

Note on the Great Mino-Owari Earthquake of Oct. 28th 1891.

BY

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1.—The Mino-Owari earthquake of Oct. 28th 1891 was probably as violent as any ever recorded. In the meizoseismal area some of the towns and villages were almost entirely destroyed, and especially at many places in the western part of the province of Mino the number of people killed amounted to 4 % or 5 % of the population. The total number of people killed was 7000, while the number of dwelling houses entirely destroyed amounted to 80,000, so that one person was killed, on the average, for every 11 houses destroyed. The comparatively small number of the killed was doubtless due to the fact that common Japanese houses are built of wood.

The earthquake was felt in the whole southern and central part of Japan, the land area disturbed being about 250,000 sq. km. As the mean radius of propagation was about 520 km, the total area of disturbance was probably about 900,000 sq. km, or a little greater than double the area of the whole Empire.

In the present note, I limit myself to giving the result of my investigations on the intensity and direction of the motion at various places in the most strongly shaken districts.

2.—As the motion in the meizoseismal area was nowhere satisfactorily recorded by seismographs, I observed at various places a great number of well-formed stone lanterns and tomb-stones which

were overturned, as well as those which were not overturned, and calculated the horizontal acceleration a necessary for overturning by the usual formula*

$$a = \frac{x}{y} g, \quad (1)$$

in which g is the acceleration due to gravity, y the height of the centre of gravity, and x the horizontal distance between the latter and the edge about which the body is overturned.**

The values of the maximum acceleration estimated by this method are given in table I.

It is to be remarked that the calculation has been made on the assumption that the motion was entirely horizontal. This would produce no sensible error in the result except for places very near to the epifocus, where the vertical motion might have been considerable. To take an example, the estimated value of the maximum acceleration at Nagoya is 2600 mm per sec. per sec. Now according to the seismographic diagram of the Nagoya Meteorological Observatory, which gives the vertical and the horizontal motions respectively till the 10th and 15th seconds after the commencement of the earthquake, the ratio of the two components was as 1:3, the angle of emergence being thus about 20° . If we assume that the ratio of the principal vertical and horizontal movements had likewise been as 1:3, the correction to the value of the maximum acceleration, obtained on the above-stated supposition, would be ± 200 mm per sec. per sec.

The nature of the damage caused by this earthquake at different places in the strongly shaken area will be understood by comparing

* The introduction of this formula into seismology is due to Prof. C. D. West.

** See § 31 of the present author's paper: *Seismic experiments on the fracturing and overturning of columns.*

the list of the maximum accelerations (table I) with the *absolute scale* of destructive earthquakes given at the end of my paper on the fracturing and overturning of columns.

TABLE I.—LIST OF THE MAXIMUM ACCELERATIONS AT DIFFERENT PLACES IN THE STRONGLY SHAKEN AREA OF THE GREAT EARTHQUAKE OF OCT. 28TH 1891.

Province.	Place.	Maximum Acceleration.
		mm. per sec. per sec.
Mikawa.	Toyohashi... ..	1700.
„	Okazaki	900.
Ise.	Tsu	Less than 2000.
„	Yokkaichi	Less than 1900.
„	Kuwana	2000.
Owari.	Handa	Between 2000 and 2700.
„	Tokonabe	Less than 2400.
„	Nagoya, north-eastern	
„	part	2600.
„	Nagoya, central part..	2600.
„	Atsuta	Between 2300 and 3500.
„	Nishi-Biwajima ...	3800.
„	Jinmokuji... ..	Less than 3900.
„	Bamba	4100.
„	Kanie	2700.
„	Torigae	3000.
„	Saya	Less than 4000.
„	Tsushima	3000.
„	Shobata	Less than 3500.
„	Inaba... ..	4000.
„	Ichinomiya	Between 2500 and 3500.
„	Koori... ..	Greater than 2100.
„	Iwakura	Greater than 4300.
„	Komaki	Greater than 4300.
„	Imaichiba	Greater than 2600.
„	Utsutsu	2500.

