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ESTIMATIONS OF MAGNITUDES OF FUTURE EARTHQUAKES

By

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Abstract

The estimation of the seismic magnitude of an imminent earthquake is highly important in estimating and prevention of the disaster.

Estimations of the seismic magnitudes of future earthquakes all over Japan and especially in Kyoto Prefecture are studied using lengths of faults, areas of topographical blocks and so on.

Recently, it has been possible to trace some seeds of earthquakes where earthquakes are out of action, around Kyoto Prefecture. Then, the maximum magnitudes of approaching earthquakes are evaluated according to the areas of these seeds.

1. Introduction

It is necessary first to find countermeasures of preventions of earthquake disaster to estimate these magnitudes and probable frequencies of these future earthquakes. T. Rikitake[1] has studied the short estimations of the magnitude of earthquakes in the Southern Part of the Kanto District of Japan by means of the formulae of Gutenberg-Richter, Tsuboi's energy[35], Dambara's crustal deformation area, Utsu's aftershock area and area of anomalous secular change of the terrestrial magnetism. In general, there are some useful methods of estimations as follows,

(1) The frequencies of the occurrences and the maximum magnitudes of the coming earthquakes have been evaluated from the data of the dates of remarkable earthquakes in human history. For example, T. Usami[2] and S. Hisamoto have studied generally the periods of the occurrences of the earthquakes in Kyoto using the dates of major destructive earthquakes in this district. K. Shimazaki[3] has examined the limit of the abandonment for the existence of the power spectrum of the time series of the earthquakes' occurrences in Tokyo District. M. Ogawara[4] has dealt with the probability of the earthquake's occurrence in Tokyo. Utsu[5] has worked on the time distribution of earthquakes for the five time-series of earthquakes all over Japan, in Matsushiro, in Urakawa and so on. H. Kawasumi[6] has studied the probability of the occurrence of earthquakes in the Kanto District of *69* year's periodic band which is *20* years wide.

(2) When there is not a long time series of the destructive earthquakes but an active seismicity in recent time to obtain the formula between the magnitude and the numbers of the earthquakes like Gutenberg-Richter or Ishimoto-Iida, these for-

mulae can be extrapolated to the occurrence of the destructive earthquake in future.

(3) Relation between the seismic magnitude M and the maximum value h meters of the vertical crustal movement by Y. Fujii[7] as follows,

$$\log h = -1.51 + 0.46M \quad \text{for the rapid changes,}$$

$$\log h = -1.45 + 0.34M \quad \text{for the chronic changes.}$$

(4) Relation between the seismic magnitude M and the duration time T years of the anomalous changes before the destructive earthquake by I. Tsubokawa[8] as follows,

$$\log T = 0.79\,M - 4.44.$$

(5) Relation between the seismic magnitude M and the fault-length l kilometers or the product of the fault-length l *km* and the difference D *cm* between both sides of the fault by D. Tocher[9], K. Iida[10], C. Wideman[11] et. al. and so on.For example, the formulae of Iida are are shown as follows,

$$M = 6.07 + 0.76 \log l,$$

$$M = 6.2 + 0.4 \log Dl.$$

(6) Relation between the seismic magnitude M and the area A km^2 of the space where there is no earthquake nowadays. K. Goto and Y. Sakai[12] have called this space the seed of the coming earthquake, and they have studied the seed of earthquakes off the Tokachi region where there was a great earthquake in 1951.

(7) Relation between the seismic magnitude M and the radius r *cm* of the anomalous crustal movement. For example, K. Dambara[13] has evaluated as follows,

$$\log r = 0.51\,M + 2.73.$$

(8) Relation between the seismic magnitude M and the mean radius r_0 *cm* of the fracture or plastic zone caused by the earthquake. I. Ozawa[14] has studied the estimation of r_0 using the magnitude of strain-step which is observed with extensometers in the time of the earthquake, and has obtained the relation as follows,

$$\log r_0 = 0.45\,M + 3.00.$$

(9) Relation between the seismic magnitude and the area A cm^2 of tsunami's origin obtained by K. Iida[15], K. Hatori[16] and others. Idia's formula is shown as,

$$\log A = 1.04\,M + 5.98.$$

(10) Relation between the seismic magnitude M of the main shock and the area A cm^2 of the region of the aftershocks obtained by Utsu[17] et. al. is shown as follows,

