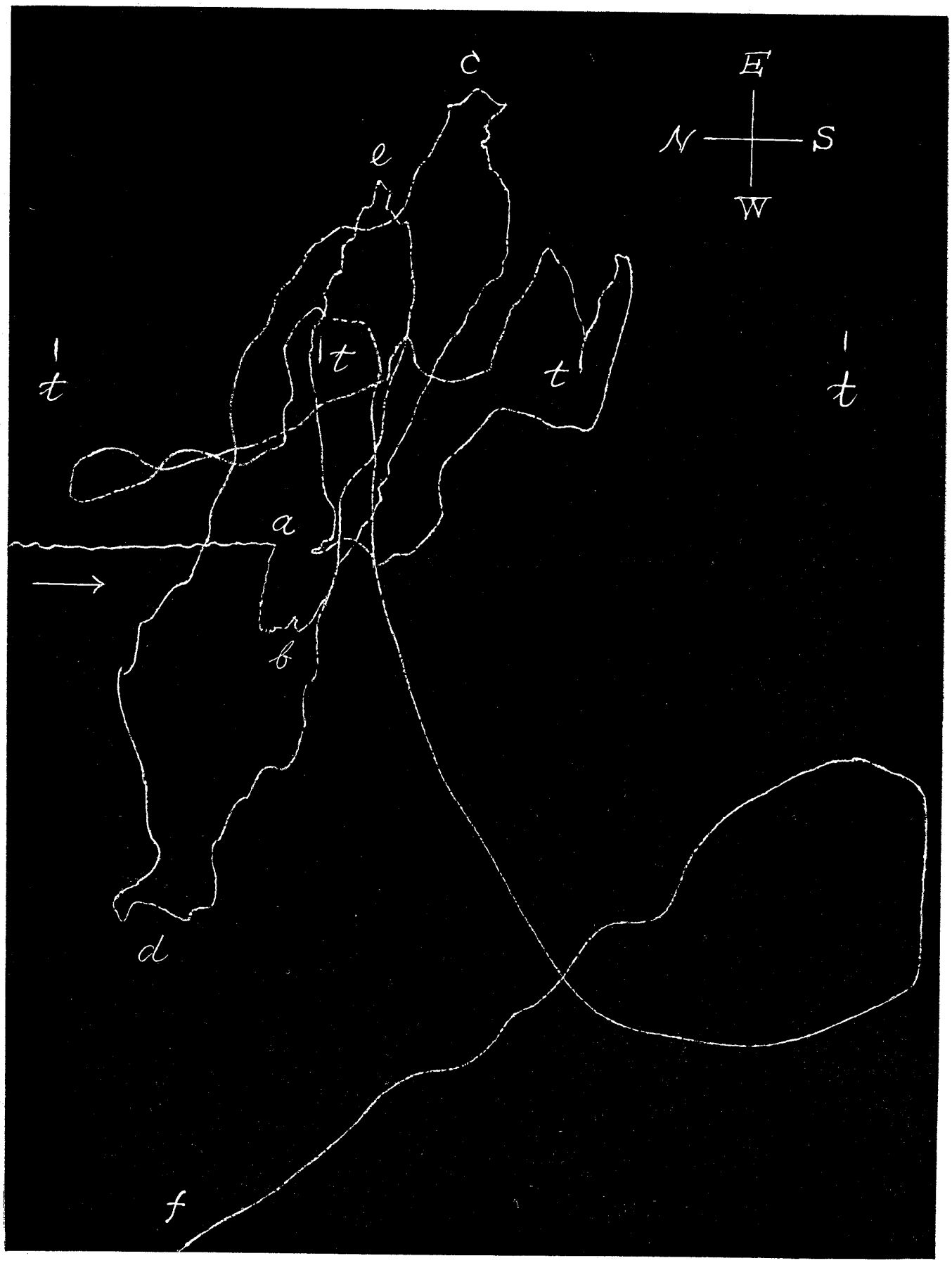
2nd Earthquake.

Time of Occurrence = 4. 03. 12 P. M.
Duration of Preliminary Tremor = 5.2 sec.

* The earthquake motion of *strong* intensity is one which is felt strongly, but which causes no damage.

Fig. 6. The 2nd Destructive Omachi Earthquake, on Nov. 11, 1918, at 4 P.M.

Duplex Pendulum Tromometer Record at Tokyo. Multiplication = 23.



a .....Commencement. *ab*.....1st Displacement.
bc.....2nd Displacement. *cd*.....3rd „ .
de.....4th „ . *t* .....*t*, successive minute marks.

(The writing pointer got out of the smoked paper at *f*.)

Duplex Pendulum Tromometer Records Multiplication = 30.

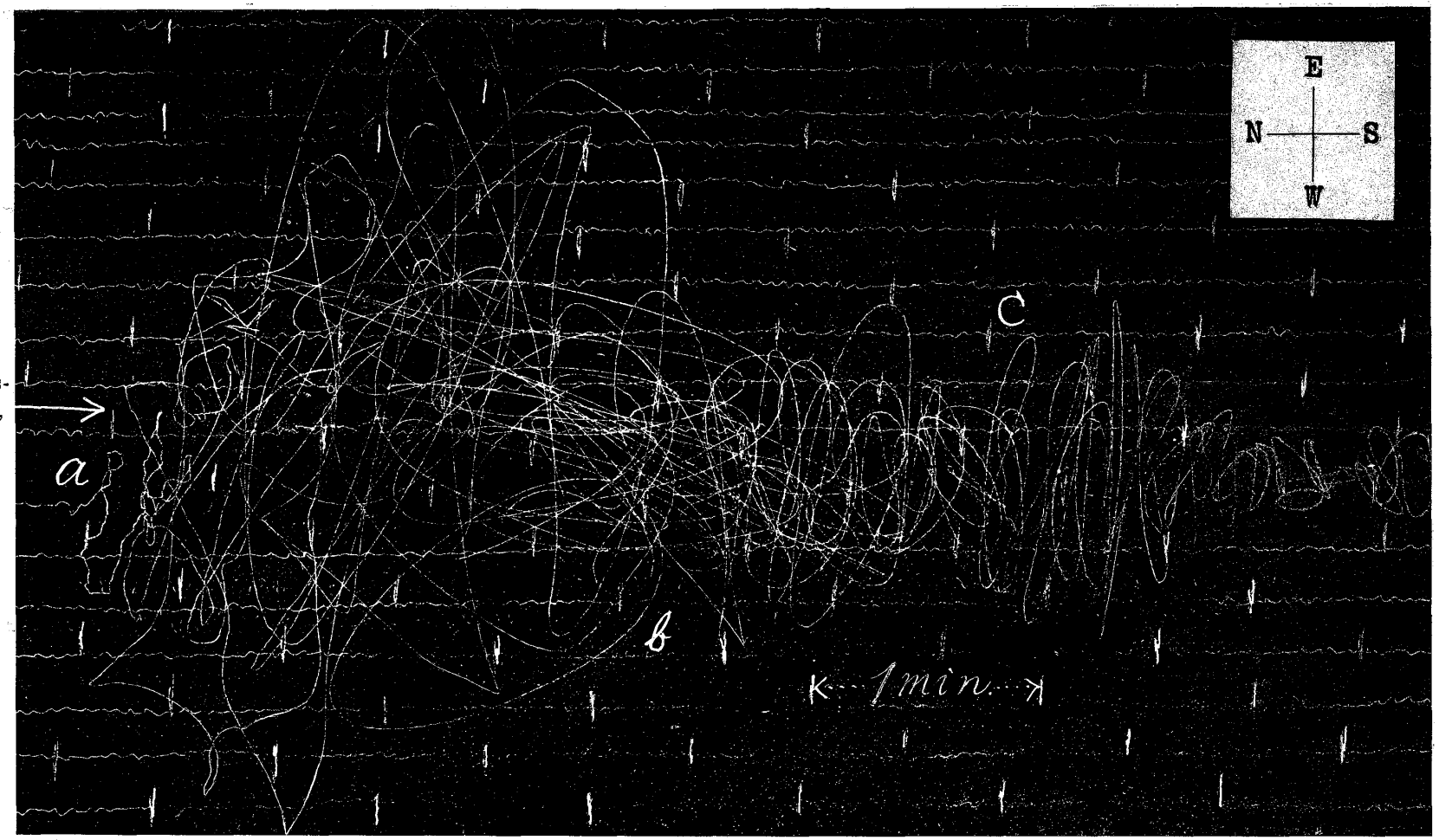


Fig. 7. The 1st Destructive Earthquake, on Nov. 11, 1918, at 2.58 A.M.

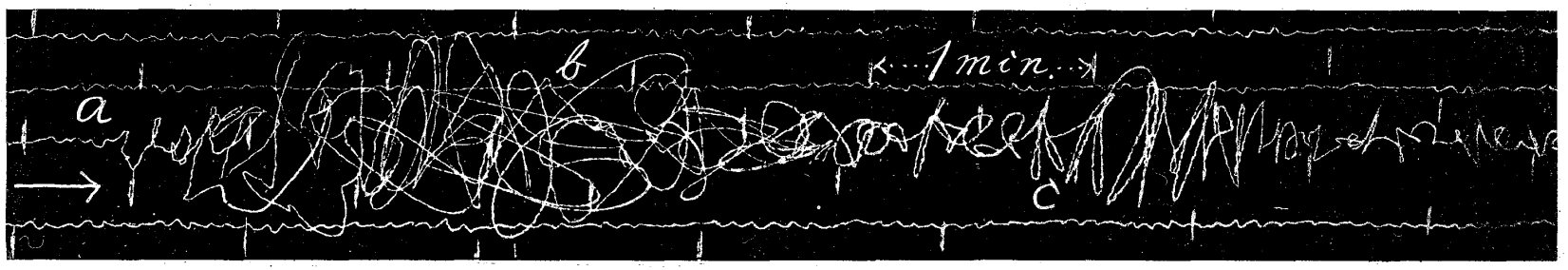
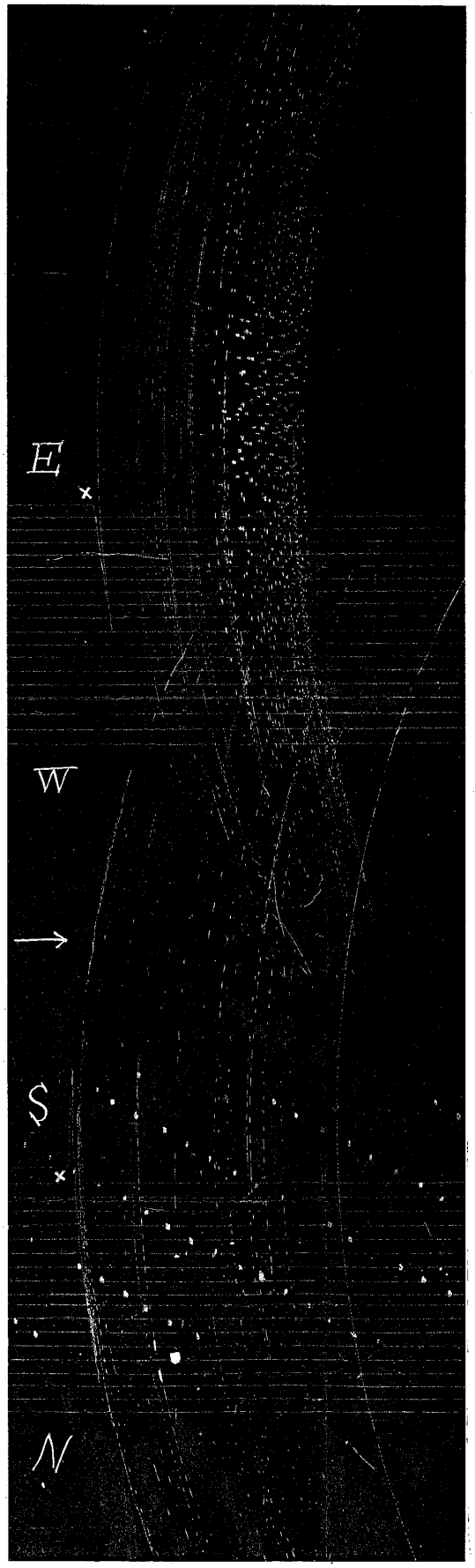


Fig. 8. The Strong Aftershock on Nov. 11, 1918, at 3.16 A.M.

Fig. 9. The 2nd Destructive Omachi Earthquake, on Nov. 11, 1918, at 4.03 P.M.

Horizontal Pendulum Tromometer Record at the Nagano Meteorological Observatory.

Multiplication = 62.



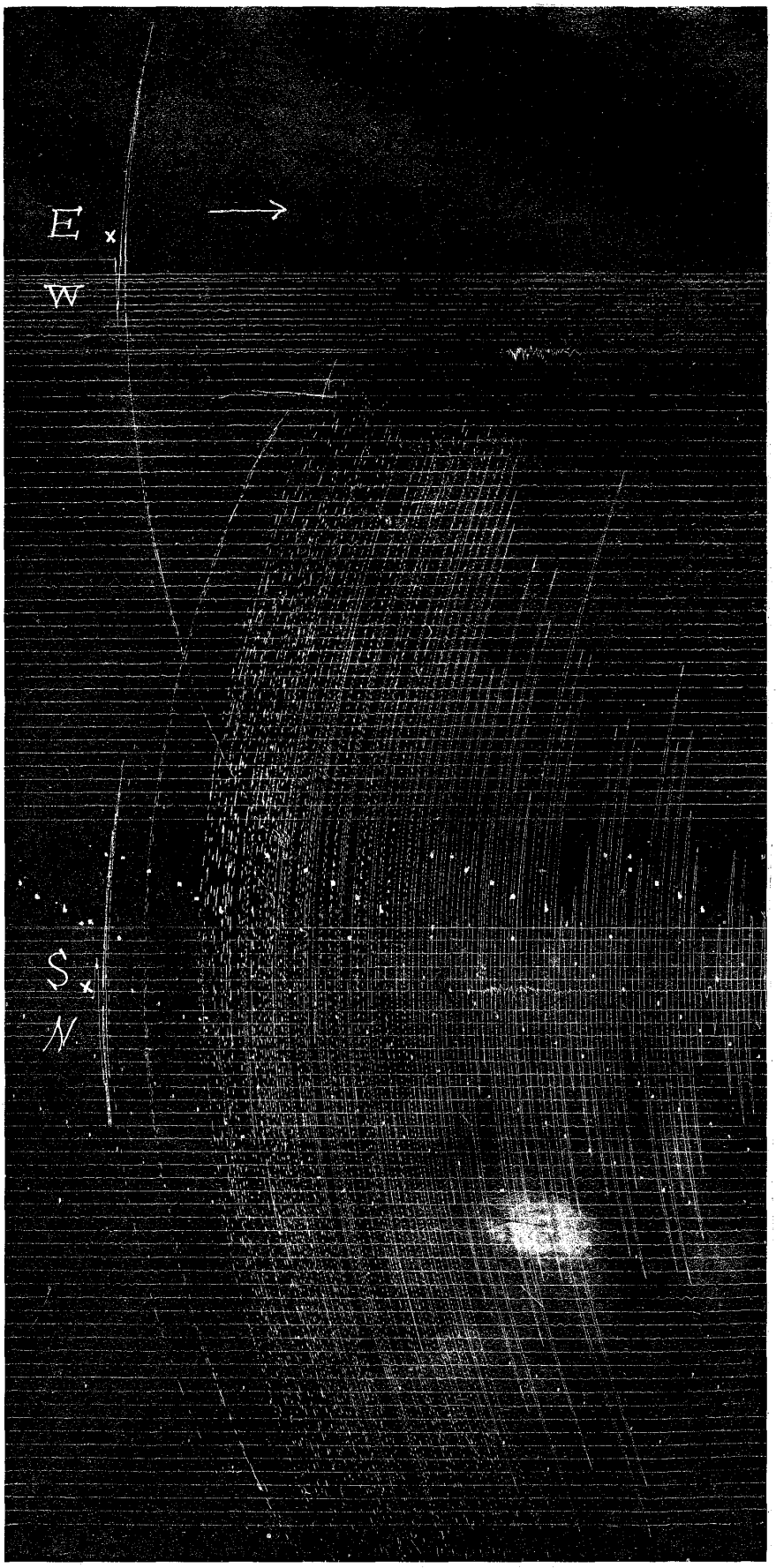
(×).....Earthquake Commencement.