Province.	Place.	Maximum Acceleration.
		mm. per sec. per sec.
Owari.	Ikeda	Greater than 2000.
"	Inuyama	Between 2300 and 4000.
Mino.	Tokiguchi	Greater than 2000.
"	Takayama	Greater than 1800.
"	Mitake	1600.
"	Dota	Less than 2200.
"	Higashi-Katabira ...	Greater than 2400.
"	Gifu	3000.
"	Kasamatsu ...	4000.
"	Takegahana	Greater than 4000.
"	Nodera	Greater than 4000.
"	Takasu	3000.
"	Imao	Greater than 3200.
"	Beppu	4000.
"	Ōgaki	3000.
"	Kochibara	Less than 1900.
"	Kōmi	Greater than 2000.
"	Kitagata	4000.
Ōmi.	Hikone	2700.
"	Nagahama	2400.
Echizen.	Tsuruga	1200.
"	Higashiura	1300.
"	Takefu	1200.
"	Sabae	1800.
"	Midochi	2000.
"	Asōzu	1100.
"	Fukui	2500.
"	Fujishima	1300.
"	Katsuyama	1200.
"	Ōno	Greater than 1200.
Yamashiro.	Kyoto	1000.
"	Fukakusa	Greater than 1000.
Yamato.	Nara	2000.
Settsu.	Ōsaka	1000.

3.—*The Range of Motion at Nagoya.* Judging from the seismographical diagram obtained in the Nagoya Meteorological Observatory the complete period T of the principal motion there seems to have been about 1.3 seconds. From this as well as from the value of the maximum acceleration, the probable range of motion or double amplitude $2a$ at Nagoya may be estimated as follows:—

$$2a = \frac{aT^2}{2\pi^2} = \frac{2600 \times 1.3^2}{2\pi^2} = 233 \text{ mm.}$$

The range of motion thus obtained is by no means too great* when we remember that the range of motion in Tokyo (Hongo) at the time of the far smaller earthquake of June 20th 1894 was 71 mm.

Ideas respecting the magnitude of the motion in the other places may similarly be obtained from the list of the maximum accelerations.

4.—*The Direction of Motion.* In the absence of satisfactory seismographic records, we may determine the direction of motion from observations of the overflowing of liquids, cracks in the ground, rotation of bodies, etc. The best result however is to be obtained from observations of overturned bodies.

It is unnecessary to remark that in direction observations we must choose those cases, in which the direction of falling would not be influenced by the form of the body such as stone lanterns and tomb stones of square or circular section. It is necessary to multiply the number of the observations and take the mean.

The direction of the overturned bodies in the meizoseismal area was at some places irregular, but at others very uniform.

* This is a slight modification of the conclusion given in my note on the overturning of columns. Vol. II. Seis. Jour. Japan.

As an example of the latter case, I shall describe the direction observations in Nagoya.

The brick buildings of the Nagoya Post and Telegraph Office and two bazaars had their walls parallel NS completely knocked down, while those parallel EW were only cracked. From this, the direction of the earthquake motion at Nagoya may be inferred to have been nearly EW. Besides this, I observed in different parts of the city 200 stone lanterns with cylindrical stems, whose directions of overturning are given in table II. Of these, 15 were overturned towards W, 119 between W and S, 3 towards S, 10 between S and E, 6 towards E, 36 between E and N, 1 towards N, and 10 between N and W. The maximum number of columns was thus overthrown towards WSW, and the next greatest number towards the opposite direction ENE, the mean direction being S 60° W and N 60° E. Table II is graphically illustrated by fig. 1, where each mark (×) indicates a stone lantern overturned in the proper radial direction. When more than one were overturned in one and the same direction, an equal number of the marks has been put on the corresponding radius.

The tendency to be overturned towards W was likewise ascertained to be the case with other bodies in Nagoya. Thus, twenty-seven stone lanterns and tomb stones of square section, with sides parallel to the cardinal directions, which were observed in different parts of the city were overturned as follows:—2 towards E, 21 towards W, 1 towards S, and 3 towards NE. Further, the tops of the chimneys of the Electric Light Company, the Aichi Cotton Mill and the Cement Factory were all projected towards WNW.

Similarly in Gifu, the principal direction of overturning was WSW. Here the four chimneys in the Prison House and the Kasōjō, as well as the anemometer observatory of the Meteorological Station

were all overthrown nearly towards W. Again, the brick court-walls of the Prison House and the mud walls of the Nishi-Betsuin, which were parallel NS, were overturned towards W, while those parallel EW remained uninjured.

TABLE II.—DIRECTION OBSERVATION IN NAGOYA.

