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4. *Map Showing Disaster Areas of Historical Earthquakes in Japan.*

By Tatsuo Usami,
Earthquake Research Institute.

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§ 1. Short history of the study of historical earthquakes in Japan

At 06 h 38 m of October 28, 1891, a disastrous shock, called the Nobi Earthquake, hit the central part of Honshu. The magnitude was estimated as about 8.0 and the epicenter was located at $\lambda = 136.6°$ E and $\varphi = 35.6°$ N. Damage reported was:

dead: 7,273
wounded: 17,175
houses totally destroyed: 142,177
houses partly destroyed: 80,324
land-slides: 10,224

Famous Neo-Dani fault appeared across central Honshu, running about 70 km in the NNW-SSE direction. The fault is left-lateral and maximum relative displacements across the fault are about 6 m in the vertical and 2 m in the horizontal directions.

Stimulated by the earthquake, the Earthquake Investigation Committee, a government organization, was born on June 25, 1892, with the purpose of studying methods of preventing earthquake disaster by investigating methods of predicting earthquakes and means of mitigating their destrutive effects. One of the 18 tasks set forth for the fullfilment of the Committee's goal is the compilation of a history of earthquakes based on the collection of historical documents. Tayama[1] collected such documents and published them in 1904. Musha succeeded him, adding many more newly found documents and published the revised and enlarged edition amounting 4000 pages in 1941—1949[2].

The repetition of earthquakes in the same area is rare. As Terada[3] said, nature is stubbornly conservative and a big shock similar to the one in the 20th century B.C. may take place in the 20th century A.D. Therefore, the study of historical earthquakes is important for the prediction of earthquakes and the mitigation of the damage.

In 1943, Kawasumi[4] introduced the magnitude scale M_k, which nowadays is known by his name, by which the magnitude of big historical earthquakes is easily determined.

He gave the epicenter and magnitude of all major historical earthquakes in Japan. Thus historical earthquakes provided scientifically valuable data for the study of earthquake occurrence. He has made maps[5] showing the expected maximum acceleration during the coming 75, 100 and 200 years which were used in revising the codes for the earthquake-proof constructions in Japan.

Utilising the data of historical earthquakes, he proposed the 69 year periodicity theory[6] for the occurrence of earthquakes giving intensity V or more in the Tokyo area. According to the theory, the danger period comes at every 69 ± 13 years. Some papers criticizing the periodicity theory have appeared, concluding that the existence of the 69 year periodicity is statistically doubtful and insisting on the random occurrence of such earthquakes[7].

Epicenters of historical earthquakes given by Kawasumi were revised by the present author[8], who also compiled a descriptive table[9] of historical earthquakes accompanied by damage, which contains the latitude and longitude of epicenter, depth, occurrence time, magnitude, tsunami magnitude, a brief explanation of the damage, results of survey of land deformation, aftershock observation, forerunning phenomena and other geophysical data. Such a descriptive table was first made by Musha[10] in 1950—1953. The present author revised it by adding modern seismological data, maps showing intensity distribution, figures explaining the change of aftershock activity, tables of damage and so on. The table will serve as a springboard for further study on the time sequence of earthquake occurrence, prediction of earthquakes and on the method of mitigating disasters. It is also useful for the establishment on the governmental, prefectural and community levels of countermeasures for earthquake damage.

§ 2. Map showing the source region of historical earthquakes

One of the important themes of the study of historical earthquakes is to find out the local pattern of the sequential occurrence of disastrous earthquakes. To this effect, the selection of earthquakes belonging to the same earthquake region and/or to the neighboring region must be made first. However, owing to the scarcity of available data of historical earthquakes, it is quite difficult to estimate the precise epicenter location. Moreover, in historical earthquakes, faults are rarely reported and the aftershock regions usually cannot be found out. Therefore, in order to determine which earthquakes belong to the same and/or the neighboring regions, we choose regions where the intensity was VI or more as the indicator. Because the aftershock area A and the area

MAP SHOWING AREA OF INTENSITY LARGER THAN Ⅴ FOR DISASTROUS EARTHQUAKE IN JAPAN (416 ~ 1973)