Small white dots are successive minute marks.

Fig. 10. The 1st Destructive Omachi Earthquake, on Nov. 11, 1918, at 2.58 A.M.

Horizontal Pendulum Tromometer Record at the Nagano Meteorological Observatory.

Multiplication = 60.



(×).....Earthquake Commencement.

Small white dots are successive minute marks.

Radial Distance=39.3 km.
1st Displacement of the earthquake motion=0.32 mm.
Direction of the 1st Displacement=S.55°.4W.

The origin of the two destructive earthquakes were thus respectively 35 km. to the S.60°.4W. and 39.3 km. to the S.55°.4W. from the meteorological observatory of Nagano. These distances, representing the radial distances, must be some 1 km. greater than the corresponding epifocal radii. The epicentres thus determined (fig. 12.) coincide almost exactly with the actual positions determined from the field study. (See fig. 2.)

Both from the Tokyo and the Nagano tromometer observations it may be concluded that the 2nd earthquake was at least twice so large as the 1st.

9. TROMOMETER DIAGRAMS. Figs. 6 to 8 are reproductions of the duplex pendulum tromometer register of the two destructive earthquakes and their strongest after-shock observed at the Seismological Institute (Tokyo), each giving the resultant horizontal motion with magnification. In the 2nd destructive earthquake, whose motion was large and caused the writing pointer to be thrown out of the smoked paper at the commencement of the principal portion, the initial displacement was clearly directed toward the seismic origin, the average direction of motion in the prelimary tremor being N.66°.6W. and S.66°.6E. In the case of the 1st destructive earthquake and the after-shock, the motion was smaller and was registered completely, without throwing the pointer out of the smoked paper. In figs. 7 and 8, *a* marks the beginning of the earthquake motion, and the interval of about 1^m 50^s between *a* and *b* belongs to the longitudinal wave. The latter class of movement was again markedly indicated at *c* about 4^m 12^s after the start. This second group of the longitudinal wave was also shown in the Tokyo seismograms of the strong Asama-yama earthquake of July 16, 1912, where the time interval between its appearance and the commencement of the earthquake motion was 3^m 35^s.* The second longitudinal group whose propagation velocity was very low and amounted to some 0.6 km. per sec., may be the effect of the propagation of seismic disturbances through the inner magmatic mass.

Figs. 9 and 10 represent the portable tromometer registers at the Nagano meteorological observatory. The initial displacement pointed in each case clearly toward the origin.

10. CRACKS AND SLIGHT DEPRESSION OF GROUND. In the Omachi earthquakes in question there was no surface manifestation of well

* See the Bulletin of the Imp. Earthq. Inv. Comm., 7, No. 3, Pl. XLIV.

defined faults or dislocation of the ground. There were, however, some cracks of long extension with an accompaniment of vertical disturbances. Thus in the Tokiwa-mra district the crack 2″.5 in maximum width stretched in the direction of N.30°E.—S.30°W., through the village ground and mulberry fields, for the distance of about 1 km. from Osaki to a place called Butai and thence further to Nagabata, where a landslip was produced; there being at some places several lines formed parallelly within the breadth of 10 to 20 feet. The crack zone indicated the area of a slight relative depression, of maximum amount 6″, always on its E.S.E. side. Again another crack, 1″ in width, was formed in the direction of N.73°W. and S.73°E. for the distance of 400 metres across the cultivated field to the south of Shimizu temple in the Shimizu district of Tokiwa-mra, with a slight depression of 1″ to 2″ on its N.N.E. side. (See fig. 2.) These two crack lines were different from the ordinary fissures formed along roads, river banks, or cliffs, and may be supposed to mark the western boundary of the area of apparent depression, being the result of the level disturbances at the epicentral area.

11. DIRECTION OF MOTION IN THE EPICENTRAL AREA. At the localities of Reishoji, Jokoji, and the Yamashita temple, in the meizoseismal area the stone-lanterns were overturned by 3 A.M. shock on the 11th, while the displacement of the pedestals and temple gates took place on the occasion of the 4 P. M. shock on the same day. Again, the overturning and other seismic damage at the different districts of the Tokiwa village were entirely due to the 2nd earthquake. The mean overturning and sliding directions at different places in the strongly shaken area were as follows.

Reishoji Temple. By the 3 A.M. earthquake were overturned a cylindrical stem stone lantern toward N.15°E. and 6 square stem stone lanterns toward S.6°E.; S.5°W.; N.5°E.; S.45°W.; S.30°W. Fifteen circular section tombstones were overturned toward S.20°W.; S.20°W.; S.40°W.; S.40°W.; S.40°W.; S.20° E.; S.20°E.; N.25°W.; N.15°W.; N.20°W.; N.20°W.; S.15°E.; S.15°E.; S.35°E.; S.10°E. A shed consisting of a roof supported by 4 posts was thrown toward S.20°W. In the 4 P.M. earthquake there were three cases of sliding of pedestals of stone lanterns, respectively toward N.; N.; S.71°E.

Matsuzaki. 4 stone lanterns were overturned toward S.E.; S.E.; S.5°W.; S.40°W. The roof covering of a dozo was overthrown toward N. A stone monument structure was thrown toward S.

Omachi. At the Omachi station of the Matsumoto and Omachi Light Railway (gauge=3′ 6″) in the southern part of the town, a train without engine, and composed of 6 cars, with the breakvan secured, was lying along the platform parallel E.–W.; the two goods wagons at the end being each 18′

long and 7′ wide. By the earthquake shock at 4 P.M. the last car, 4.75 tons in weight, was thrown 0.65 foot off the rails and landed on the sleepers toward the S. The last but one car, 4.86 tons in weight, was also partly derailed toward the same side. The rails of 40 lbs. type were 3″.5 in height, the top width being $1\frac{1}{8}$″.

At the Dansei-ji temple (彈誓寺) in the S.W. part of Omachi, 5 stone-lanterns were overturned toward S.35°E., S.8°E., N.12°W., S.35°E., S.65°E., while tomb stones were overturned as follows :— 26 toward W., 6 toward E., 6 toward S., and 4 toward N. In two cases the sliding took place toward N. and toward N.70°E. At another temple, the Tensho-ji (天正寺) in the same part of the town, the directions of overturning of 12 stone-lanterns and tomb stones were : S.E., E., E., S., S., W., E., S., E., W., W., and N.60°E. The sliding took place in two cases toward S.E., and toward S.31°E.

At the Oji temple (王子若一ノ宮) in the northern part of Omachi, 4 stone lanterns had their round ball tops thrown respectively toward S.20°W., S.10°E., N.8°W., and S.55°W. Three stone lanterns were overturned toward E., S.40°E., and S.70°E. In one case the sliding took place toward S.55°W. The stone temple fence was uniformly thrown toward the E. by the 4 P.M. earthquake. At a street corner nearby 2 stone lanterns were overturned toward E. and toward W., by the 3 A.M. earthquake.

At the temple Rokkakdo (六角堂) immediately to the S. of Omachi, the sliding of a tomb stone pedestal was directed toward S.57°E.

Matsuzaki. 4 stone lanterns were overturned toward S.E., S.E., S.5°W., and S.40°W. A small stone shrine was overthrown toward S.

Yamashita temple, Jokoji. By the first earthquake, two cylinder-stem stone lanterns were overturned toward N.35°W. and S.63°W., and six square-stem ones toward N.25°E., N.15°E., N.10°E., S.55°W., N.5°W., and N.60°E. The direction of the sliding caused by the second earthquake were as follows :— the pedestals of two stone-lanterns displaced toward N.56°E. and N.E.; a wooden *torii* (Shinto gate) displaced toward E.

Table II. Direction of Overturning and Displacement of Bodies.

Locality.	1st Earthquake. (2.58 A.M.)	2nd Earthquake. (4.03 P.M.)	
	Overturning.	Displacement.	Overturning.
Reishoji (靈松寺), N.E. from Omachi.	S.	S.75°E.	—
Omachi (大町), W. and S. parts.	S.35°W.	E.	—
Omachi Railway Station.	—	(Two cars of a train at rest derailed towards the S.)	
Oji (王子若一宮), N. from Omachi.	S.35°W.	—	S.72°E.
Rokkakdo (六角堂), S. „ „	S.40°E.	S.62°E.	—
Ohara (大原町), N.W. „ „	S.14°E.	—	—
Matsuzaki (松崎), Yashiro-mra.	N.19°E.	—	—
Jokoji (常光寺) , „	N.19°E.	N.65°E.	—
Kirikbo (切久保), Yasaka-mra.	—	—	N.45°W.
Ippongi (一本木), Tokiwa-mra.	—	N.	N.E.N.
Shimizu and Nakahara, (清水, 中原)	—	N.80°E.	S.58°E.
Shingyo (新行), Mima-mra.	—	N.45°E.	E.

Tokiwa-mra. The overturning and sliding in the village districts of Tokiwa were due entirely to the earthquake shock at 4 P.M. on Nov. 11. At the cemetery of Shimizu (清水), the directions were as follows:— 1 cylinder-stem stone lantern was overturned toward N.75°E.; nine tomb stones were overturned toward N.75°E., E., S.10°E., S., E.70°N., S., S.S.E., N.70°W., and S.20°W.; the pedestals of six tomb stones were displaced toward N.75°E., E., N.75°E. (to the amount of 3.2 feet), N.55°E., E., and N.60°E. At the Shimizu temple, a circular section tomb-stone was overturned toward S.40°W., while the sliding of a pedestal amounted to 0.3 foot toward S.20°W. At the Mishima temple (三島神明社), 4 cylinder stem stone lanterns were overturned toward S.25°E., N.70°W., S.20°W., and N.23°W., while the displacement directions were N.W., W., and N.30°W. At Nakahara (中原) three tomb stones were overturned all toward the N.E. At the Ippongi (一本木) temple, two square-stem stone lanterns were overturned toward the N. and N.E., while a sliding took place toward the N.

The mean directions of motion at the different places are given in Table II and are graphically indicated in fig. 2. With respect to the 1st earth-

quake the direction of overturning of bodies has been assumed to represent the direction of the maximum earthquake displacement.

12. ORIGINS OF THE EARTHQKEUAS. In the 1st earthquake, the maximum motion was directed principally toward S. or S.E. at Omachi, Reishoji, Matsuzaki, and the vicinity, while it was toward N.N.E. at Jokoji. From this variation in the direction of motion coupled with the position of the strong motion area before described, the origin of the earthquake in question may be located to the N. of Jokoji and to the S.E. of Matsuzaki, namely, some 2 km. to the S.E. of the district office of Omachi, at the point marked P_1 in fig. 2. (Pl. II).

On the other hand, in the 2nd earthquake, the directions of motion at the different places do not converge toward a common centre but are directed generally toward the east. Now an approximate parallelism or a more or less parallel symmetry of the direction of motion about a horizontal line may be taken as one of the consequences of the geological dislocation or fault formation at the seismic origin. Further, in the present instance, there was no special difference in the intensity of motion at the Shimizu locality of the Tokiwa village and at the Matsuzaki and Jokoji localities of the Yashiro village, separated by a distance of about 6 km. to the N.E. from the former ; the shock in the meizoseismal area being reported as having been essentially horizontal. From these considerations the 2nd earthquake seem to have been caused by an underground disturbance having the line P_1 P_2 (fig. 2.) for its axis. From the direction of motion it may be assumed that the ground about the town of Omachi had been gradually pushed toward the S.W. and reached the limit of stress, when the sudden dislocation finally took place, causing first a displacement toward the same direction, followed by a greater counter motion toward the opposite direction. The vertical disturbance which accompanied this action, probably resulted in the formation of the cracks and the relative depression at Osaki and Shimizu. The origin (P_1) of the 1st earthquake is situated on the axial line P_1 P_2. The main centre of the 2nd earthquake, whose focus extended over the whole length of the latter, seems to be the vicinity of the point P_2. The axis P_1 P_2 forms evidently the S.W. continuation of the Shinano-gawa valley earthquake zone (fig. 1).

13. RECORDS OF OLD OMACHI EARTHQUAKES. The town of Omachi and the vicinity suffered more or less from the great Zenkoji earthquake on May 8, 1847, the great Ansei earthquake of Tokaido on Dec. 23, 1854, and the Matsushiro earthquake on April 23, 1858. At the time of the first named earthquake, the Reishoji temple, on the flank of the sandy hill of the same name, $1\frac{1}{2}$ km. to the N.E. of Omachi, was overthrown and burnt.

At the times of the two latter earthquakes, the after-shocks lasted for several weeks, and the people of Omachi passed more than 10 days in temporary shelters. In these cases, however, Omachi has simply been affected by distant destructive shocks, and not by one properly belonging to the region about the town. As an instance of the latter may be mentioned the Omachi-gumi earthquake in the 4th year of Shotoku (1714).