(DIRECTIONS TOWARDS WHICH 200 STONE LANTERNS WITH CYLINDRICAL STEMS WERE OVERTURNED).

S 50° W	S 30° W	S 27° W	S 55° W
S 40° W	S 15° W	S 60° W	N 80° E
S 70° E	S 60° W	S 60° W	E
N 70° E	S 55° W	S 58° W	S 15° E
W	S 40° W	S 60° W	S 63° W
N 70° E	W	S	S 40° W
S 50° W	S 70° W	S 65° W	S 73° W
S 65° W	N 50° W	N 73° E	N 56° E
N 65° W	S 70° W	S 52° W	N 60° E
E	N 85° E	S 35° W	S 55° W
N 50° W	S	N 45° E	S 55° W
S 40° E	S 40° W	S 50° W	N 55° W
N 40° E	S 40° W	S 33° W	S 55° W
N 10° W	S 20° W	S 42° W	S 30° W
S 55° W	S 40° W	S 42° W	S 73° W
N 70° E	S 57° W	N 70° E	S 65° W
S 60° W	N 65° E	S 30° W	S 65° W
S 80° W	N 50° E	W	S 72° W

S 60° E	W	N 72° E	S 85° W
N 80° E	N 50° E	S 57° W	S 80° W
N 50° W	N 40° E	S 60° W	S 80° W
W	S	S 60° W	S 70° W
W	N 40° E	N 68° E	N 35° W
W	S 75° W	N 55° E	N
S 65° W	N 20° E	S 65° W	N 47° E
N 60° W	S 85° W	N 65° E	S 83° W
S 70° W	N 60° E	S 75° W	S 70° W
S 40° W	S 30° W	S 68° W	N 50° E
S 40° W	S 10° W	S 74° W	S 82° W
S 60° W	S 50° W	W	N 10° E
N 75° E	S 40° W	S 70° W	S 60° W
S 45° W	S 40° W	S 50° W	S 60° W
S 75° W	S 65° W	S 70° W	S 25° W
W	S 85° E	S 80° W	N 60° E
S 72° W	N 25° E	W	S 65° W
S 55° W	S 70° W	S 55° W	S 70° W
S 40° W	N 70° W	N 45° E	S 30° W
S 35° W	S 65° W	W	S 40° W
S 32° W	S 70° W	N 45° E	S 20° E
S 35° W	S 35° W	S 55° W	S 45° W
S 45° W	S 68° W	S 40° W	N 65° W
S 85° W	S 40° E	S 30° W	S 60° W
S 60° W	S 77° E	S 35° W	E
S 57° W	S 55° W	N 40° E	S 40° E
S 55° W	W	E	W
S 50° W	W	N 85° E	W
S 55° W	S 80° E	N 60° E	E
S 40° W	S 65° W	S 60° W	
S 70° W	E	S 80° W	
S 55° W	S 70° W	N 55° E	
S 62° W	S 70° W	S 60° W	

In table III are given the direction of motion at various places in the strongly shaken area, deduced from my observations of numerous overturned stone lanterns and tomb-stones.

TABLE III.—LIST OF THE DIRECTIONS OF MOTION AT VARIOUS PLACES IN THE STRONGLY SHAKEN AREA OF THE GREAT EARTHQUAKE OF OCT. 28TH 1891.

Province.	Place.	Direction of motion.
Mikawa.	Toyohashi... ..	S 80° E → N 80° W
Ise.	Tsu	N 75° W → S 75° E
„	Yokkaichi	WNW → ESE
„	Kuwana	S 75° W → N 75° E
Owari.	Tokonabe	W → E
„	Handa	NW → SE
„	Atsuta	ENE → WSW
„	Nagoya	N 60° E → S 60° W
„	Bamba	ENE — WSW
„	Tsushima	E — W
„	Jinmokuji	E — W
„	Shimo-otai	S — N
„	Komaki	WSW — ENE
„	Iwakura	SWS → NEN
„	Koōri... ..	SW — NE
„	Inuyama	S 10° W → N 10° E
„	Ichinomiya	WNW → ESE
„	Ikeda... ..	S 20° W — N 20° E
„	Utsutsu	N 30° E → S 30° W
Mino.	Kasamatsu	ESE → WNW
„	Gifu	ENE → WSW
„	Ōgaki	SWS — NEN
„	Kitagata	E → W
„	Kurono	S 50° W — N 50° E