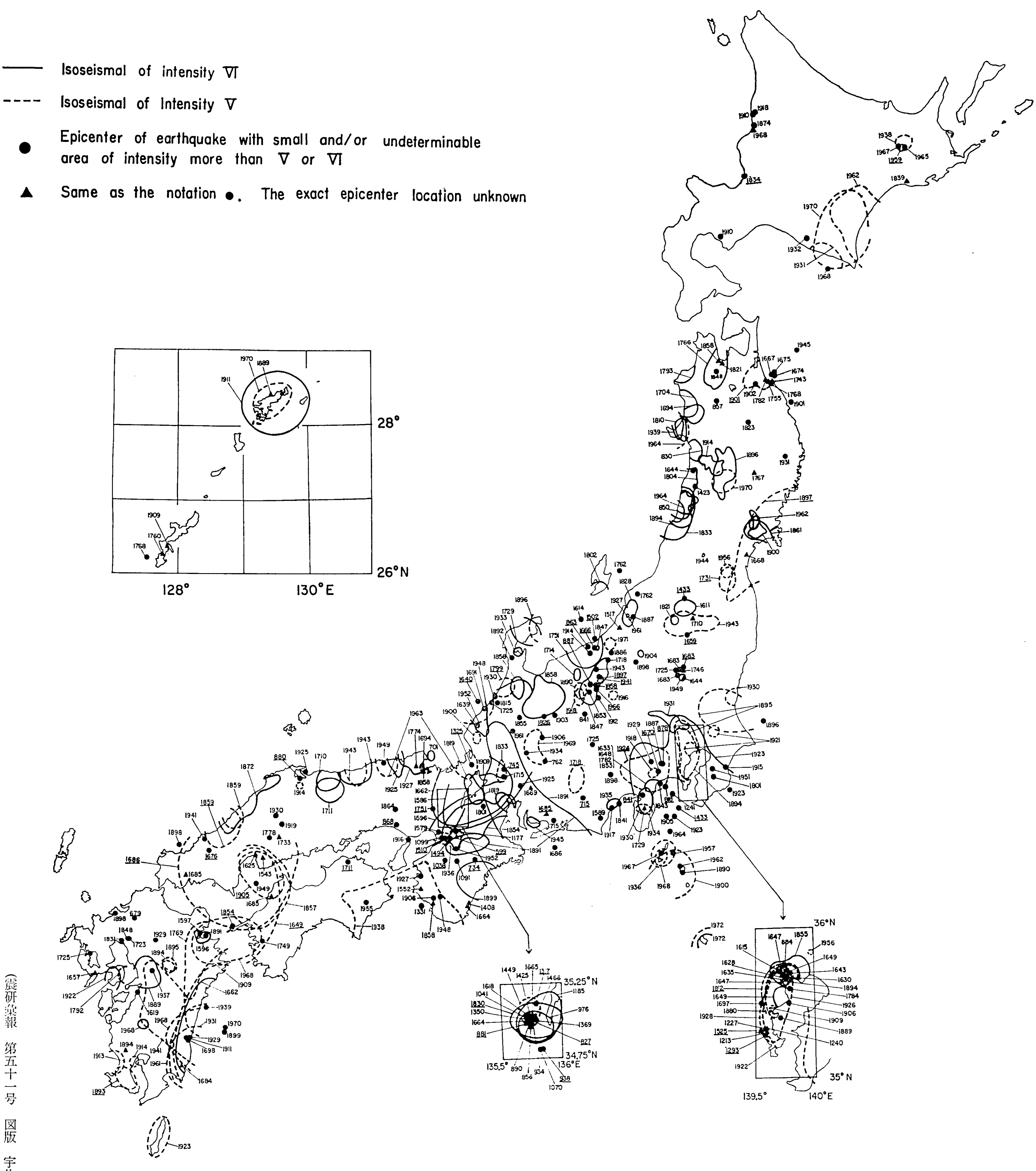

Fig. 1. Map showing regions of intensity V or more for destructive earthquakes in Japan, 416—1973. It should be noticed that the solid curve of the Nobi-Earthquake (1891) is divided into 2 regions.

of the region with intensity VI or more S_{VI} are nearly equal, they are expressed as

$$\log A = M - 3.7^{11)}$$
$$\log S_{VI} = 1.36M - 6.66^{12)}$$

respectively. Units of A and S_{VI} are km^2. For actual earthquakes, these areas A and S_{VI} partly overlap each other and they do not occupy completely separated areas.

The attempt is made to determine the extent of the area with intensity VI or more for the historical earthquakes by the distribution of destroyed houses, land deformation and the number of the dead and the wounded. The region of intensity VI or more thus determined is drawn in Fig. 1. In preparing the figure, earthquakes accompanied by damage from 416 to 1973 are used. Big earthquakes off the Pacific coast of Japan are omitted. Because sometime the region of intensity VI or more does not reach the land area and/or even if such regions reach the land area, it does not necessarily represent the aftershock area. Earthquakes with maximum intensity IV, even though they give slight damage, are omitted. The solid line shows the region with intensity VI or more and the broken line that with intensity V or more. The broken line was adopted principally for earthquakes which lack an area of intensity VI or more, but have a clear boundary for the area of intensity V. A solid circle means an earthquake with small and/or undeterminable region of intensity V or VI. Numerals give the Gregorian calendar year of each earthquake. Underlined numerals indicate that the earthquake may have regions of intensity VI or more. Since the region of intensity V is much larger than that of intensity VI, it is not appropriate to reconstruct the region of intensity VI or more from the broken line. A solid triangle has the same meaning as a solid circle, except that the epicenter location is not given by latitude and longitude. Therefore, the triangles are plotted at approximate locations.