$$\log A = 1.50\,M + 6.0.$$

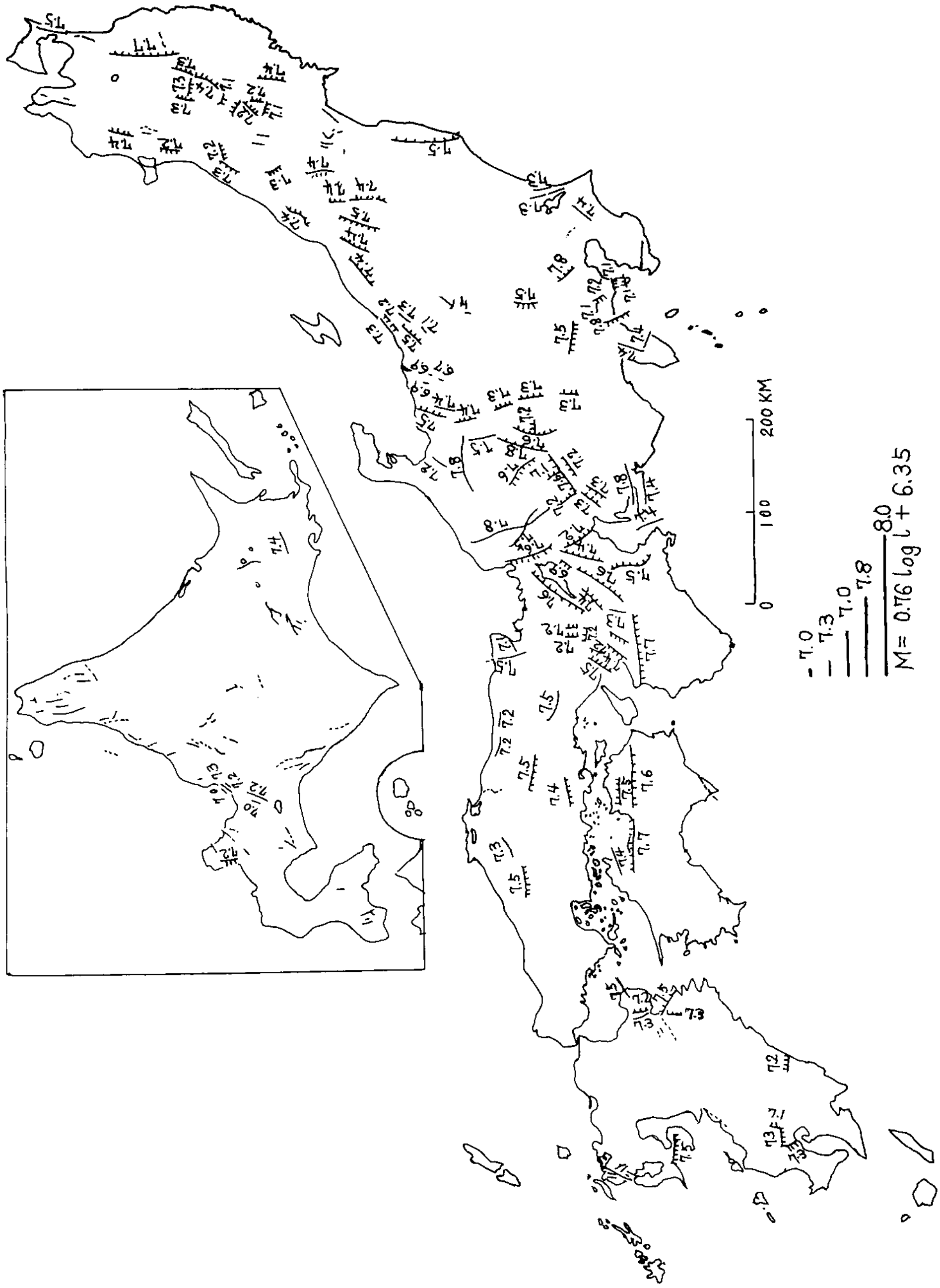


Fig. 1. Seismic magnitude M corresponds to active fault in Japan.