Province.	Place.	Direction of motion.
Mino.	Monju	S 60° W — N 60° E
„	Higashi-katabira ...	S — N
„	Dota	S 20° W — N 20° E
„	Tokiguchi... ..	N → S
„	Tajimi	SWS — NEN
Echizen.	Ōno	W → E
„	Katsuyama	S — N
„	Fujishima... ..	S — N
„	Fukui	SWS → NEN
„	Asōzu	S 30° W → N 30° E
„	Takefu	S — N
„	Tsuruga	NWN → SES
Ōmi.	Nagahama	N → S
„	Hikone	NWN — SES
Yamashiro.	Kyoto	SWS — NEN
„	Inari	N 15° W — S 15° E
„	Fukakusa	S — N
„	Fushimi	SES — NWN
Yamato.	Nara	NEN → SWS

5.—*Relation between the Intensity and the Direction of Motion.* The direction of motion and the variation of the intensity in the three most strongly shaken provinces of Mino, Owari and Echizen will be seen from fig. 2, which embodies the results contained in tables I and III and my other observations in the mountain districts of Mino and Echizen.

The zone of extreme violence of the earthquake motion, shaded in the figure, begins, on the north, at the villages of Nukumi and Kumanoko in Echizen, is continued to the valleys of Oppa and

Okawara in the Motosu county of Mino, then runs in a SES direction along the famous Neo-valley till it reaches the tract about the town of Takadomi where it is divided into two branches. The principal course thence passes between Gifu and Ogaki, is continued to the towns of Komaki and Iwakura, and ends in the tract between Nagoya and Tsushima. The other branch is continued from the vicinity of Takadomi to the village of Higashi-Katabira in the Kani-county of Mino.

The two curves, marked 1 and 2, are the isoseismal lines, along which the maximum accelerations of the earthquake motion were respectively 2000 and 800 mm per sec. per sec. It will be observed that the shaded zone forms the axis of the isoseismal line 2, whose general direction is NWN and SES.