Earthquake of 1714. The earthquake occurred on April 28, 1714, at about 10 P.M., and was strong in the old so-called Omachi-gumi, or the district under the jurisdiction of Omachi, which included 54 villages in the northern part of the Kita-Atsumi county (province of Shinano) to the east of the river Takase; the total amount of damage amounting to 300 houses totally or partially destroyed, and 56 persons and 46 horses and cattle killed. The motion, which was felt strongly also at the city of Matsumoto, proved destructive at places between the lake of Aoki and the boundary of the province of Echigo in the narrow valley stretching northward from the plain of Omachi through the region of the lakes of Kizaki, Nakatsuna, and Aoki, to the course of the river Hime-kawa. In Chikni-mra (千國村) the mountain flanks at Tsubono-sawa (坪之澤) slid down and buried the houses and the cultivated fields, killing 30 persons and 8 horses and cattle. At Horinouchi (堀之內), 48 houses were destroyed, killing 14 persons and 36 horses and cattle. The number of the houses destroyed was 2 at Uchu (谷中村雨中); 4 at Kruma-mra (來馬村雨中); 4 at Miyamoto; 6 at Kdarise (土谷村下リ瀨); and 2 at Yoshiwo (同村由尾). The Hime-kawa was inuandated, washing away several houses. The earthquake origin seems to have been situated about 10 km. to the N.N.E. of the lake of Aoki.

Iiyama and Matsushiro earthquakes. Four and half years later took place on Oct. 5, 1718, a local destructive earthquake which caused damage at and about the town of Iiyama in the extreme N.E. part of the province of Shinano. More recently there occurred on April 23, 1858, at 8. A.M. another local shock, some distance to the S.E. of the city of Nagano, which caused damage at and about the town of Matsushiro. These two shocks must have been geographically related to the Omachi-gumi earthquake of 1714, although the origins were mutually apart by distances of 35 to 50 km.

14. ZENKOJI CATASTROPHE AND SHINANO-GAWA VALLEY SEISMIC ZONE. The Shinano-gawa valley forms an active seismic zone, along which occurred recently in succession the three great earthquakes of Sanjo, in Echigo (1828), of Sado and Uzen (1833), and of Zenkoji (1847)*.

* See the Bulletin of the Imp. Earthq. Inv. Comm., **1**, No. 3, and **2**, No. 2.

Of these the last was an extensive and an unusually violent seismic disturbance, being much greater than the two others.

15. LOCAL DESTRUCTIVE SHOCKS AND THE SEISMIC ZONE OF HIME-KAWA AND TENRYU-GAWA. Beside the three great earthquakes mentioned in the preceding §, there were other strong shocks in the province of Shinano, as indicated in the following table.

Date.	Strongly Shaken District.
	[Earthquakes in Recent Years.]
(a) July 23, 1886.	Minuchi (and Higashi Kbiki, in Echigo).
(b) Jan. 7, 1890.	Kami-Minuchi, Higashi-Chikma, Kita-Atsumi, Sarashina.
(c) Jan. 17, 1898.	Kami-Takai, Kami-Minuchi.
(d) Jan. 22, 1899.	Suwa, Kami-Ina, Higashi-Chikma.
(e) Aug. 17, 1912.	Ueda and vicinity.
	[Earthquakes in Old Times. § 14.]
(f) April 28, 1714.	Omachi-gumi, in the N. part of Kita-Atsumi District.
(g) Oct. 5, 1718.	Iiyama and vicinity.
(h) April 23, 1858.	Matsushiro and vicinity.

All of the earthquakes above tabulated were of the catagory of local destructive shocks and far smaller than the Zenkoji earthquake of 1847. The origins of the three disturbances (b), (d) and (f) belong together with that of the strong earthquake of May 18, 1917, in the Shizuoka prefecture, to an earthquake zone extending in the N. and S. direction along the courses of the rivers Hime-kawa and Tenryu-gawa flowing respectively toward north and toward south, on the eastern base of the high mountain range of the Japan Alps. This Hime-kawa and Tenryu-gawa seismic zone is much weaker in energy than the Shinano-gawa valley seismic zone.

16. RELATION TO THE ZENKOJI EARTHQUAKE. The great violence and extension of the Zenkoji earthquake of 1847 was probably due to its occurrence at the intersection of the two seismic zones of the Shinano-gawa valley and of the Hime-kawa and Tenryu-gawa valley, and it is noteworthy that the origins of all the other seismic disturbances in the province of Shinano tabulated in the preceding § were situated around the area of the strongest motion of the Zenkoji earthquake. In other words, the latter forms

a seismic disturbance of fundamental or primary importance causally related to the other destructive earthquakes, both recent and old, which may be regarded merely as geotechtonic events of secondary or auxiliary magnitude. We may presume, therefore, the Zenkoji earthquake to be equivalent to the removal of the main seismic instability existing in this part of the earth's crust, such that the future destructive shocks in and about the region in question will be local in nature and not be excessively violent in intensity. The two Omachi earthquakes on Nov. 11, 1918 also belong to the same class of the seismic manifestation. The frequent occurrence of the comparatively strong after-shocks in the present instance may probably be traced to the secondary nature of the two chief earthquakes themselves.

17. DESTRUCTIVE MOTION AREA. The area within which took place more or less damage to buildings, cracks of the ground, landslips, etc. extended to the lake of Kizaki and the village of Aogai on the north, to the river Sai-gawa on the east, to the Tokiwa-mra and town of Ikeda on the south, and to Rikgo-mra and Aisome-mra on the south-east. The maximum extension was 26 km. in the N. S. direction from the valley districts of the lakes of Kizaki and Aoki and of the Takase river to the eastern hills of Tertiary formation, and to over 16 km. in the E.W. direction from the Sai-gawa to the granite mountains to the west of Omachi. To the west of the Takase-gawa, the ground is hard and is composed of sand and granite masses, the shock being there light except in the vicinity of the epifocal region.

Outside the above-mentioned area, slight damage was produced in a few places, as follows :— At Minuchi-mra, Kamiminuchi district, some roof tiles fell down, wall plasters were shanken off and sliding glass doors were thrown out of their grooves, while at a place called Kokra was formed a ground crack 20 ft long and 2″.5 wide. At Miyamasato (Hisato-mra) in the same district a two-story *dozo* ware-house $12' \times 24'$ in size was thrown down. At Ooka-mra, in Sarashina district, some rock masses were detached from cliffs by the earthquake at 4 P.M.; no damage being done, however, to buildings. It is likely that the Minuchi-mra localities, lying to the N.E. of the epifocal area of the Omachi earthquakes, were shaken with a comparatively strong intensity on account of their location on the Shinano-gawa valley seismic zone.

18. AREA OF SENSIBLE MOTION. The shock at 3 A. M. on Nov. 11, 1918 was strong within a circular area, about 75 km. in diameter, extending from Iiyama on the north to Matsumoto and Shiojiri on the south, and from the vicinity of Komoro on the east to the confines of the Japan Alps on the west. The motion was, however, felt slightly or weakly within a long narrow zone stretching on the whole along the valleys of the rivers Shinano, Kiso,

Fig. 11. Positions of the Epicentres of the Two Destructive Omachi Earthquakes on Nov. 11, 1918, determined from the Tromometer Observations in Tokyo.

I.....Epicentre of the 1st Destructive Shock.

II..... „ „ 2nd „ „

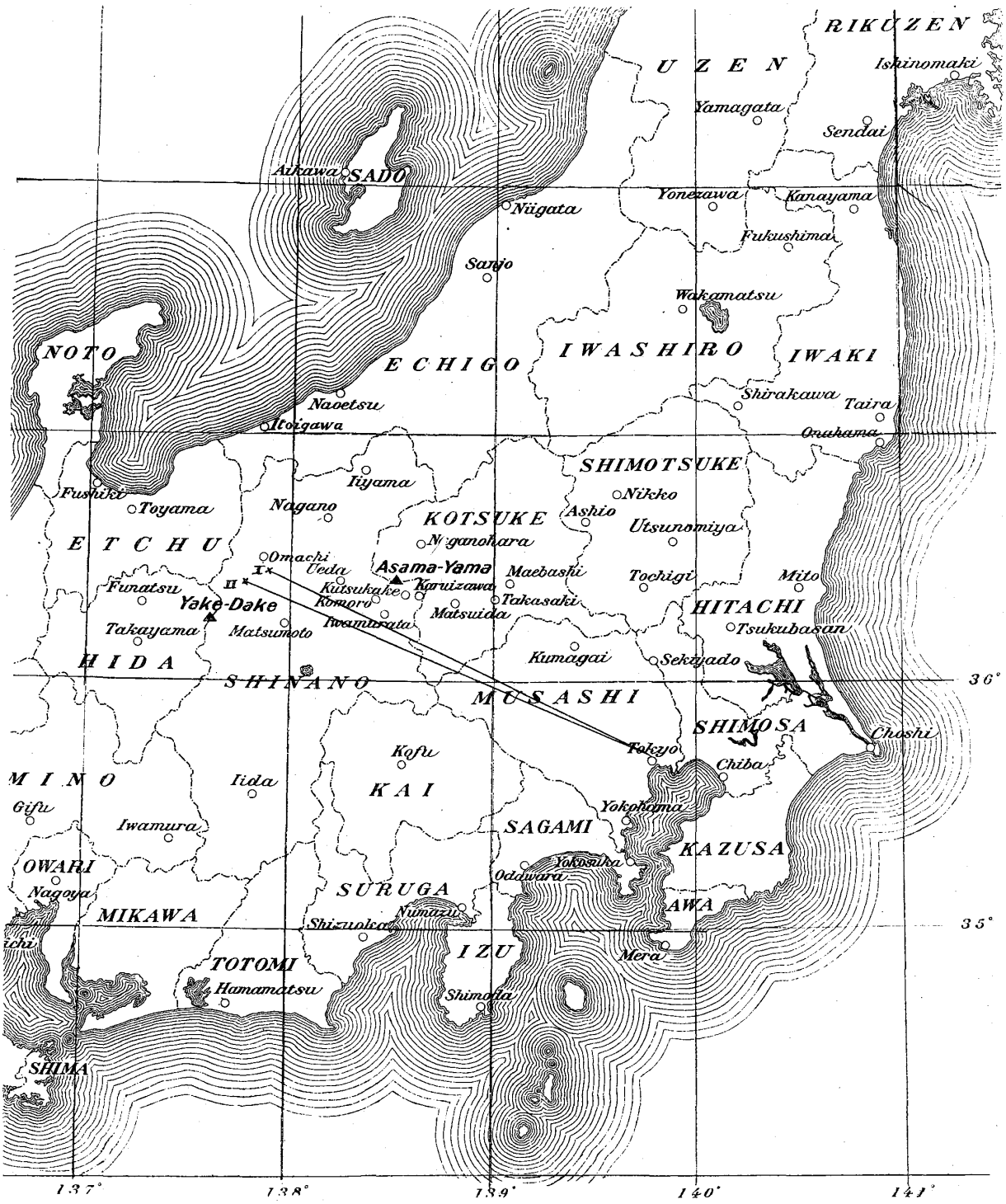
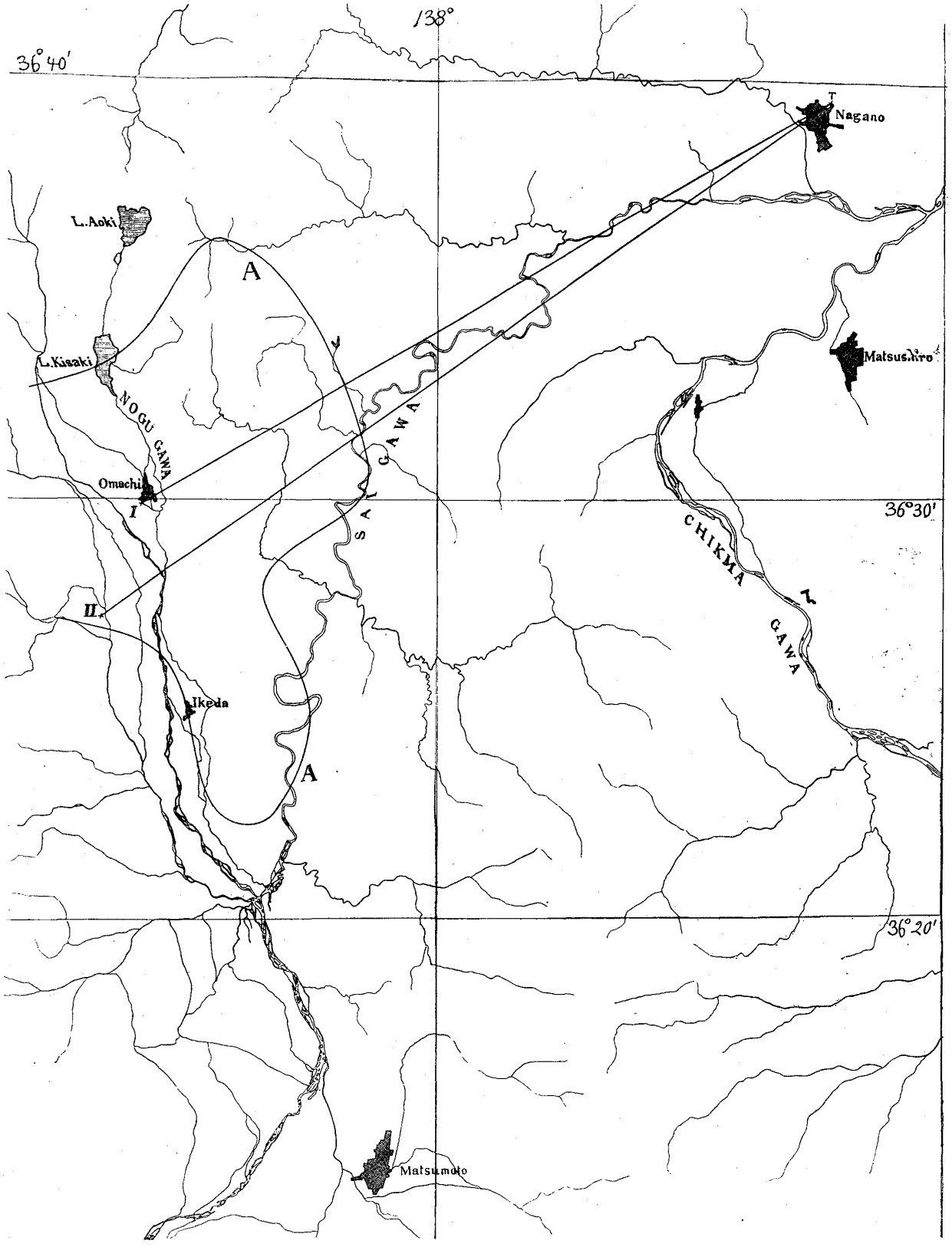


Fig. 12. Positions of the Epicentres of the Two Destructive Omachi Earthquakes on Nov. 11, 1918, determined from the Tromometer Observations at Nagano.

T.....Nagano Meterological Observatory.
I.....Epicentre of the 1st Destructive Shock.
II..... „ „ 2nd „ „



The curve **AA** indicates the area of destructive motion.