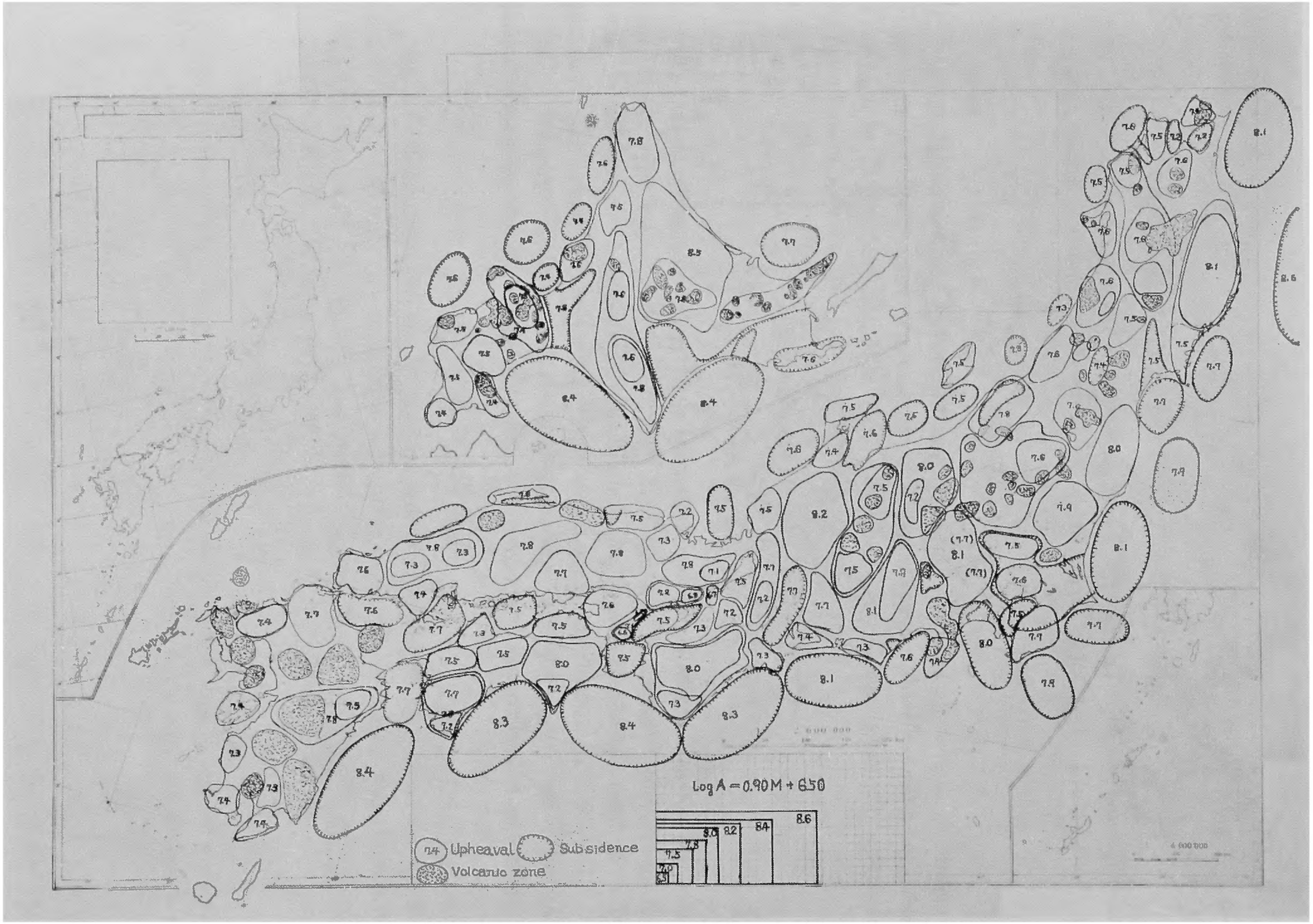


Fig. 2. Seismic magnitude M corresponds to active block in Japan.

(11) Relation between the seismic magnitude M and the area A cm^2 of the region where the seismic intensity is 6 (*C. M. O.*). Such relations have been obtained by H. Berckhemer[18), K. Iida[19) and Y. Muramatsu[20). For example, the relation obtained by Iida is shown as follows,

$$\log A = 1.30M + 3.71.$$

2. Topographical estimations of the magnitude of coming earthquake

When we have had few destructive earthquakes in these past times, and have low seismicity lately in the pending region, we must consider the topographical factor of the such region in adition to the seismicity. When we find faults in this region, we may estimate that the faults have been made within the last ten thousands years. When we find structural valley, we mays estimate that there are frequent seismic movement. Similarly, there are crustal movements accompanied with many earthquakes in mountains, plateaus, basins, lakes, bays, peninsulas and so on. Therefore, we may estimate the orders of the maximum magnitudes of coming earthquakes.

The idea of the block has studied has introduced by some geologists, and this idea has developed by N. Yamazaki, K. Muto, K. Atami, C. Tsuboi, N. Miyabe and so on. C. Tsuboi has studied the block motions by means of the analyses of the results of levellings, and N. Miyabe has done chiefly by those of the triangulations. It is important to consider the maximum area of the seismic movement like an earthquake volume in the determination of topographical blocks. For example, C. Tsuboi[21) has studied that the maximum diameter of the earthquake area is *2* or *3*, times of the thickness of the crust which is about *50 km*. K. Mogi[22) and S. Nagumo[23) have decided the series of the earthquakes' blocks on and off the coast of the Pacific Ocean of Japan and the Kurile Islands. Mogi has ascertained that the area of the great earthquakes for about fifty years have not superposed each other. The author (I. Ozawa) estimates the seismic magnitudes M corresponds to the active faults in Japan[24),25) and shows in Fig. 1. The relation between the seismic magnitude M and the length l *km* of the fault is given as follows,

$$M = 0.76 \log l + 6.35,$$

in this estimation. He has considered seismic blocks all over Japan, and estimates their seismic magnitude as shown as in Fig. 2. The relation between the magnitude M and the area A cm^2 of the block is given as follows,

$$\log A = 0.90\ M + 6.50.$$

3. Estimations of the magnitudes of future earthquakes around Kyoto Prefecture

About fifty destructive earthquakes have taken place around Kyoto City for last about one thousand years. According to the work of Usami and Hisamoto[1), it seems that these earthquakes have occured over a period of *38.5* years. I. Ozawa[25] has found that there are periods of about *100*, *200*, *300* and *500* years. The outstanding earthquakes are the erathquake of *1596* at Fushimi whose magnitude is *7.0*, and that of *1662* at the western coast of Biwa Lake whose magnitude is *7.6*. We can therefore assume the maximum limit of the earthquake. But we have had only 3 outstanding earthquakes in the northern part of Kyoto Prefecture, and none of which have been in the middle part of Kyoto Prefecutre, in our civilized history. Therefore, we can not obtain the period of the occurrence and the maximum magnitude of future earthquakes by means of the analysis of the time series of the occurrence.