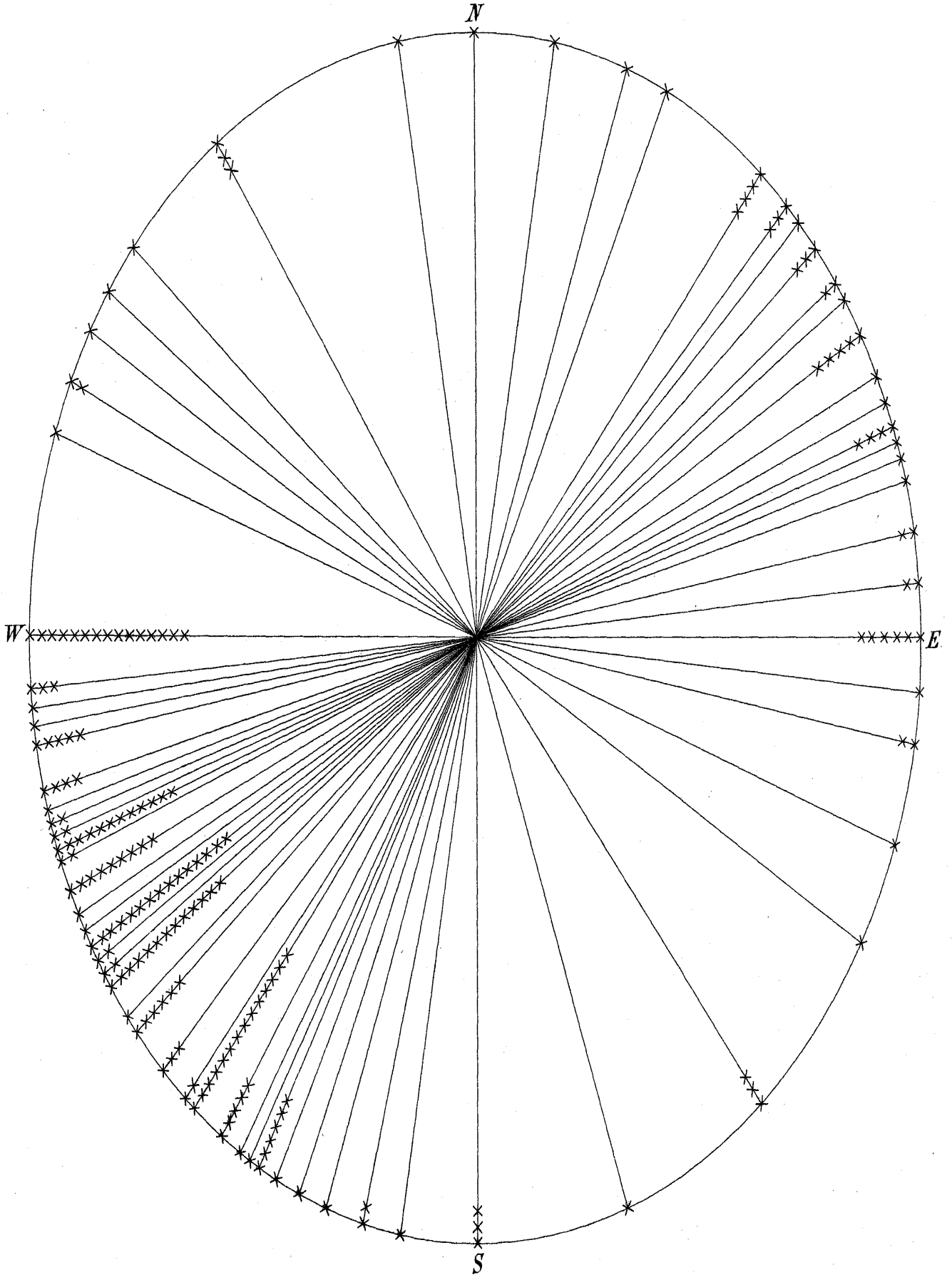
The directions of motion at different towns and villages are indicated by short red lines, the arrow indicating the direction towards which the majority of the bodies at a given place were overturned. As already mentioned, the principal directions of overturning at Nagoya and Gifu were respectively S 60° W and WSW. At the towns of Ichinomiya and Kasamatsu situated between the two above-named cities, the mean direction of motion was ESE and WNW, greater numbers of bodies having been overturned towards W than towards E. At the villages of Monju and Kurono, to the NW of Gifu, the principal direction of the overturning was SW, while that at Kitagata was W. Similarly, at Atsuta which forms the southern continuation of Nagoya, the direction in question was WSW. At the town of Toyohashi, in the province of Mikawa, the direction of motion was S 80° E and N 80° W, more bodies having been overturned towards W than towards E. It is here to be noticed that all these places lie on the eastern side of the meizoseismal zone. Turning next our attention to the places on its western side, we

see that the direction of motion at the town of Tsushima, as well as in the counties of Kaisei (Owari) and Kuwana (Ise) was nearly E and W, more bodies having been overturned towards E than towards W. The directions of motion at the towns of Kuwana and Tsu were very uniform and respectively $N 75^{\circ} E-S 75^{\circ} W$ and $S 75^{\circ} E-N 75^{\circ} W$, a far greater number of bodies having in each case been overturned towards E than towards W. Further, one chimney at Kuwana, two at Yokkaichi, and one at Tsu, had their tops thrown down all nearly towards E, that is, respectively towards SE, SE, SES and $N 70^{\circ} E$. At the towns of Tokonabe and Handa in the Chita Peninsula, the direction was nearly EW, more having been thrown towards E than towards W.

It thus appears that in the Mino-Owari plane and along the Ise Sea and the Mikawa Bay, the direction of the earthquake motion was approximately normal to, and directed towards, the meizoseismal zone; in other words, the principal displacement was at the places on the east side of the epifocus directed towards W; and at places on its west side towards E, the earthquake motion converging, as it were, towards the origin. (Iwakura and Shimo-Otai, Owari, where the direction of motion was nearly NS, form exceptions to the above conclusion. It is however to be observed that the intensity of motion at these two places was also abnormally greater than that at the neighbouring places.) Again, the direction of motion at Inuyama, Utsutsu, Ikeda, Takayama, Tajimi, Dota and Higashi-Katabira, was NS or NEN-SWS, and was therefore approximately normal to the course of the branch zone which runs from the vicinity of Takadomi to the Kani-county, and along which all these places are situated.

Fig. 1.