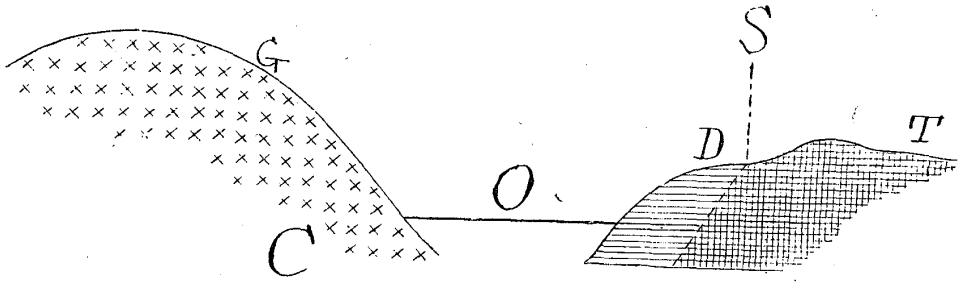
and Tenryu, for the extension of about 450 km. from Niigata on the north to the provinces of Owari, Mikawa, and Totomi on the south. This marked elongation of the earthquake area was probably due to the facility of the seismic propagation along the Shinano-gawa valley and the Hime-kawa and Tenryu-gawa seismic zones.

The strong earthquake on Jan. 12, 1919, at 10 P.M., which caused some damage at Hamamatsu, Shizuoka and the vicinities, originated in the Tenryu-gawa valley at the central part of the province of Totomi, immediately to the south of the centre of the destructive earthquake of Shizuoka prefecture on May 18, 1917. These two disturbances together with the two Omachi earthquakes under consideration indicate the seismic activity manifested from different points of the Hime-kawa and Tenryu-gawa zone.

19. **SOUND AREA.** (Fig. 14.) It was quite characteristic of the Omachi earthquakes of 1918 that their numerous after-shocks were always accompanied with marked *meido*, or earth-sound like that caused by a heavy weight falling on the ground or like a distant booming of gun discharge, when perceived in the valleys of the Nogu-gawa and the Takase-gawa, namely, at the village localities of Matsuzaki and Jokoji (Yashiro-mra), Ippongi, Shimizu and Osaki (Tokiwa-mra), and northwards at Mori and Inao around the lake of Kizaki. It was found out, however, that the earth-sounds could not be heard at several places on the hilly region forming the eastern boundary of the above-mentioned plain of Omachi. Thus at the Kirikbo (Yasaka-mra), only the strongest after-shocks were accompanied by a feeble rushing sound like that of wind blowing, but none was accompanied by a *meido*. Likewise no *meido* was heard at Chishanota, Tabata, Soyama, and other districts lying to the north of the last mentioned place. Going westward from Soyama, the *meido* could be heard first at the Norikoe path on the southern flank of the mount Reishoji. Northwards from Soyama no *meido* could be heard even at Ohshio ; neither was it perceptible at Shingyo (Mima-mra) 6 km. to the N.W. from the latter. At Tera, however, midway between these two places, the *meido* could be distinctly heard. Thus, in the case of the present Omachi earthquakes, the area of the sound perception was clearly demarked from that of the non-perception ; the boundary, as shown in fig. 14, coinciding on the whole with the line separating the diluvial formation of the western edge of the hilly segion at the eastern limit of the Omachi plane and the Tertiary formation adjacent on the eastern side. To explain this phenomenon, it is to be remembered that the seismic *meido*, unlike the detonation of a volcanic outburst made up of sound waves of air, is composed of the minute vibrations of the ground sufficiently quick to be audible to human ears. Now the after-shocks

Fig. 13. Diagrammatic Section representing the Geological Formation of the District about Omachi.

S.....Eastern Boundary Line of the Sound Area.



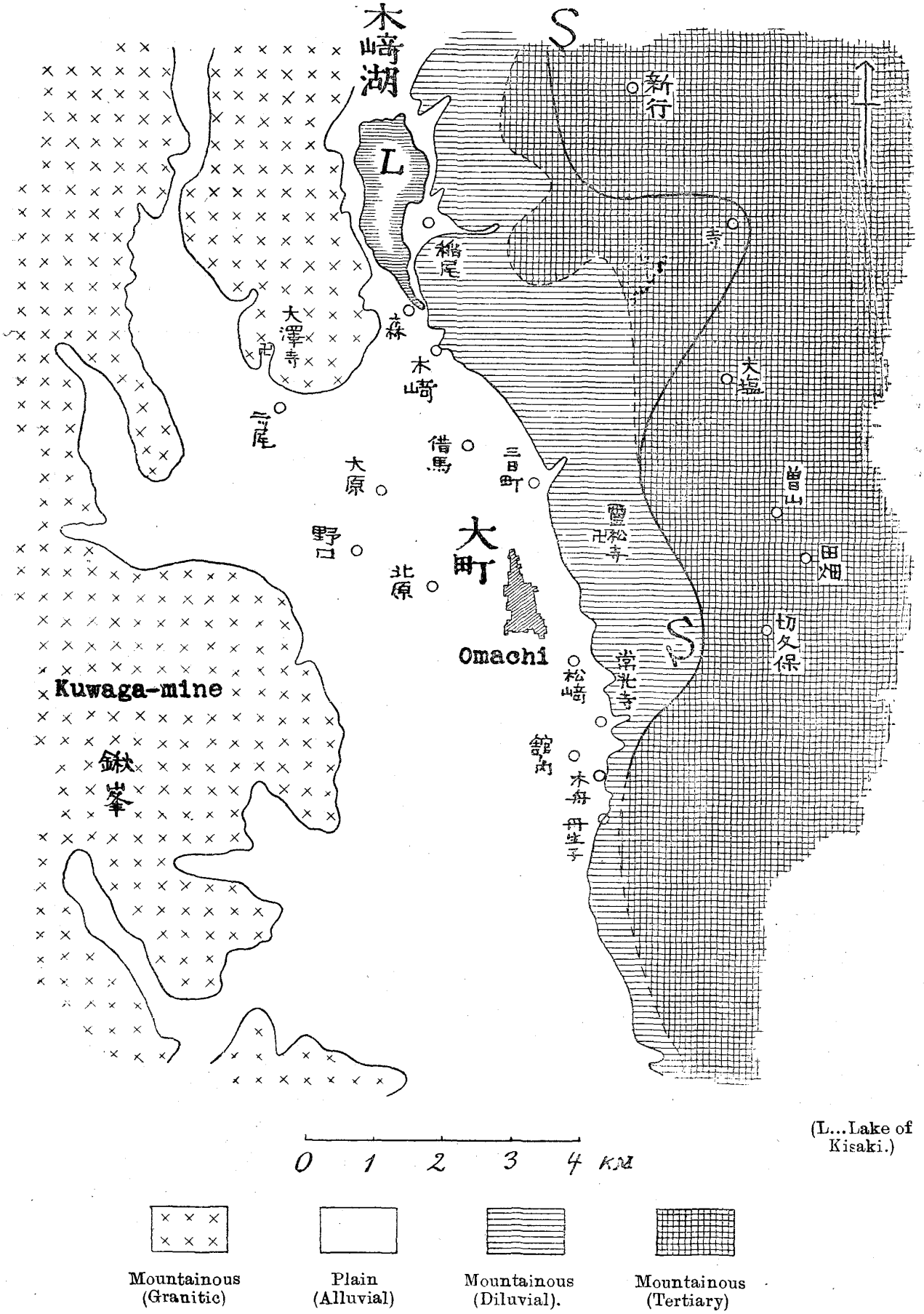
O.....Omachi Plain. G.....Granitic Mountain on the West.
D, T...Respectively the Diluvial and the Tertiary Hills on the East.
C.....Principal Centre of the After-shocks.

under consideration had their main centre at about 4 km. to the S.W. of Omachi (C in fig. 13). As the focal depth was shallow, the minute earth vibrations were propagated into, and caused the *meido* on, the diluvial hills on the east side. These were, however, prevented from penetrating sufficiently into the comparatively hard Tertiary formation, resulting in the absence of the *meido* on the region further eastward. Had the seismic origin existed among the Tertiary mountains on the east side, the *meido* would naturally have been percieved strongly there.

20. **AFTER-SHOCK FREQUENCY.** Table V give the hourly frequency of the after-shocks of the destructive earthquakes on Nov. 11, 1918, registered with a tromometer at the meteorological observatory of Nagano. As the latter place is distant 35 and 39 km. respectively from the centres of the two destructive earthquakes, the list in the table does not contain very small ones among the after-shocks. Still the seismic frequency at Nagano on Nov. 11 amounted to 190; the daily numbers for the two next days being respectively 69 and 50. (See Table IV.) The frequency quickly decreased and was reduced to about 10 or less, totalling to 416 in the course of the 20 days between the 11th and the 30th of the same month. The daily frequency for Omachi, given in Tables IV and V, are based on the reports from the Omachi police station, dating from Nov. 15, which were limited to the sensible shocks and do not include the cases of mere earth-sounds. Yet the daily frequency between the 15th and the 18th (Nov.) was from 25 to 35, aggregating to 112. The total earthquake number tromometrically registered at Nagano during the same 4 days was only 35, or less than 1/3 of that for Omachi. Thus it is

Fig. 14. Map showing the Area of Audibility of Seismic Sounds in the vicinity of Omachi in the days following the Two Destructive Earthquakes on Nov. 11, 1918.

SS.....The Demarkation Line to the west of which the Sounds were head, but to the east of which the Sounds were not perceptible.



(L...Lake of Kisaki.)

probable that the number of the sensible shocks and *meido* at the latter place was over 600 or 700 on Nov. 11, and over 300 or 400 on the next day.

The strong after-shocks clearly registered on the tromometer at the Seismological Institute in Tokyo are indicated in Table III.

Table III. List of the Strong After-shocks.

No.	Date.	Tokyo Observation.	
		Time of Occurrence.	Maximum Motion.
A	**1918** Nov. 11.	2^h 58^m 45^s A.M.	mm 3.3.....1st Destructive Eqke.
1	"	3 16 45 "	0.92
B	"	4 03 40 P.M.	11.8 .....2nd Destructive Eqke.
2	Nov. 12.	0 02 26 A.M.	0.23
3	"	3 34 23 P.M.	0.007
4	"	10 57 31 "	0.068
5	Nov. 13.	0 00 46 A.M.	0.006
6	"	3 53 42 "	0.070
7	"	11 45 04 "	0.071
8	"	11 52 42 "	0.012
9	Nov. 14.	0 57 41 "	0.014
10	Nov. 20.	9 48 55 "	0.020
11	Nov. 25.	4 56 55 "	0.200
12	Nov. 26.	4 05 58 P.M.	0.052
13	"	5 38 56 "	0.113
14	"	10 44 59 "	0.012
15	Dec. 1.	4 11 31 A.M.	0.019
16	Dec. 14.	5 34 43 P.M.	0.240
17	Dec. 21.	7 42 00 "	0.280
18	**1919** Jan. 21.	6 15 00 "	At Omachi, this was felt pretty severely and resulted in damage to porcelain, some people trying to run out of doors. In Tokyo the pulsatory oscillations which existed at the time confused the record. Yet it is clear that this shock was not so large as Nos. (2), (11), (16), and (17). The origin was probably right under the town of Omachi.

According to the Table III, excepting (1) which succeeded immediately the 1st destructive earthquake (A), the strongest after-shock was (17) which happened on Dec. 21st, namely, 40 days after the commencement. The three previous shocks (2), (11), and (16), were somewhat smaller. All these different disturbances, though not destructive, were fairly strong at Omachi and the vicinity. The occurrence of the predominant after-shocks is probably due to the general stress accumulation in the region to the S.W. of the meizoseismal area of the Zenkoji (1847) earthquake, the neighbourhood of the epifocus of a great destructive earthquake becoming frequently the seat of small local destructive shocks.

21. FREQUENCY FLUCTUATION OF AFTER-SHOCKS. From fig. 19, based on Table V, it will be seen that the daily frequency of the after-shocks observed at Nagano and Omachi was rather greater with high barometric pressure. Again, from fig. 17, which illustrates the course of fluctuation in the hourly seismic frequency observed at Nagano on Nov. 11th and 12th, it will be noted that the after-shocks of the destructive earthquake on the 11th, at 3 A.M., reached the maximum already between 7 and 11 o'clock in the same morning; the subsequent increase in the frequency being evidently preparately to the 2nd destructive earthquake at 4 P. M. on the same day. The number of the after-shocks which took place during the 7 hours subsequently to the occurrence of the 2nd destructive earthquake was 105, while that for the 1st destructive earthquake during the equal time interval was 57. These two numbers are in the ratio of 2 : 1 nearly.

Fig. 18 shows the quick rate of decrease in the daily frequency of the after-shocks observed at Nagano.

22. DIURNAL FREQUENCY VARIATION. Figs. 15 and 16, based on Tables III and IV, illustrate the diurnal frequency variation of the after-shocks at Nagano and Omachi respectively. The list of the shocks prepared by the Omachi Police Station, not being the result of an instrumental observation, is to be regarded as not furnishing proper material for the study under consideration. The instrumental observation at Nagano made subsequent to Nov. 12, 1918, indicates the principal frequency minimum between 2 and 3 P.M. and another between 2 and 3 A.M. It was just at these minimum frequency hours of the day, that the two destructive earthquakes took place. According to the tromometer observation in Tokyo, the 18 strong after-shocks registered there indicate a diurnal frequency variation similar to that for Nagano, being more numerous about noon, midnight, 4 A.M., and 5 P.M., as follows :

Hour.	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
A.M.	3	0	0	2	2	0	0	0	0	1	0	2
P.M.	0	0	0	1	1	2	1	1	0	0	2	0

Diurnal Variation of the Frequency (=y) of the Omachi After-shocks.

Fig. 15.

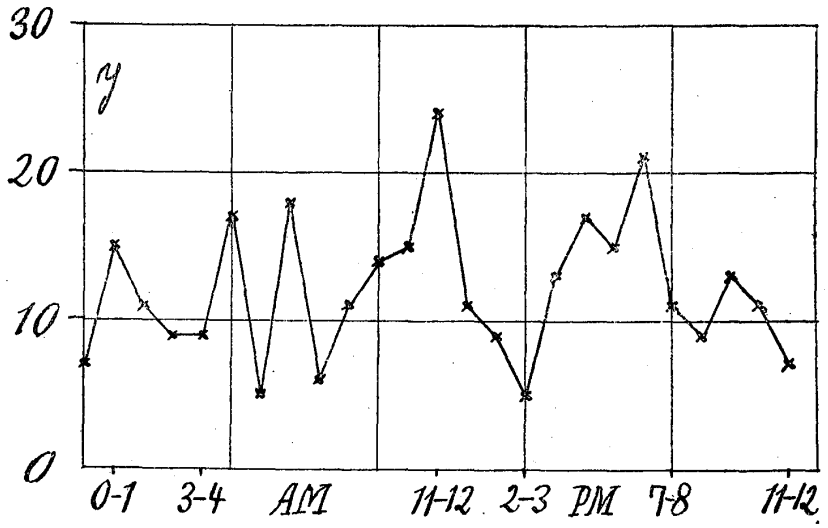


Fig. 16.