Fourtunately, we have been able to about one hundred faults in the northern part of Kyoto Prefecture and Wakasa Bay. So, we are able to assume that there were about one hundred earthquakes whose magnitude were greater than about *7* for about one hundred thousand years, Fig. 3 and 4 show the distribution of the faults in the northern part of Kyoto Prefecture and in the middle part of the Kinki District, respectively. The numbers in these figures show the seismic magnitudes calculated by the formula, $M=0.76 \log l+6.35$. It can be seen that there are few faults in the middle part of Kyoto Prefecture. This does not mean that there is no probability of the occurrence of earthquakes, because there is evidence of remarkable crustal movement in the shape of deep structural valleys and steep mountains.

According to the levelling of the Geographical Survey Institute, Tanba-cho has fallen about *8 cm*, Kameoka-city about *10 cm*, and Kyoto city about *15 cm*, partly *60 cm* against to Yakuno-cho during the period 1927–1965. Kizu city has fallen about

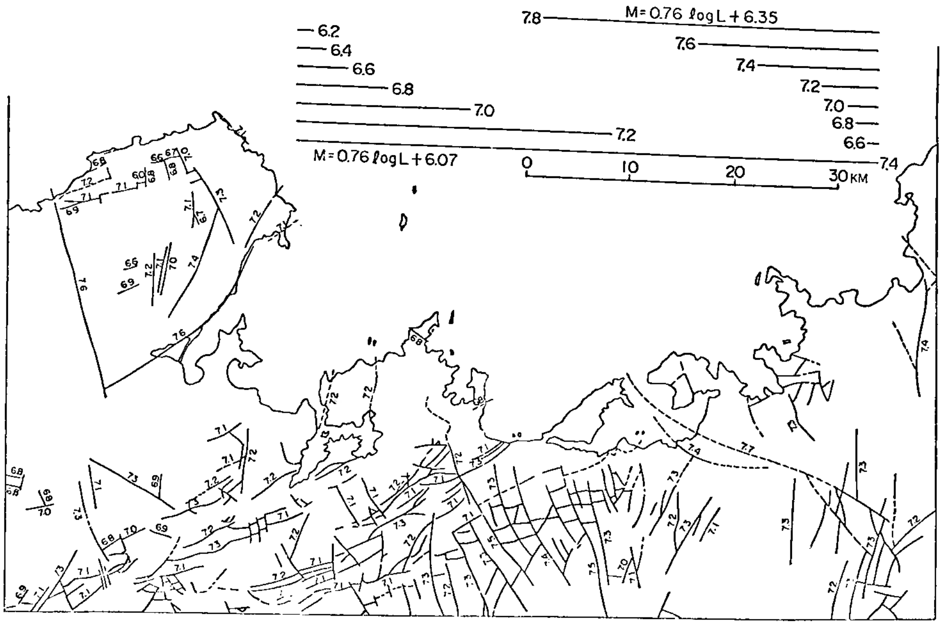


Fig. 3. Seismic magnitude M corresponds to fault around the northern part in Kyoto Prefecture.

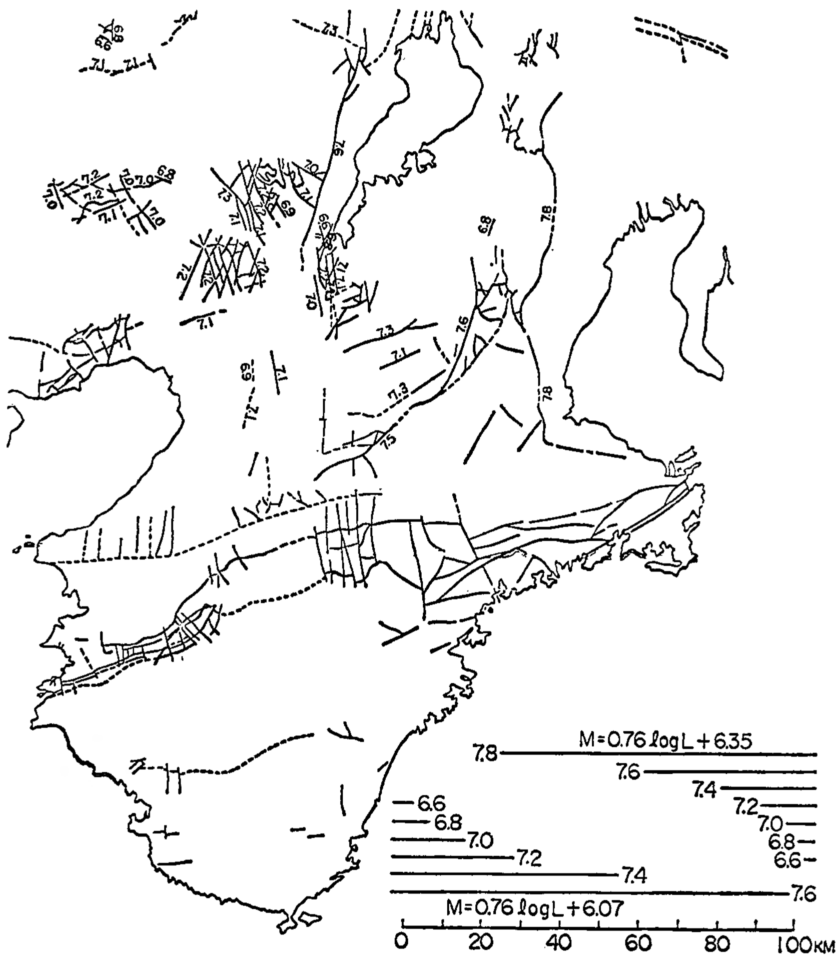


Fig. 4. Seismic magnitude M corresponds to fault in the middle part of the Kinki District.