The figure is helpful in grouping earthquakes belonging to the same and/or the neighboring seismically active regions. After such grouping, we can proceed to further investigations on historical earthquakes. Figure 1 reveals such important features as the following:

1) Areas which have not experienced intensity VI or more can be found in most places in Japan. In other words, since the intensity V is not so dangerous, districts free from serious disaster are wider than commonly thought. Remember that big earthquakes off the Pacific coast of Japan are omitted in this study.

2) The regions of intensity VI or more are situated one by one

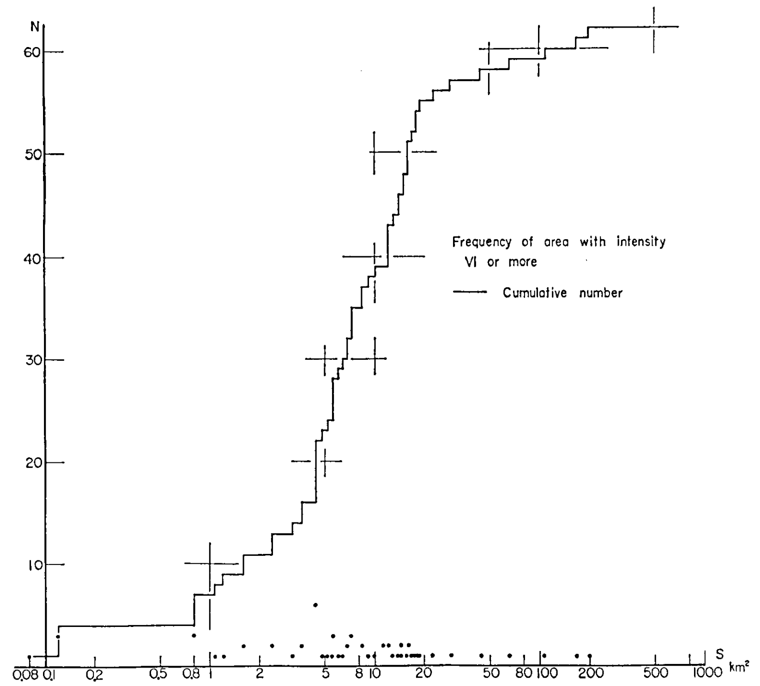

Fig. 2. Frequency of area of regions having intensity VI or more (solid circle). Solid stepwise curve shows the cumulative number.

without overlapping along the Japan Sea coast of Honshu. The magnitude of these earthquakes is about 7.0 and upheaval of the coast line before the shock is often reported. This feature, which is different from the Pacific side of Japan, still waits for a reasonable explanation.

3) The number of disastrous earthquakes is larger in Kyoto, Kamakura and Edo areas than in the other regions. These cities were old capitals of Japan. This fact explains in part the abundance of remaining old documents and shows the seismicity of these areas to be higher than other regions.

The distribution of disaster regions, namely the areas of intensity VI or more is plotted in Fig. 2 by solid circles. The solid stepwise curve shows the cumulative number, showing that the area is distributed between 0.1 and 200 km^2. The area of intensity VI or more is smaller than 10 km^2 in about two-thirds of all earthquakes, and half the earthquakes investigated have disaster areas of less than about 7 km^2. The area is astonishingly small compared with the feeling we have of damage.

A study of the pattern of earthquake occurrence as a function of time based on Fig. 1 will be reported in the near future.

Appendix

Japanese intensity scale, defined by the Japan Meteorological Agency and widely used throughout in Japan consists of 8 grades from 0 to VII. The correspondence between this scale and acceleration is as follows:

Intensity	0	I	II	III	IV	V	VI	VII
Acceleration	0.8	2.5	8.0	25	80	250	400	gal

Grade VII: More than 30% of houses is destroyed. Faults and fissures appear.

Grade VI: With average ground conditions more than 1% of houses is destroyed. Landslides and fissures appear. Most people can not keep standing.

Grade V: Cracks appear on the walls. Tomb stones and stone lanterns fall down. Chimneys and stone walls suffer slight damage.

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4. 日本被害地震地籍図

地震研究所　宇佐美　竜夫

わが国の過去の被害地震の地籍を示すものとして震度 VI 以上の地域を採用し，これを第1図に示した．この図から，どれどれの地震が同一地震域に属するか，あるいは隣接する地震域に属するかをきめることが出来る．この図は地震の地域的グループわけをより確度の高いものとし，地震発生パターンの研究の基礎として役に立つ．

震度 VI 以上の地域の面積の頻度を第2図に示した．