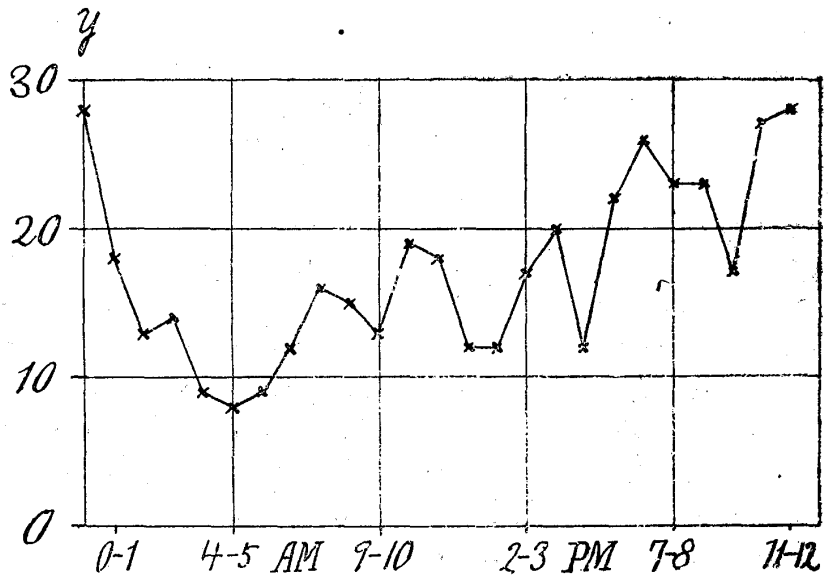


Fig. 15. Earthquakes instrumentally registered at the Nagano Meteorological Observatory.

Fig. 16. Sensible Earthquakes observed at Omachi Police Station.

Table IV. Diurnal Distribution of the Omachi After-shocks.

Hour.	Earthquakes instrumentally registered at Nagano Meteor. Observatory.*		Sensible Eqkes observed at Omachi Police Station, Nov. 15, 1918 to Jan. 24, 1919.
	Nov. 11, 1918.	Nov. 12, 1918 to Feb. 28, 1919.	
0 — 1 A.M.		15	18
1 — 2		11	13
2 — 3	1	9	14
3 — 4	29	9	9
4 — 5	14	17	8
5 — 6	2	5	9
6 — 7	4	18	12
7 — 8	1	6	16
8 — 9	6	11	15
9 —10	1	14	13
10 —11	1	15	19
11 —12	5	24	18
0 — 1 P.M.	6	11	12
1 — 2	1	9	12
2 — 3	1	5	17
3 — 4	7	13	20
4 — 5	29	17	12
5 — 6	29	15	22
6 — 7	14	21	26
7 — 8	9	11	23
8 — 9	9	9	23
9 —10	7	13	17
10 —11	7	11	27
11 —12	7	7	28
Total	190	296	403

* The frequency given in this table is the result of a careful re-examination of the original Nagano tromometer diagrams, and is in some instances higher than that reported by the Nagano meteorological observatory.

Table V. Mean Daily Barometric Pressure at Matsumoto compared with Daily Frequency of the Sensible Earthquakes observed at the Police Station of Omachi and of the Earthquakes registered instrumentally at the Meteorological Observatory of Nagano. Nov. 1918–Feb. 1919.

Day.	Barometric Pressure at Matsumoto. 700 mm +				Sensible Earthquakes at Omachi.			Eqkes instrumentally registered at Nagano.*			
	1918 XI	1918 XII	1919 I	1919 II	1918 XI	1918 XII	1919 I	1918 XI	1918 XII	1919 I	1919 II
1	20.2	16.9	8.6	15.3		6			2	2	0
2	16.7	15.3	5.0	16.5		7	2		1	2	0
3	12.2	15.9	7.9	13.0		4	2		3	2	0
4	17.1	15.4	9.4	6.0		6	2		2	3	1
5	13.3	14.3	11.5	14.5		3	1		1	1	0
6	6.0	14.5	16.1	20.8		11	1		3	1	0
7	10.1	10.3	18.2	17.5		3			2	0	0
8	12.8	8.5	18.2	14.1		1			0	0	0
9	13.7	11.9	12.8	15.5		4			3	2	1
10	9.3	15.5	13.7	7.5		1			0	2	2
11	14.1	9.2	11.0	8.7		1	1	118	1	0	0
12	20.5	4.3	4.4	14.5		9	1	69	2	0	0
13	24.1	9.6	4.7	19.8		3		50	2	0	1
14	12.8	5.3	11.2	9.1		6		12	11	1	0
15	13.3	8.6	11.8	14.8	25	5	3	14	2	1	0
16	17.8	14.5	13.3	16.7	27	0		12	0	0	0
17	14.7	14.0	15.7	12.9	35	0	2	4	0	1	0
18	9.2	16.5	16.3	10.0	25	1		7	1	0	0
19	9.7	17.7	5.3	5.6	17	2		1	0	0	1
20	14.4	12.5	3.0	11.1	15	1		8	0	1	0
21	16.4	17.2	4.3	12.8	18	5	7	3	5	2	0
22	11.7	14.5	7.1	5.1	15	6	1	4	6	1	0
23	8.5	12.4	12.7	3.5	16	—	—	5	1	0	1
24	9.7	16.6	14.5	7.0	17	—	1	3	0	1	0
25	12.7	15.6	9.9	7.3	19	—	—	6	2	0	0
26	14.3	13.0	13.2	11.6	24	—	—	9	0	0	1
27	12.2	10.4	14.8	11.4	15	—	—	8	0	4	0
28	16.7	12.7	14.5	9.2	10	—	—	4	0	0	1
29	22.5	12.2	14.5		15	2	—	4	0	0	—
30	21.6	13.6	12.3		6	6	—	3	2	1	—
31		15.5	12.1		—	1	—	—	0	0	—
Total					310	83	24	344	52	28	9

* The frequency is the daily number of earthquakes reported by the Nagano Meteorological Observatory.

Table VI. Hourly Frequency of the Earthquakes instrumentally registered at the Meteorological Observatory of Nagano. Nov. 11–30, 1918.

Hour. \ Day.	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A.M.																				
0 — 1	—	8	1	1	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0
1 — 2	—	4	0	1	2	1	0	2	0	0	0	0	0	0	0	0	0	0	1	0
2 — 3	1	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 — 4	30	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
4 — 5	14	1	5	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0
5 — 6	2	2	1	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
6 — 7	4	1	1	2	5	0	0	0	0	2	0	0	1	0	0	0	2	0	0	1
7 — 8	1	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
8 — 9	6	2	1	1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	1	0
9 —10	1	2	4	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	1
10 —11	1	4	4	0	0	0	2	0	0	1	0	0	1	0	0	2	0	0	0	0
11 —12	5	4	9	0	0	0	1	3	0	0	0	1	0	0	1	0	0	1	0	0
	65	39																		
P.M.																				
0 — 1	6	1	4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 — 2	1	0	5	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2 — 3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 — 4	7	1	0	0	1	2	0	0	0	0	0	0	0	1	0	0	0	0	1	0
4 — 5	30	5	2	2	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0
5 — 6	29	1	2	0	2	0	0	0	0	1	0	1	0	0	0	2	1	0	1	0
6 — 7	14	7	2	0	0	2	0	0	0	0	0	0	1	0	1	0	1	0	0	0
7 — 8	9	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
8 — 9	9	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9 —10	7	3	1	1	0	0	0	0	0	0	0	0	0	0	2	1	2	1	0	0
10 —11	7	4	1	1	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0
11 —12	7	2	2	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0

Table VII. Hourly Frequency of the Sensible Earthquakes observed at the Police Station of Omachi. Nov. 11–30, 1918.

Hour. \ Day.	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
A.M.																				
0 — 1	—	3	—	—	3	0	1	2	2	1	0	0	1	0	0	3	1	0	0	0
1 — 2	—	5	—	—	2	0	0	1	2	0	0	0	0	4	0	0	0	0	1	0
2 — 3	—	3	—	—	0	0	0	2	2	1	1	0	3	1	0	0	0	0	1	0
3 — 4	—	—	—	—	0	1	0	0	1	0	1	0	1	0	0	0	1	0	2	0
4 — 5	—	—	—	—	0	0	0	1	1	0	0	0	0	0	2	0	0	2	0	1
5 — 6	—	—	—	—	0	3	1	0	0	0	1	0	0	0	0	1	0	0	1	0
6 — 7	—	—	—	—	1	0	0	0	1	0	1	0	1	0	3	0	2	0	1	1
7 — 8	—	—	—	—	2	1	0	1	0	0	0	0	0	4	2	0	0	1	1	1
8 — 9	—	—	—	—	2	0	0	1	0	1	2	1	0	1	0	0	0	1	1	0
9 —10	—	—	—	—	2	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1
10 —11	—	—	—	—	2	1	1	0	1	1	2	3	0	0	1	2	1	0	1	0
11 —12	—	—	20	—	0	0	1	4	0	0	0	3	0	0	2	0	0	1	0	0
P.M.																				
0 — 1	—	—	—	—	2	0	2	0	1	2	1	0	1	0	1	0	0	0	0	0
1 — 2	—	—	—	1	0	1	0	1	3	1	0	1	0	0	0	1	1	0	0	0
2 — 3	—	—	15	0	2	0	2	1	0	2	0	1	1	2	0	0	0	2	0	0
3 — 4	—	—	—	0	3	1	2	2	0	0	0	2	1	3	0	0	0	0	0	0
4 — 5	—	24	—	3	0	2	1	0	0	0	1	0	0	0	0	2	0	0	1	0
5 — 6	—	—	—	0	0	0	6	0	0	1	1	1	1	0	0	4	1	0	1	0
6 — 7	39	—	—	0	2	2	4	0	0	0	0	1	1	0	1	4	1	1	2	0
7 — 8	48	—	—	1	1	2	1	0	1	1	3	0	0	0	1	2	1	1	0	1
8 — 9	—	48	—	0	0	5	4	0	0	1	0	1	1	1	0	2	0	0	1	0
9 —10	—	1	—	2	0	4	0	0	0	0	0	0	0	0	2	1	2	1	0	0
10 —11	—	30	—	3	0	1	0	4	0	1	2	1	1	0	1	1	2	0	1	1
11 —12	—	—	—	3	1	2	9	4	2	1	2	0	3	1	2	1	2	0	0	0

Fig. 17. Variation in the Hourly Frequency (=y) of the Omachi After-shocks registered instrumentally at the Meteorological Observatory of Nagano.

Nov. 11–13, 1918.

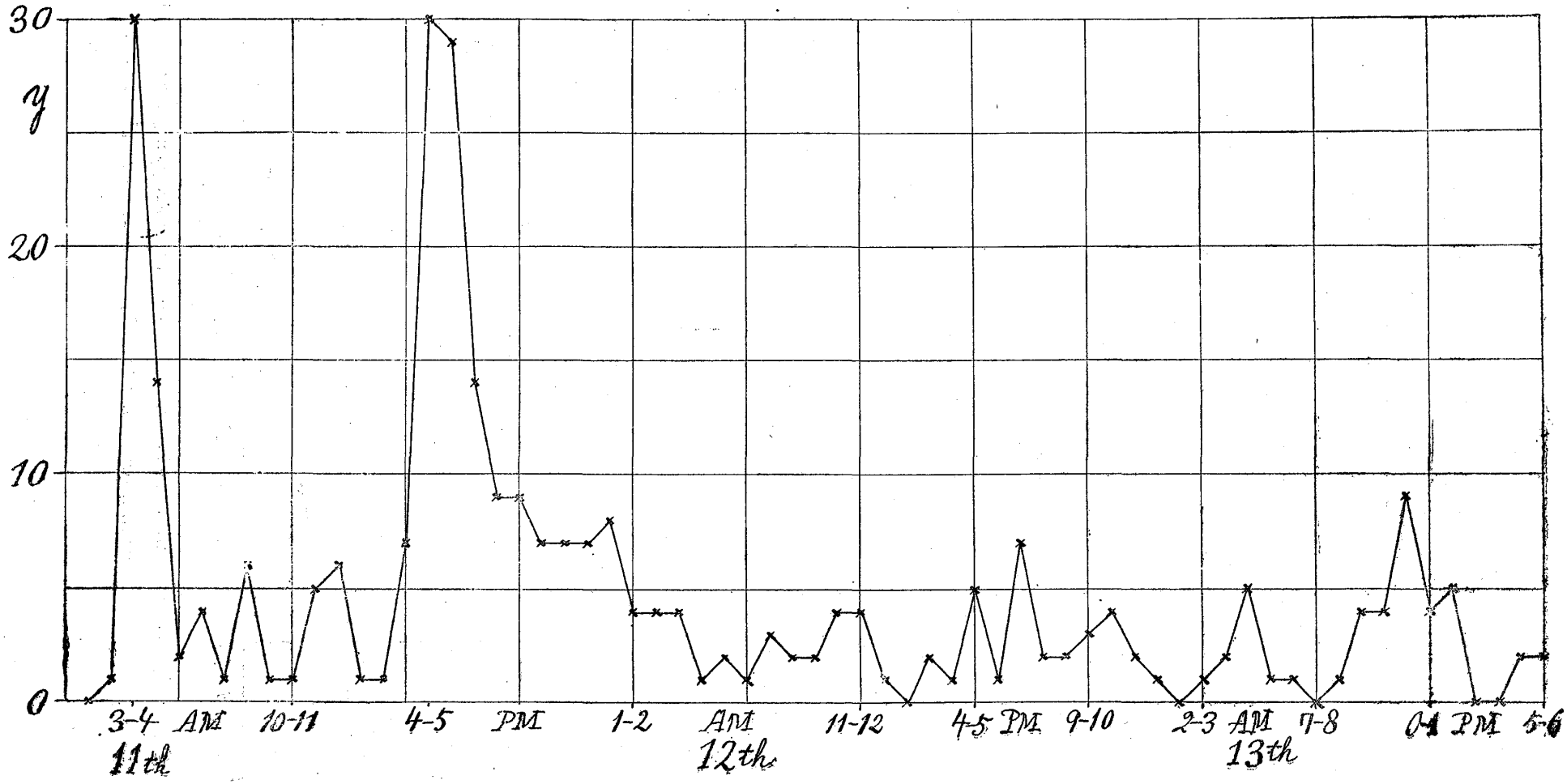
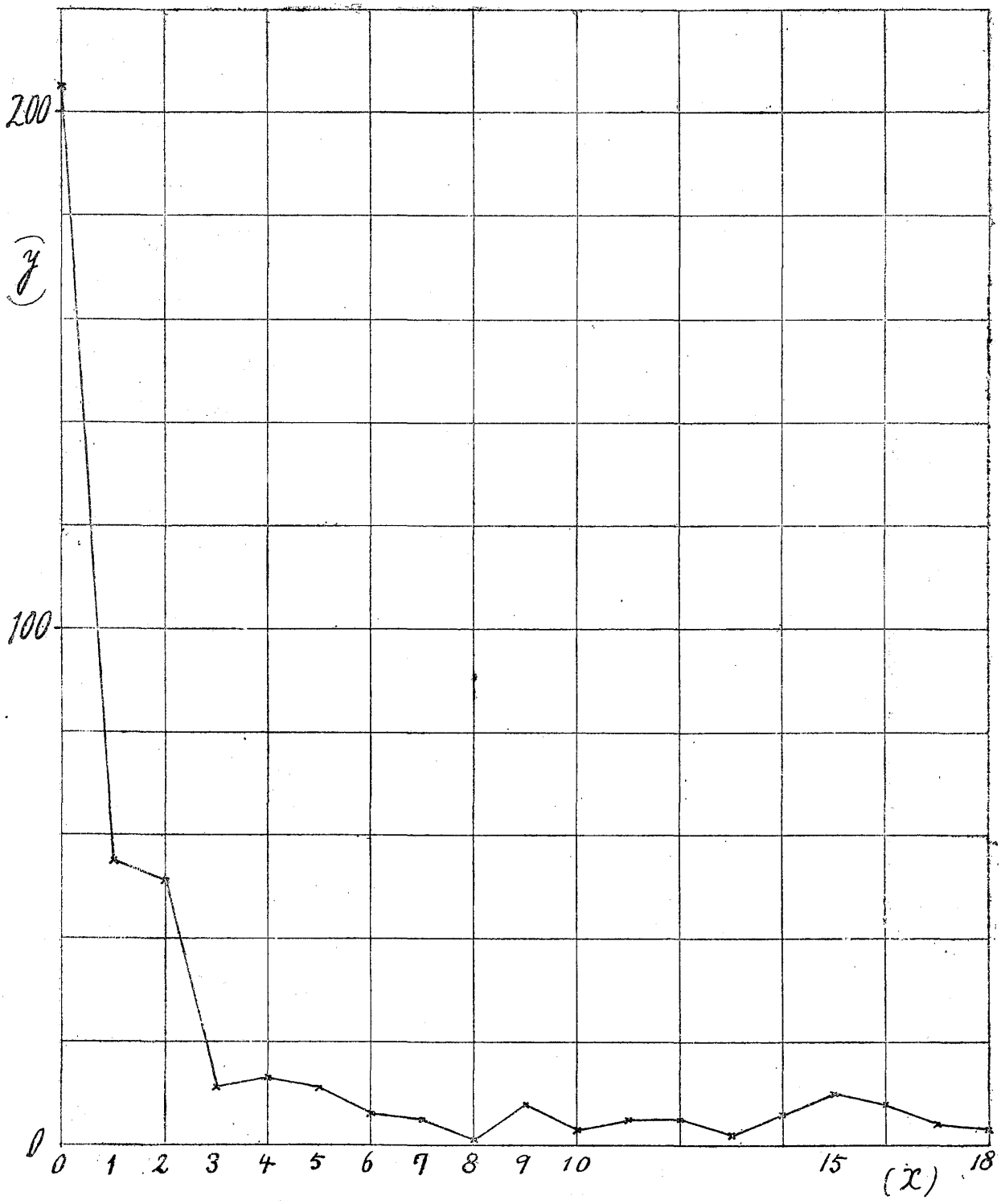