8 cm against Otsu city during the period 1934–1948. Imazu city has risen *8 cm* against Otsu city during the period 1948–1968. Namely, the northern part of Kyoto Prefecture and the east-northern side of Biwa Lake risen, and the southern part of Kyoto Prefecture has fallen, recently. According to the observations made on the sea-level by means of the tide gauges[27], Miyazu and Maizuru have been rising 3 mm per year for about 20 years.

Results of the triangulations[28] in Kinki District and that of the observations of the crustal movements[29] at Osakayama similarly show that the crust around Kyoto Prefecture has extended in the direction of the south-east to north-west as shown in Fig. 5. It looks all the blocks constituting the crust in the Kinki District are scattering toward the north and the south with the R. Yodo as a center line.

According to study of C. Tsuboi[30], A. Jitsukawa and M. Tajima, there are

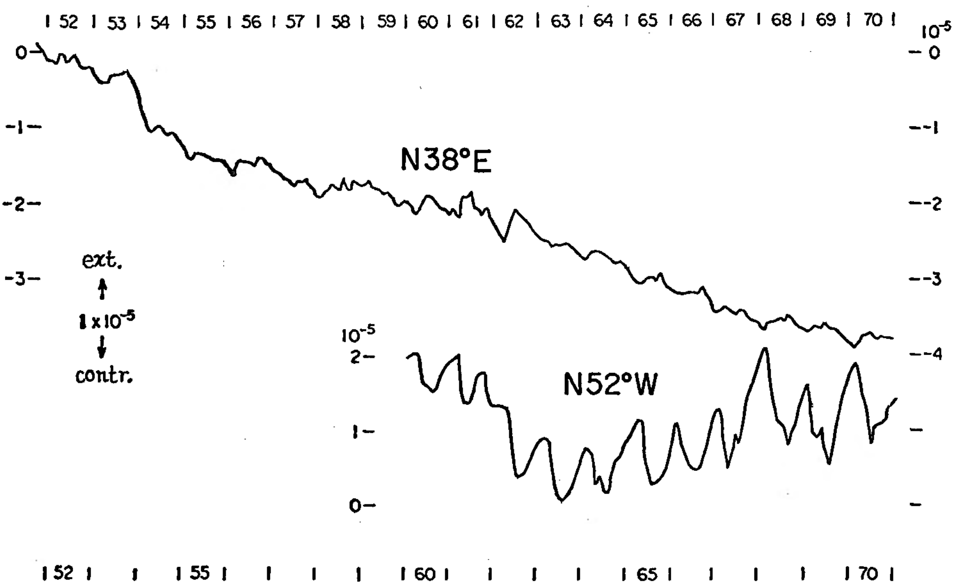


Fig. 5. Secular changes of linear strains of the ground at Osakayama.

eyes of Bouguer anomaly of the gravity acceleration in the regions of Miyazu-Maizuru and of Yakuno. And the gradient of the anomaly is much large on the western part of Biwa Lake.

M. Tajĭma[31)] has found that the secular change of the terrestrial magnetism has been anomalously large and recently its change has assumed to *3.9 gammas* per year in total intensity around Wakasa Bay.

The author (I. Ozawa) studied twenty or more seismic blocks in and by Kyoto Prefecture, and he estimates that the maximum seismic magnitude corresponds to their areas of these blocks using the formula of $\log A=0.90\ M+6.50$ shown as in Fig. 6 and 7. The one dotted chain line — • — shows the boundary of the block contains a few blocks which are closed with the full lines, and the two dotted chain line — •• — shows the boundary of the block contains a few blocks which are closed with one dotted chain lines in these figures. The numbers in these figures show the maximum magnitudes correspond to each block. We can see that there is the seismic block of $M=7.8$ in Tanba plateau, $M=7.\ 6$ around Biwa Lake, $M=7.6$ in the region of Miyazu-Maizuru, $M=7.4$ in the region of Yamashiro and so on.

According to the Seismological Bulletin of Japan Meteorological Agency, we can find no earthquake in the region of Miyazu-Maizuru and that of Yamashiro since 1885 as shown in Fig. 8. The estimated maximum magnitudes of the coming earthquakes are *7.6* in the region of Miyazu-Maizuru, and *7.4* in the region of Yamashiro. The periods of these greatest earthquakes are about *1,000* years long in the northern part, and about *500* years long in the sourthern part of Kyoto Prefecture, respectively.