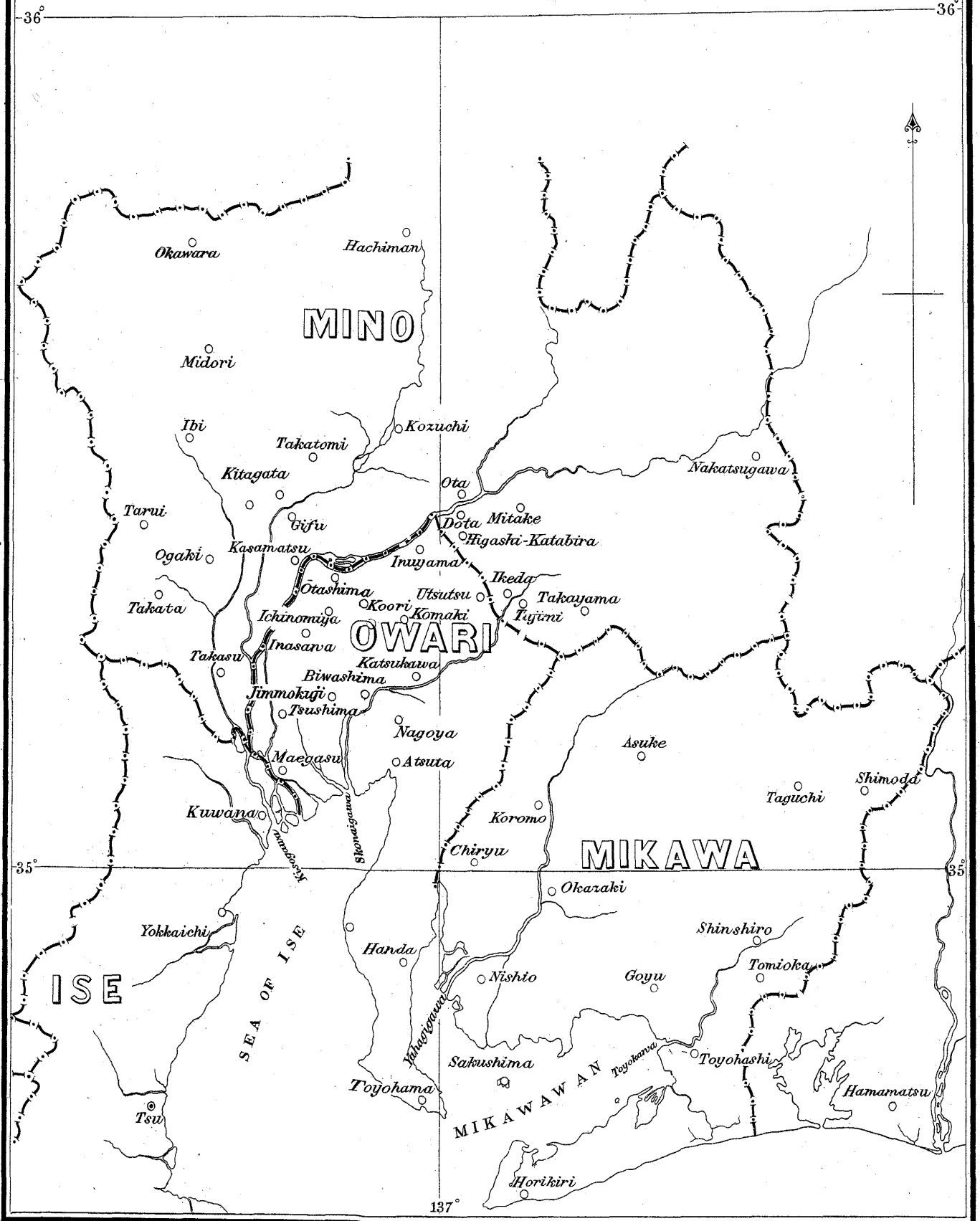
*Diagram showing the directions of overturning
of 200 stone lanterns, observed in Nagoya.
(Earthquake of Oct. 28th 1891.)*



137°
Fig. 2. *The Great Earthquake of Oct. 28th 1891.*

(1) and (2) are isoseismal lines along which the maximum accelerations of earthquake motion were respectively 2000 and 800 mm. per sec. per sec.

The area most strongly shaken is indicated by red shades.



○..... Observing station