Fig. 18. 24-Hour Frequency Variation of the Omachi After-shocks registered instrumentally at the Meteorological Observatory of Nagano.

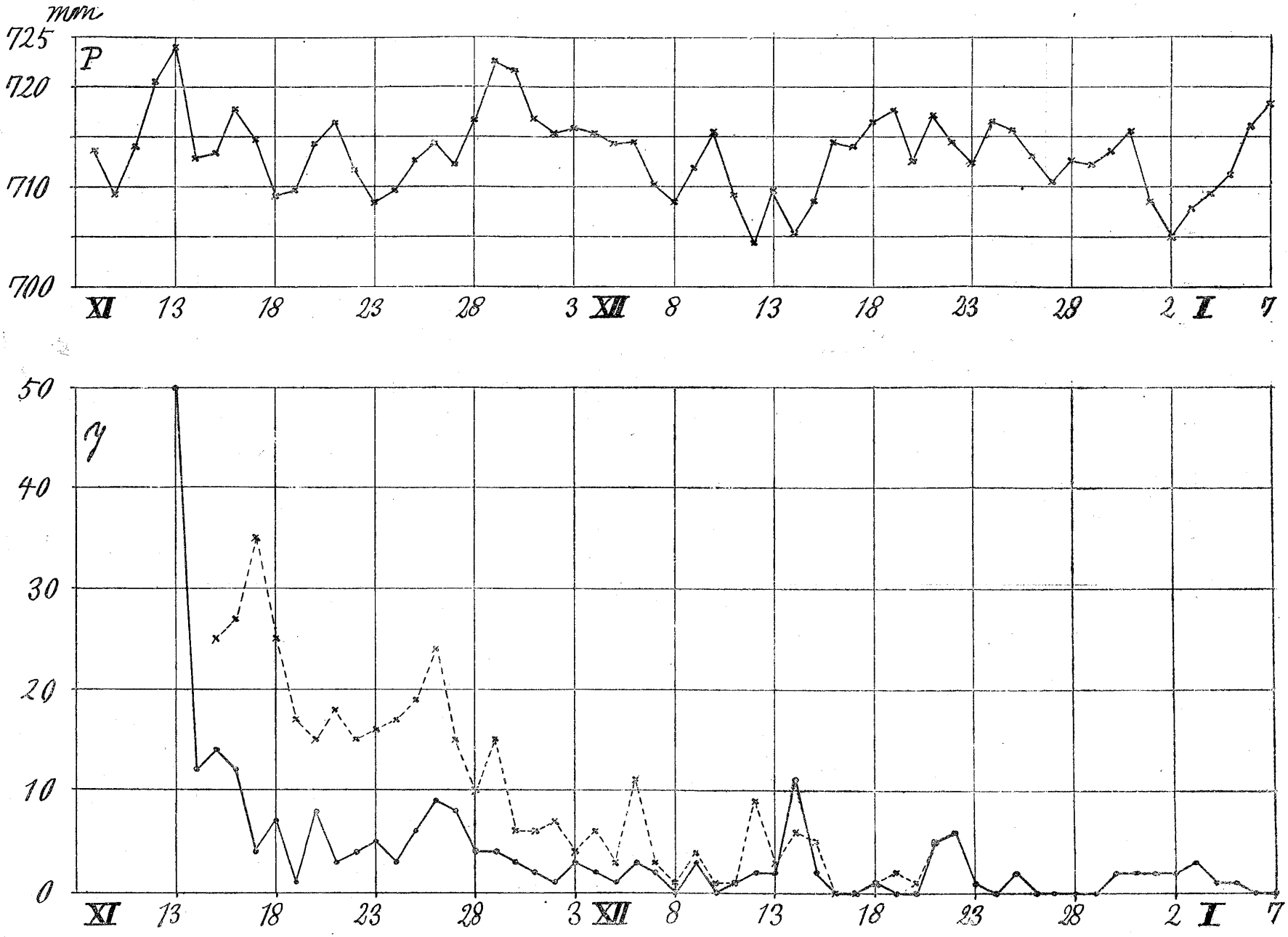


X=Time in unit of 24 hours. y=Seismic Frequency corresponding to x.

x=0.....corresponds to 11th, 3 A.M.-12th, 3 AM., Nov. 1918.

Fig. 19. Daily Seismic Frequency (=y) at Nagano and Omachi compared with Mean Barometric Pressure (=P) at Matsumoto.

Nov. 9, 1918–Jan. 7, 1919.



Dotted and full broken lines refer respectively to Omachi and Nagano Eqke. Frequencies.

23. ORIGIN OF THE AFTER-SHOCKS AND MEIDO. During my stay at the Omachi districts, Nov. 14 to 20, and Nov. 28 to Dec. 5, 1918, I have perceived 155 after-shocks whose daily frequency was as follows :—

Date.	Number of shocks.	Date.	Number of shocks.
Nov. 14th	15 (after 1 P.M.)	Dec. 1st	2
15th	32	2nd	6
16th	30	3rd	3
17th	24	4th	4
18th	18	5th	1 (till 6 A.M.)
19th	13		
20th	7		

The sensible after-shocks were very sharp in nature. Each began with an earth-sound or "meido," *dōn* or *tōn* like the noise caused by the fall of a heavy body on the ground, or *dodo*.....like the peal of a distant thunder, followed immediately after by quick vertical earthquake tremors apparently emanating from under the feet of the observer; the accompaniment of the horizontal component being often insignificant. The time interval between the initial earth-sound and the principal movement, or the duration of the preliminary tremor, was judged to be mostly from 0.5 to 1.0 sec. The duration of the sensible earthquake motion was also short, varying mostly from 1 to 3 sec., as follows :—

Duration of sensible motion.	Number of cases.	Duration of sensible motion.	Number of cases.
under 1 sec.	6	5 sec.	5
1 sec.	17	6 ,,	2
2 ,,	13	7 ,,	2
3 ,,	17	10 ,,	2
4 ,,	3		

At Omachi, the *meido* were most frequently heard toward the S.W. At Matsuzaki, Jokoji and other places on the hilly districts to the east of the Omachi plain, these were heard toward the S.W. or the N.W.; in the neighbourhood of the lake of Kizaki in the north, toward the S. or the S.S.W.; in the vicinity of Ippongi in the south, toward the N.W.; at Nagahata, Osaki,

Nakahara, and other places in the hilly districts to the west of the Omachi plane, toward the S., S.E., or N.N.W. The direction observation may be summarized as follows :—

Omachi	Mostly S.W.
Immediately to the south of Omachi	S.60°W.; W.N.W.; W.S.W.
Vicinity of Takase Bridge	N.; N.W.
Ippongi	N.W.
E. shore of Lake Kizaki (夏期大學)	S.15°W.; S.15°W.
S. end of Lake Kizaki (仁科紀念碑附近)	S.
Ozasa	N to S.
Hirako (一ノ宮)	N.E.; N.E.; S.30°W.; S.60°W.
Matsuzaki	S.60°W.; S.40°W.; S.W.; N20°W.
Jokoji	N.W.; N.40°W.
Nagahata	S.S.E.
Osaki	S.10°E.
Nagahara	N.; N.W.
Ohara	N.70°W.

The principal origin of the after-shocks and *meido* were located in the region lying to the S.W. of the town of Omachi, and did not necessarilly coincide with the centres of the two destructive disturbances themselves ; it being generally true that after-shocks occur most abundantly in the immediate neighbourhood of the epifocus of a great earthquake.

24. TROMOMETER OBSERVATION AT OMACHI. Temporary seismographical observation of the after-shocks was made during the 9 days between Nov. 27th and Dec. 25th, 1918 by means of a portable horizontal pendulum tremor-recorder set up on the concrete floor of the Coronation Memorial Hall in the compound of the Kita-Atsumi District Office, in Omachi. The observation work was carried on by Mr. Y. Takahashi, mechanic of the Seismological Institute, and Mr. J. Nishizawa, director, and Mr. M. Kawazoe, observer, of the Nagano meteorological observatory.

The result of the observation is summarized in Table VIII, from which it will be seen that the duration of the preliminary tremor was sometimes absolutely zero, but in many cases it was about 1 sec., signifying that the distances of the after-shock origins from the town of Omachi varied mostly from 3 to 7 km., with the mean of 5.0 km. The very first displacement of the preliminary tremor was generally directed toward the N.E. or N.N.E., which fact, combined with the observations relating to the after-shocks and the *meido*, indicates that these latter originated at places about 5 km, principally to the S.W. or W.S.W. of Omachi.

Table VIII. Summary of the Tromometer Observations at Omachi.

R=Distance between Omachi and Eqke Origin.
Max. 2a=Maximum Motion.

Time of Occurrence.	Duration of Preliminary Tremor.		R	Max. 2a		1st Displacement of Prel. Tremor.	1st Displacement of Principal Portion.	Duration of	
	E.W.	N.S.		E.W.	N.S.			Princ. Port.	Total Eqke.
					29, Nov.				
	sec.	sec.	km.	mm.	mm.	mm.			
9.30 A.M.	0.9	0.9	5.4	0.066	0.045	0.012→N70°E	——	—	—
11.45 „	—	1.1	6.9	0.044	0.034	——	——	—	—
5.58 P.M.	0?	0?	0?	0.013	0.022	——	mm. 0.017→S36°E	—	—
6.30 „	1.0	1.0	6.0	0.044	0.040	→N45°E	0.030→S45°E	—	—
					30, Nov.				
								sec.	
6.57 A.M.	1.3	1.3	8.6	0.017	0.025	0.005→N72°E	0.020→N43°E	2.0	—
7.30 „	1.0	0.9	5.4	0.047	0.034	0.007→N73°E	0.020→N45°W	—	sec. 4.0
9.48 „	0.6	0.94	3.6	0.058	0.047	——	——	2.7	—
11.45 „	0	0	0	0.038	0.034	0.016→N45°W	——	1.0	—
					1, Dec.				
4.10 A.M.	—	0.77	4.6	—	—	0.149→N75°W	——	—	—
5.00 „	0.96	0.70	4.2	0.15	0.13	0.006→N59°E	——	0.7	—
0.15 P.M.	0.93	0.93	5.6	0.055	0.034	0.004→N14°W	0.026→S71°E	2.3	—
6.35 „	1.00	1.00	6.0	0.15	0.13	0.010→N24°W	——	—	—
					2, Dec.				
2.48 A.M.	0.53	0.53	3.2	0.13	0.12	0.015→S71°E	0.156→N46°W	3.0	9.0
3.00 „	0.80	—	4.8	0.051	0.051	0.012→E	——	1.1	2.5
4.15 „	1.00	0.90	5.4	0.035	0.032	0.014→N69°E	——	—	—
10.38 „	—	0.96	5.8	0.035	0.015	——	——	0.6	—
4.00 P.M.	1.10	1.10	6.9	0.015	0.006	0.010→N82°E	0.015→N71°E	0.3	—
7.00 „	1.40	0.80	4.8	0.020	0.013	0.003→N39°E	——	1.0	—
8.39 „	0.88	0.88	5.3	0.039	0.035	0.012→N66°E	→N45°E	2.0	—

Time of Occurrence.	Duration of Preliminary Tremor.		R	Max. 2a		1st Displacement of Prel. Tremor.	1st Displacement of Principal Portion.	Duration of	
	E.W.	N.S.		E.W.	N.S.			Princ. Port.	Total Eqke.
				3, Dec.					
7.23 A.M.	sec. 1.10	sec. —	km. 6.9	mm. 0.085	mm. 0.082	mm. 0.016→N72°E	mm. 0.099→N66°E	sec. 1.6	sec. 3.5
7.41 „	0.31	0.52	3.1	0.272	0.155	0.012→N26°E	——	3.1	11.0
				4, Dec.					
3.13 P.M.	1.37	1.37	9.0	0.155	0.260	0.020→N41°W	0.178→S29°W	5.5	8.0

25. LEVELING SURVEY BETWEEN MATSUMOTO AND ITOIGAWA. It is well known that the great Mino-Owari earthquake of 1891, the Usu-san eruption in 1910, and the Sakura-jima eruption in 1914 were accompanied by remarkable vertical and horizontal displacements of the ground. In the province of Shinano, noted for its volcanic and seismic disturbances, there were within comparatively recent times the eruptions of the Asama-yama and the Yake-dake and the great seismic catastrophe of Zenkoji (1847). It seemed likely that the present Omachi earthquakes, which occurred in the valley skirting the eastern base of the heavy mountain range of the Japan Alps, might possibly have been accompanied by vertical and horizontal disturbances in the earth's crust of the focal region. As a part of the investigation in this connection there has been instituted, through the liberality of the Imperial Academy, the height revision of the 56 bench marks for the distance of 111.7 km., beginning with B.M. No. 2873 in the city of Matsumoto in the south, thence proceeding northward and reaching B.M. No. 2928 in the town of Itoigawa on the coast of the Japan sea ; the survey work having been finished in the course of 81 days between June 20 and Sept. 9, 1920. The southern portion of the line of the precise leveling is laid through the plane ground, for the distance of 40 km. from Matsumoto to the north of Omachi. Thence the valley narrows and there is formed for the distance of 8 km. a series of three high elevation lakes of Kizaki, Nakatsuna, and Aoki. The Sano-saka at the northern flank of the last named lake forms the water-shed, thence the valley of the Hime-kawa leading northward to Itoigawa. (See fig. 20.)