Fig. 9 and 10 show the time transitions of the epicentral distances whose magni-

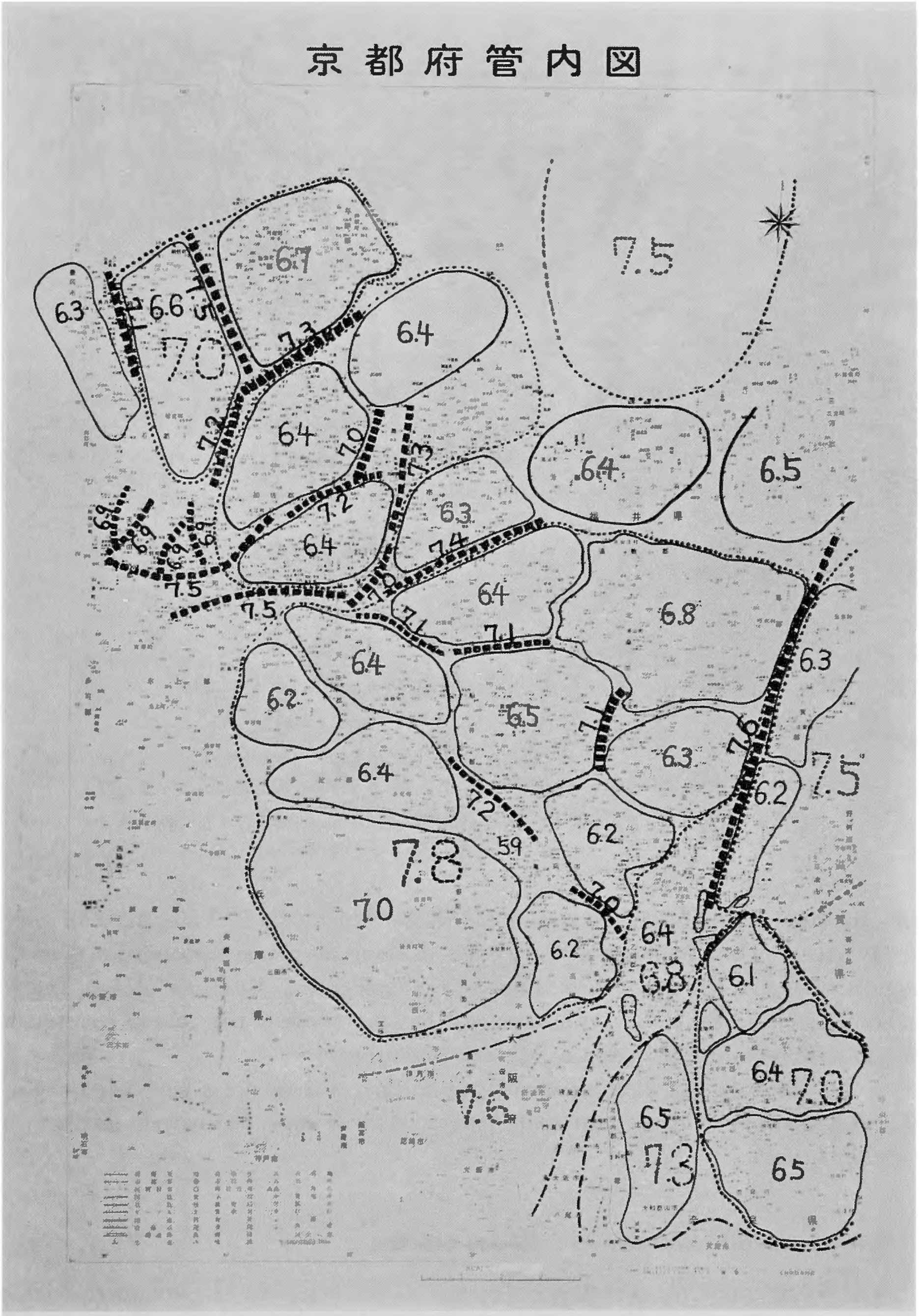


Fig. 6. Seismic magnitude M correspond to active block around Kyoto Prefecture.

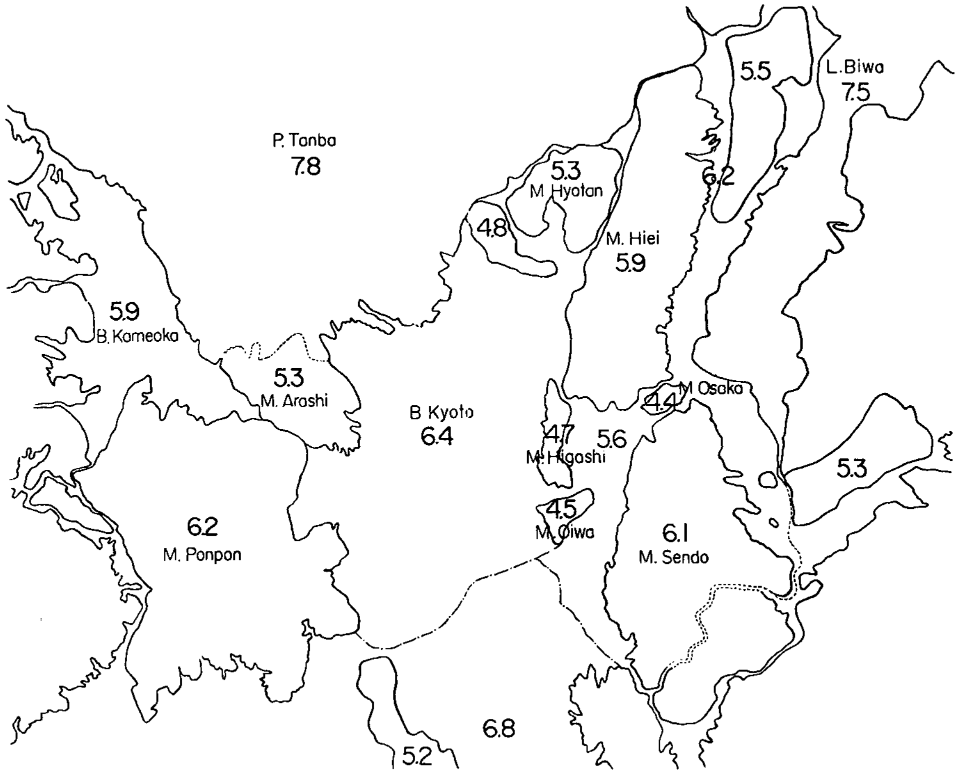


Fig. 7. Seismic magnitude M correspond to active block around Kyoto city.

tudes are larger than *3.5* at the region of Miyazu-Maizuru and Yamashiro for every *5* or *20* years. The diameters of the circles in these figures are proportional to the magnitudes. According to these figures, the epicentral distances of the nearest earthquakes have been almost constant, but the magnitude of the nearest earthquake gradually decrease in the region of Miyazu-Maizuru.

As the transitions of these seismicities at borders of these areas have been negligible, the possibility of maximum earthquakes in these areas fortunately seems to be in the far future.

4. Size of seismic activity in various blocks.

The seismic activity is estimated by use of the relations of Gutenberg-Richter and Ishimoto-Iida, provided that the seismic data is abundant. On the contrary, if there is little seismicity in the pending region, we are forced to use the seismicity in the adjacent regions, or the geodetic or geographical conditions. There were

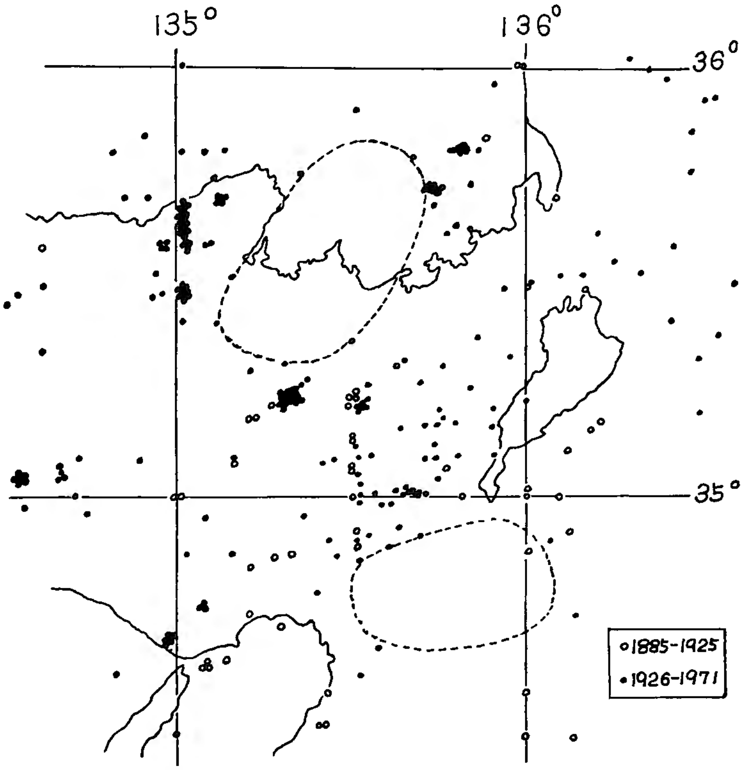


Fig. 8. Locations of seismic epicenters in the northern part of Kinki District for the period from 1885 to 1971, and blank region of earthquake nowadays.

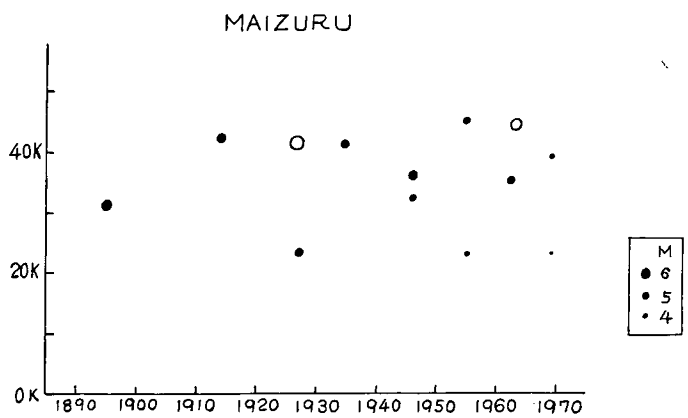


Fig. 9. Time transition of the epicentral distance of the nearest earthquake at the center of the seismic blank in the region of Miyazu-Maizuru.