I must here state my obligations to Major-General H. Matsumra,

Director, Colonel R. Terae, Chief of Triangulation Bureau, and Mr. Y. Hiraki, surveyor, of the Military Survey, who accorded me various kind assistances in this as well as in several former occasions connected with the examination of the topographical changes caused by the seismic and volcanic disturbances. My special thanks are due to Mr. Yoshitoki Ogata, assistant surveyor in the same department, who has carried on the actual leveling survey work.

Notes on the bench marks. The bench marks between Matsumoto and Itoigawa were first set in the years 1891 to 1893, with the exception of Nos. 2906 and 2908, as follows :—

B.M. 2873 (Matsumoto)...set in 1893.
2874–2895..... ,, 1891.
2896–2905..... ,, 1892.
2906 ..... reset in 1906.
2907 .....set in 1892.
B.M. 2908 ..... reset in 1906.
2909–2910 reexamined in 1906.
2911–2913.....set in 1892.
2916–2927..... ,, ,,
2928 (Itoigawa) ..... ,, 1893.

Of the different bench marks, Nos. 2906, 2919–2921, and 2912–2916 had been swept away by floods or buried in soil, while nineteen others suffered some inclination or were slightly damaged, as follows :—

List of the Damaged Bench Marks.* (Notes by Mr. Y. Ogata.)

B.M.	Damaged Condition.	Remark.
2873	Buried 0'.6 under ground.	In city ground; buried in consequence of the filling up of the road. The vicinity had originally been a puddy field.
2874	Slightly inclined toward the eastern side, where there is a ditch 4' deep.	In city of Matsumoto; on the side of a road, with a telegraph post at the distance of 2 feet.
2875	The top of the B.M. stone damaged by fire.	
2879	Exposed 1'.8, with the top spherical portion broken 8 mm.	In the town of Toyoshina. The locality of the B.M., originally a mulberry field, has since been converted into town streets.
2880	Inclined 4°.	Situated only 2' distant from a manure reservoir.

B.M.	Damaged Condition.	Remark.
2881	About 3 cm. uplifted, with a slight inclination.	Probably removed by subsequent road and ditch makings.
2883	Inclined about 11°.	Situated at the eastern side of a road, with a fish pond a few feet further eastwards.
2885	,, 5°.	On a road with puddy fields on both sides.
2886	Inclined about 8°; top portion 4 mm. broken.	
2888	Inclined about 10°; top portion 4 mm. broken.	On a road with houses on both side.
2892	Exposed 1'.8 above the ground.	In the town of Omachi, the road having an inclination in E.W. direction. Due probably to the denudation of the soil.
2893	Inclined about 10°.	On road with puddy fields and ditches on both sides.
2903	Inclined about 8°, with an exposure of 1'.8 above the ground.	On a road, with puddy fields on both sides, 4' lower in level.
2905	*Do.*	,,
2906	Carried away by flood.	
2910	Top portion 4 mm. broken off.	On road, with a mountain slope on the south and overlooking a river on the north; due probably to the falling down of sand and earth.
2911	Buried 0'.6 deep in the ground.	
2918	Lost in consequence of new road making.	
2919–21	Buried in consequence of road making or carried away by flood.	
2922	Top spherical portion 4 mm. broken off.	
2927	Inclined about 20°.	On road, with puddy fields on both sides.

* The five B.M. Nos. 2912–2916, have been restituted in the course of the present survey. The damage done to the top of the B.M. stones was evidently due to the passage over them of the wagons in winter times when the depth of snow accumulation on the road became equal to their height.

26. RESULT OF THE LEVELING SURVEY. Table IX contains the results of the height determination of the bench marks along the line of precise leveling between Itoigawa and Matsumoto. If the B.M. No. 2873 in the latter city be assumed to be unchanged in height, then the B.M. No. 2891 in the town of Omachi had the maximum elevation of 189.6 mm., while the B.M. No. 2928 in the town of Itoigawa on the Japan sea coast must have suffered a depression of 199.3 mm. If, on the other hand, the bench mark at Itoigawa be assumed to have remained unchanged in height, then the ground level at Omachi must have been elevated 388.9 mm. (See fig. 22.) Whichever of these two hypotheses be true, it will be seen that in the south the 16 bench marks Nos. 2873–2888 indicated no marked mutual height changes between the old and the new leveling survey. On the other hand, in the north, on the Japan sea side, the 21 bench marks Nos. 2928 to 2908 indicated a regular continuous mutual height variation. In other words, the tract of 40 km. in length to the south of the town of Itoigawa suffered, a relative northward depression at an average rate of 4 mm. per km., while there was no special relative height change for the distance of 30 km. northwards from the city of Matsumoto. It is, however, remarkable that the central tract of 40 km. from the B.M. No. 2889 to B.M. No. 2907 indicated height disturbances distinct from that of either end portion. Thus, (i) the distance of about 14 km. from the B.M. No. 2889 to B.M. No. 2895 about the town of Omachi is an area of upheaval, the maximum elevation relative to the region adjacent to the south being about 19 cm. On the contrary, (ii) the B.M. Nos. 2896 to 2907, for the distance of 26 km., to the north of the above mentioned elevation area, suffered a depression to the maximum amount of 6.6 to 8.7 cm when referred to the tract of 30 km. to the north of Matsumoto. The contiguity of the (i) elevation and the (ii) depression areas must be the result of the co-related mutual compensation of the upward and the downward displacements of the neighbouring portions in the earth's crust. A similar relation was also found in the case of the great Mino-Owari earthquake of 1891 which was accompanied by the well-defined dislocations of the ground in the mountainous districts amounting to 18 feet both in the horizontal and the vertical direction. In the plain of Mino-Owari, a zone of tract to the east of the line connecting the cities of Nagoya and Gifu was elevated, with the depression rigions on both sides; indicating a maximum vertical disturbance of 1.19 m., of which 0.77 m. was elevation and 0.42 m. was depression. In the Omachi earthquakes, the total vertical displacement in the meizoseismal area was 0.2763 m., of which the elevation was greater than the depression, as was the case with the Mino-Owari earthquake.

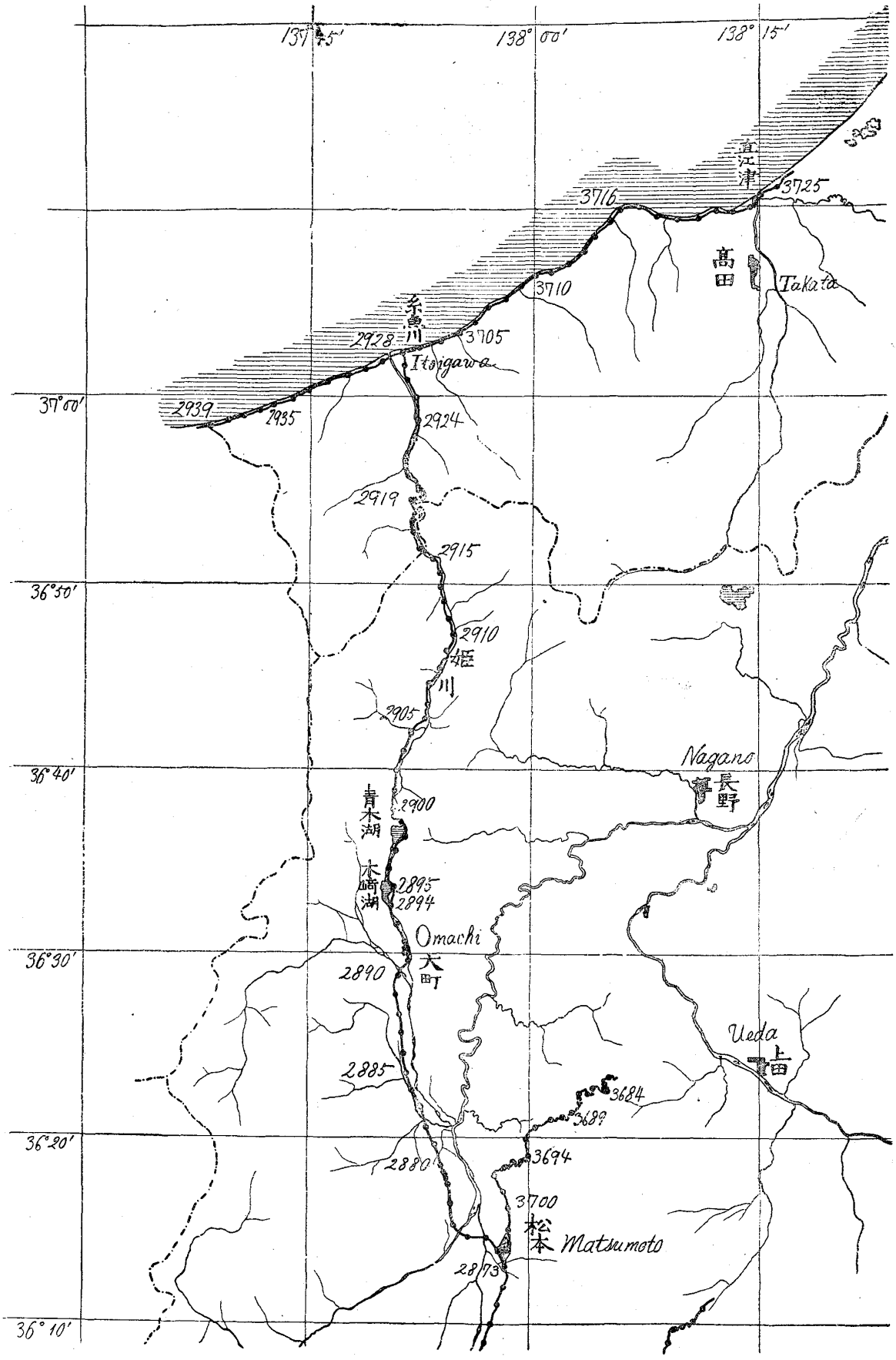
Table IX. Precise Leveling between Matsumoto and Itoigawa: Comparison of the Heights before and after the Omachi Earthquakes of Nov. 11, 1918.

Bench Mark.	(I) Height in 1920.	(II) Height in 1891–3.	Height Difference (I)–(II).	Correction due to an abnormal condition of B.M.	Corrected Height Difference.
	m	m	m.m	m.m	m.m
2873	588.4304	588.4304	0.0	0.0	0.0
2874	584.7293	584.7169	+ 12.4	+ 1.0(1)	+ 13.4
2875(†)	575.8983	575.7687	———	———	———
2876	589.6151	589.6040	+ 11.1	+ 1.0(2)	+ 12.1
2877	587.0829	587.0688	+ 14.1	+ 1.0(1)	+ 15.1
2878	576.1629	576.1583	+ 4.6	0.0	+ 4.6
2879	557.0517	557.0541	− 2.4	+ 8.0(2)	+ 5.6
2880	540.2268	540.2329	− 6.1	+ 8.0(1)	+ 1.9
2881	539.9017	539.8598	+ 41.9	+ 5.0(2)	+ 46.9
2882	535.2842	535.2847	− 0.5	+ 5.0(2)	+ 4.5
2883	542.3566	542.3634	− 6.8	+10.0(2)	+ 3.2
2884	557.8762	557.8799	− 3.7	0.0	− 3.7
2885	575.5190	575.5161	+ 2.9	+ 5.0(1)	+ 7.9
2886	597.7906	597.8004	− 9.8	+ 5.0(2)	− 4.8
2887	621.7172	621.7309	− 13.7	0.0	− 13.7
2888	647.9336	647.9518	− 18.2	+14.0(1)	− 4.2
2889	678.6073	678.5915	+ 15.8	0.0	+ 15.8
2890	704.3609	704.2015	+159.4	0.0	+159.4
2891	707.5931	707.4035	+189.6	0.0	+189.6
2892	729.8287	729.6832	+145.5	0.0	+145.5
2893	754.0815	754.0167	+ 64.8	+10.0(1)	+ 74.8
2894	765.3263	765.3114	+ 14.9	0.0	+ 14.9
2895	766.4261	766.4239	+ 2.2	0.0	+ 2.2
2896	789.7700	789.8430	− 73.1	0.0	− 73.1
2897	825.5150	825.6007	− 85.7	0.0	− 85.7
2898	823.4081	823.4859	− 77.8	0.0	− 77.8
2899	812.0371	812.1092	− 72.1	0.0	− 72.1
2900	746.7901	746.8737	− 83.6	0.0	− 83.6
2901	736.2585	736.3294	− 70.9	0.0	− 70.9
2902	722.9395	723.0055	− 66.0	0.0	− 66.0