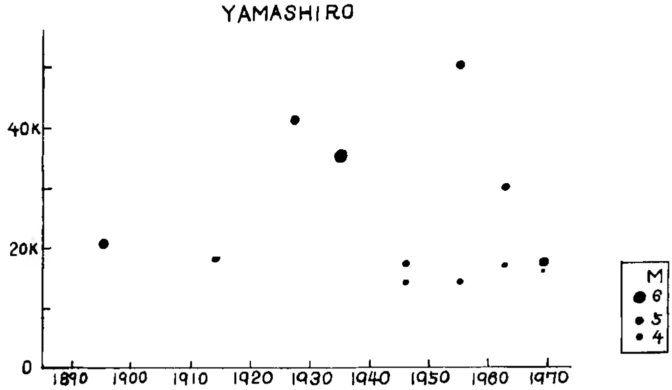
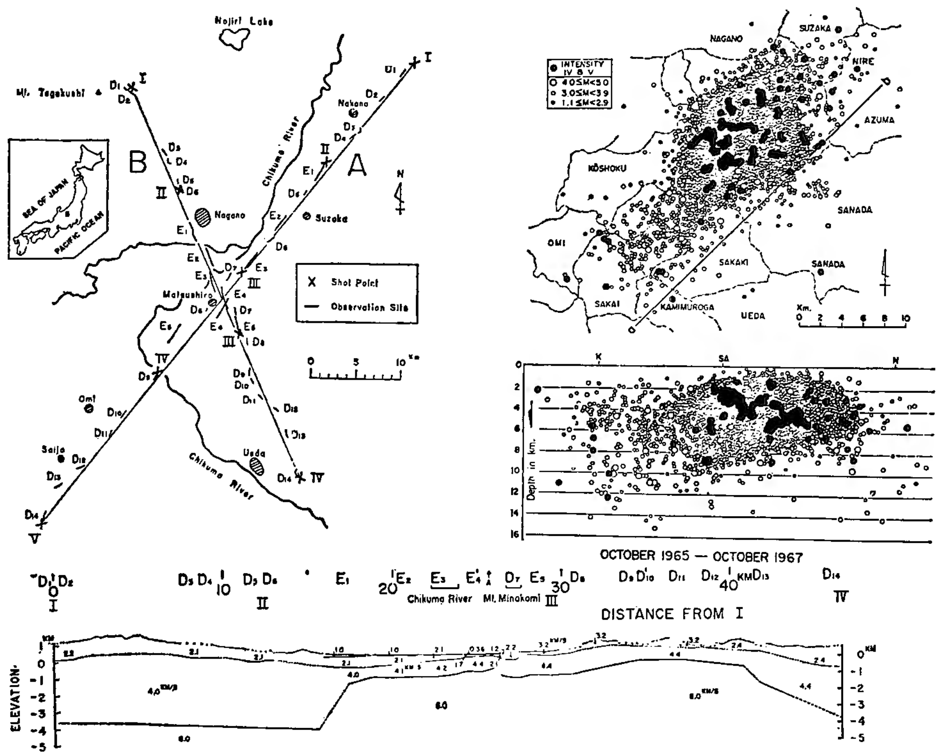


Fig. 10. Time transition of the epicentral distance of the nearest earthquake at the center of the seismic blank in the region of Yamashiro.



ig. 11. Underground structure analysed by means of seismic prospecting in Matsushiro Area, and the distributions of the hypocenters of the earthquake swarm. (after S. Asano)

the seismic regions on the protruding areas in the Great Kanto Earthquake of 1923, in the Great Kita-Tango Earthquake of 1927, in the Izu Earthquake Swarm of 1930 and in the Matsushiro Earthquake Swarm of about 1966. S. Asano[32] et. al. have found that the Matsushiro Earthquake Swarm had been on and in the swelling block of tertiary granitic rock as shown in Fig. 11. As a somewhat different idea, great earthquakes with the excepting volcanic earthquakes do not occure at volcanic areas. On the other hand, Y. Ota[33] et. al. have found that great earthquakes do not break out in the centers of swelling areas, but at the borders between the swelling and sinking areas. This idea agrees with that of Matuzawa[34] who has found that the main shock is on the edge of the area of aftershocks.

Almost all destructive earthquakes have occured at young strutum, but a few earthquakes have taken place at old strutum like palaeozoic area. For example, *10* or *11* destructive earthquakes have occured at palaeozoic areas among the 313 earthquakes that have occured in Japan since 1616. It seems that many great earthquakes have occured on the boundary between the palaeozoic plateaue and the alluvial plane, and the alluvial planes have been subsided as if the earthquakes have occured at sinking areas. Even if the ground rises in the earthquake, people fail to recognize this as the neighbouring areas subside. Perhaps, the earthquakes and apparent sinking have been repeated for long times at the law of cause and effect.

We have found some methods as mentioned above from which we can estimate the magnitudes of future earthquakes, whenever that are no data of seismic activity, seismic history and so on.

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