Bench Mark.	(I) Height in 1920.	(II) Height in 1891-3.	Height Difference (I)-(II).	Correction due to an abnormal condition of B.M.	Corrected Height Difference.
	m	m	m.m	m.m	m.m
2903	711.4931	711.5878	− 94.7	+ 8.0(1)	− 86.7
2904	698.0724	698.1449	− 72.5	0.0	− 72.5
2905	664.6884	664.7772	− 88.8	+ 8.0(1)	− 80.8
2906(†)	613.9520	616.0314	———	———	———
2907	583.9508	584.0165	− 65.7	0.0	− 65.7
2908	549.5823	549.6156	− 33.3	0.0	− 33.3
2909	516.6509	516.6947	− 43.8	0.0	− 43.8
2910	482.1895	482.2619	− 72.4	+ 4.0(2)	− 68.4
2911	461.0680	461.1170	− 49.0	0.0	− 49.0
2912(*)	491.3754	442.9159	———	———	———
2913(*)	415.9726	400.2620	———	———	———
2914(*)	383.0582	371.6001	———	———	———
2915(*)	386.6180	145.7101	———	———	———
2916(*)	410.7305	317.8007	———	———	———
2917	263.1486	263.2496	−101.0	0.0	−101.0
2918	227.2336	227.3461	−112.5	0.0	−112.5
2919	201.6372	203.9560	———	———	———
2920	164.8008	158.4492	———	———	———
2921	134.4600	130.2411	———	———	———
2922	108.4254	108.5718	−146.4	+ 4.0(2)	−142.4
2923	89.5664	89.7408	−174.4	0.0	−174.4
2924	71.6212	71.7922	−171.0	0.0	−171.0
2925	50.5236	50.6934	−169.8	0.0	−169.8
2926	31.8143	32.0064	−192.1	0.0	−192.1
2927	18.2487	18.4578	−209.1	+20.0(1)	−189.1
交叉點 2928	8.8839	9.0832	−199.3	0.0	−199.3

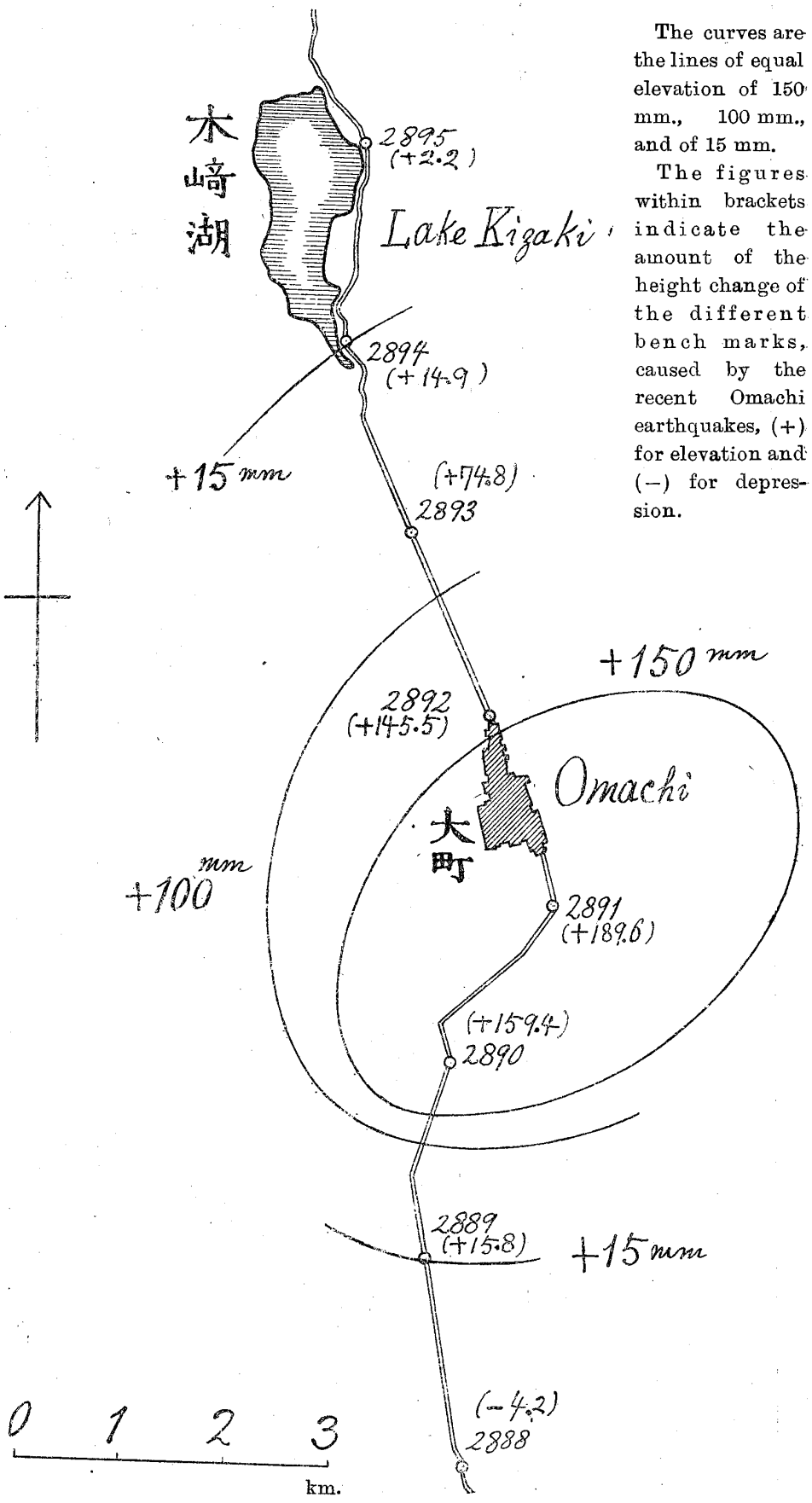
(1) Correction due to the inclination of the B.M. stone.
(2) „ „ a partial breaking of the top of the B.M. stone.
* B.M. newly set up in 1920.
† Provisionary B.M.

Fig. 20. Map showing the Precise Leveling Line between Matsumoto and Itoigawa and in the neighbouring regions.



The bench marks (•) are placed at intervals of 2 km.

Fig. 21. Map showing the Elevation of the Ground in the Epicentral Region of the Omachi Earthquakes of 1918.



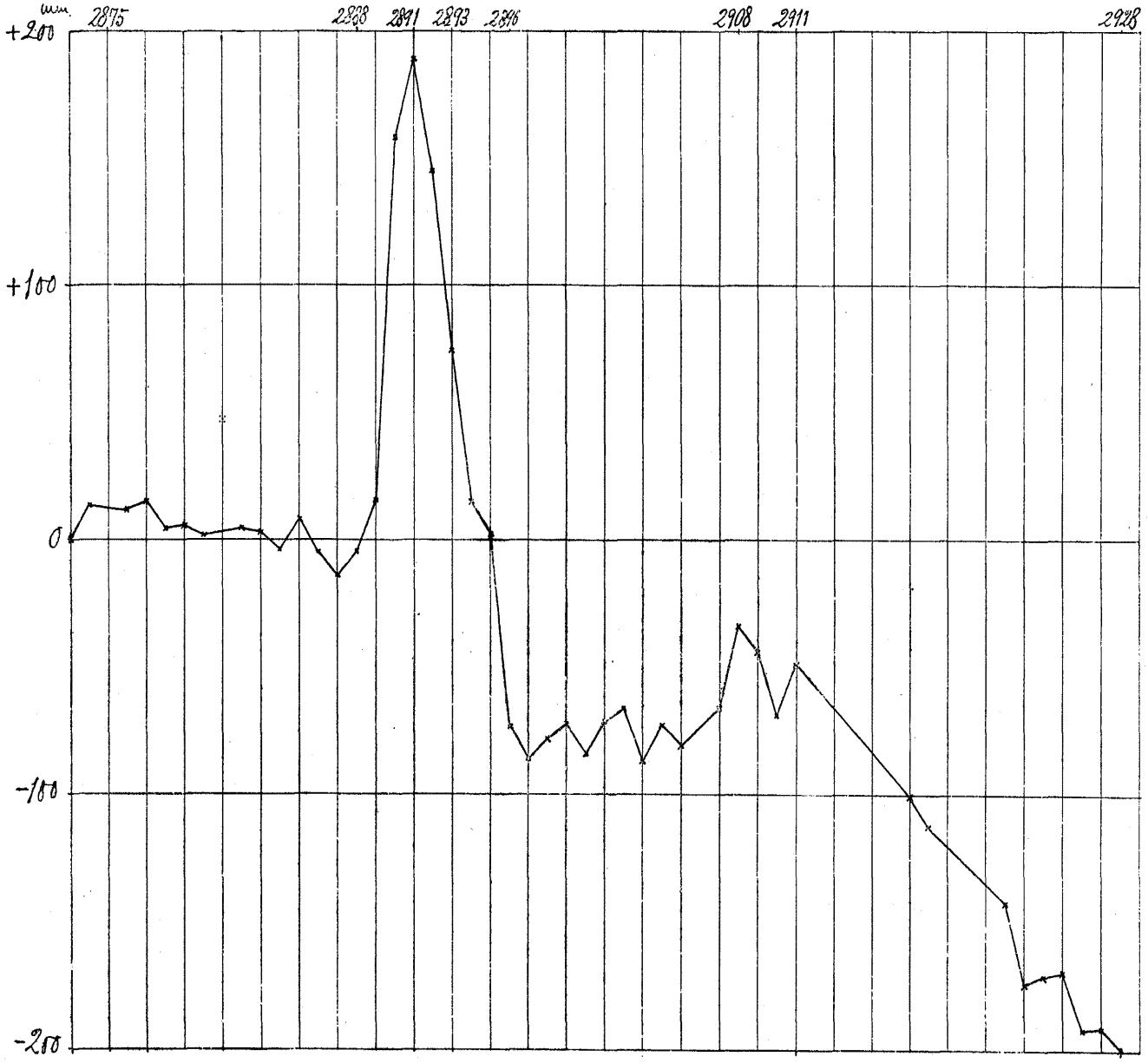
The curves are the lines of equal elevation of 150 mm., 100 mm., and of 15 mm.

The figures within brackets indicate the amount of the height change of the different bench marks, caused by the recent Omachi earthquakes, (+) for elevation and (−) for depression.

Fig. 22. Difference in Heights of the Bench-Marks between Matsumoto and Itoigawa before and after the Destructive Omachi Earthquakes of 1918.

The upper figure indicates the height change (in mm.) of the different bench-marks relative to B.M. No. 2873 in Matsumoto, (+) for Elevation and (−) for Depression.

The lower figure gives the height (in metres) of the different B.M. between Matsumoto and Itoigawa.



L. Kizaki L. Aoki

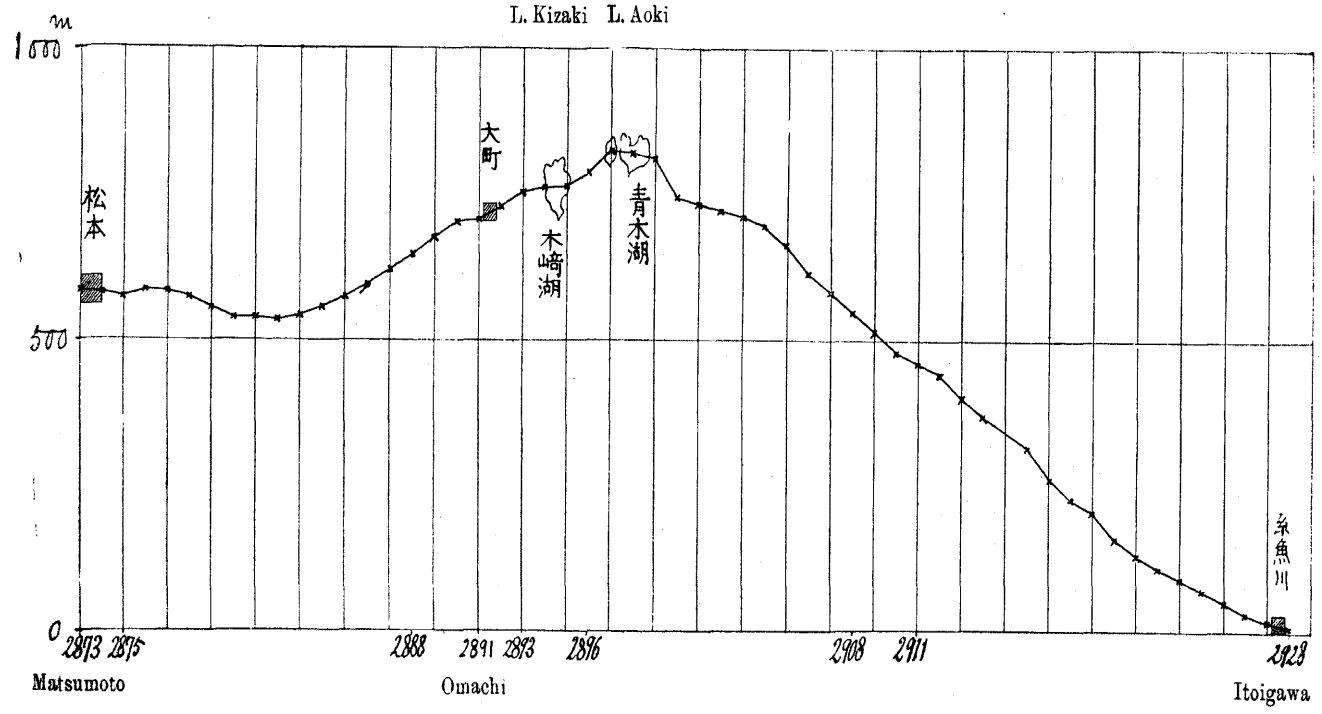


Fig. 21 indicates the position of the B.M. Nos. 2888 to 2895 in the vicinity of Omachi where the height change has been most marked. The maximum elevation was at or about the B.M. No. 2981 situated to the south of the town. The iso-elevation lines of 150 and 100 mm., which has been drawn only in a very imperfect manner from the material in hand, are also shown in the figure. The 150 mm. elevation line encloses an area extending in an N.E.—S.W. direction, whose major diameter approximately coincides with the epifocal zone of the two destructive earthquakes under consideration. (See fig. 2.)

In the map (fig. 2) are indicated two small dislocation lines formed in the Shimizu district of the Tokiwa-mra, with their eastern sides depressed. This comparative depression is probably the result of a subsidence of the region surrounding the central elevation area about Omachi and possibly continuous to the marked depression indicated by the B.M. Nos. 2896 to 2907 in the region adjacent on the north.

With regard to the simultaneous production of the (i) elevation in the area about Omachi and the (ii) depression in the adjacent region, the first was probably the principal event, as its locality coincides with the meizoseismal district about the seismic origins, the second being accessory disturbances necessitated by compensation from the surrounding or adjacent ragion. This supposition of the primary elevation impulse well agrees with the result of observation. Thus, if the ground at and above the seismic origin 0 (fig. 23) be suddenly upheaved, the very first displacement (p_1) at places A and B more or less distant from the epifocus, will be directed inwards, the next or counter displacement (p_2) being directed outwards. This is in accordance with the tromometer records obtained in Nagano and Tokyo. (See §§ 7 and 8). From the location of the (ii) depressed area to the north of the (i) elevated area, it may be assumed that the whole tract between the former and the Japan Sea coast had been undergoing a settlement combined with a horizontal pressure acting from the concave, or inner, side of the Japan Arc.

Fig. 23.