# 26. *Recent Earthquakes of the Kwanto District.*

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It may be well before proceeding with this paper to point out that although earthquake activity in the southeastern part of Japan, i.e. the Kwanto district and its vicinity, declined during the more than ten years that followed the great earthquake of September 1, 1923, in recent years, no less than thirty shocks have been felt annually in Tokyo. These activities may be said to be quite ordinary compared with those in the years that preceded the great earthquake above-mentioned, in which period the activities did not differ from those in recent years.

Our observations of earthquakes of this district have been continued up to the present, the numerical data of earthquakes that were felt in Tokyo having already been published in the "Seismometrical Report" of our Institute. A number of papers relating to earthquakes of this district have also been published by various authors.[1), 2)]

Our earlier paper[3)] mainly dealt with the problem of the three dimensional distribution of the foci of earthquakes felt in Tokyo during the years from 1924 to 1936, showing that most of the shocks that occurred in this district originated from depths shallower than 70 km, excepting a few shocks of rather deep seated origins, to which we shall come back as we proceed in this paper.

Another problem that will be dealt with in this paper is migration of the seismically active centers in the Kwanto district. During the four years from 1936 to 1939, Tokyo had 185 sensible shocks which, for convenience, are here divided into eight groups according to the times of their occurrence, and the distribution of the epicenters of these earthquakes was considered for each semi-annual period, upon doing which, it was found that there had been considerable changes in the positions of the seismically active centers. Since they will be helpful

1) T. KODAIRA, "Earthquakes of the Kwanto District." *Bull. Earthq. Res. Inst.*, **11** (1933), 350~361.

2) T. NAGATA, "Space Distribution of Earthquake Hypocentres in the Kwanto District." *Bull. Earthq. Res. Inst.*, **14** (1936), 420~426.

3) N. NASU, T. HAGIWARA and S. OMOTE, "Studies on Earthquakes in the Kwanto District." *Bull. Earthq. Res. Inst.*, **14** (1936), 427~437.

in explaining these changes, brief notes on the earthquakes that occurred in each period are given in this paper.

As to the annual changes in the seismicity of the special regions, as will be shown later, statistics of the annual number of earthquakes from 1924 to 1939 were compiled, which showed that in regions that were once seriously affected by the great earthquake of 1923, the number of shocks that originated from them gradually diminished, whereas in other regions the number increased.

*Network of Observations.*

As already stated, our network of observations was expanded so that it would cover the whole region in which earthquakes were most active. Of this network, however, in the Sea off the coast of Iwaki and the sea to the south of the Boso Penninsula, for example, earthquakes were also frequent, as well as on land, but in the case of these earthquakes, the results obtained from the present network of seismological stations did not give very accurate values.

The seismological stations where records have been continuously obtained are shown in Table I.

Table I. The seismological stations.

| Station | Position | | | | | | Approximate distance from Hongo (km). |
|---|---|---|---|---|---|---|---|
| | Longitude (E) | | | Latitude (N) | | | |
| Hongo (Tokyo) | 139° | 45′ | 59″ | 35° | 42′ | 40″ | 0 |
| Komaba | 139 | 41 | 01 | 35 | 39 | 18 | 10 |
| Mitaka | 139 | 32 | 32 | 35 | 40 | 21 | 20 |
| Tukuba | 140 | 06 | 36 | 36 | 12 | 39 | 64 |
| Kamakura | 139 | 32 | 39 | 35 | 18 | 32 | 48 |
| Misaki | 139 | 37 | 05 | 35 | 09 | 26 | 62 |
| Kiyosumi | 140 | 09 | 02 | 35 | 09 | 22 | 70 |
| Titibu | 139 | 04 | 54 | 35 | 58 | 56 | 69 |
| Koyama | 138 | 58 | 59 | 35 | 21 | 20 | 82 |
| Yosiwara | 138 | 41 | 07 | 35 | 09 | 35 | 116 |
| Susaki | 138 | 58 | 50 | 34 | 39 | 54 | 138 |

The last station, Susaki, is the Mitui Geophysical Institute, who supplied us with data for computing the positions of the seismic foci.

*Determination of the Seismic Focus.*

As usual, the positions of the seismic foci were determined graphically by means of the durations of the preliminary tremors at the respective stations.

*Earthquakes during the years 1936 to 1939.*

As already mentioned, 185 sensible earthquakes were experienced in Tokyo during the four years from 1936 to 1939, of which those whose epicenters and focal depths could be determined were 130, and those whose epicenters alone could be determined were 48, while for the remaining 7, these two data were undeterminable.

In studying the migration of seismically active centers, the following brief notes on the earthquakes for each year will be helpful.

*Earthquakes in 1936.*

In the earlier half of 1936, Tokyo had 13 sensible earthquakes, ten of which were distributed on the land side, including four that occurred in the Bay of Tokyo, while the remaining three were at sea, in the Pacific Ocean. Of these three shocks, in the one that occurred on April 26, the duration of the preliminary tremors was 51·2 sec in Tokyo and 46·0 sec at Susaki. The epicenter of this earthquake was at a point the coordinates of which were $\lambda=138{\cdot}86°$E, $\varphi=33{\cdot}48°$N, i.e., a distance of about 120 km due south of the cape of Idu Penninsula. This earthquake was one of the rare shocks that were sensible in Tokyo, notwithstanding its rather large epicentral distance.

Comparing the distribution of the eighteen earthquakes that were felt in the latter half of 1936 with those felt in the earlier half of the same year, a considerable change in the seismically active center will be noticed in that over half of the earthquakes that occurred in the latter half of that year, namely, eleven shocks, were on the sea side, and the remaining seven on the land side. Of these earthquakes, the one that occurred on November 3 was strongest at Tukuba, where its intensity was estimated at IV (rather strong), although, fortunately, there was no damage.

Near the southwestern extremity of our network of stations a shock was experienced on October 20, the duration of preliminary tremors of which was 6·9 sec at Yosiwara, its epicenter being the lower part of the River Huzi, and its focal depth 30 km.

*Earthquakes in 1937.*

In the earlier half of 1937, the sensible earthquakes in Tokyo numbered seventeen, the epicenters of sixteen of which could be determined, excepting the one that occurred on May 29. Seeing that the

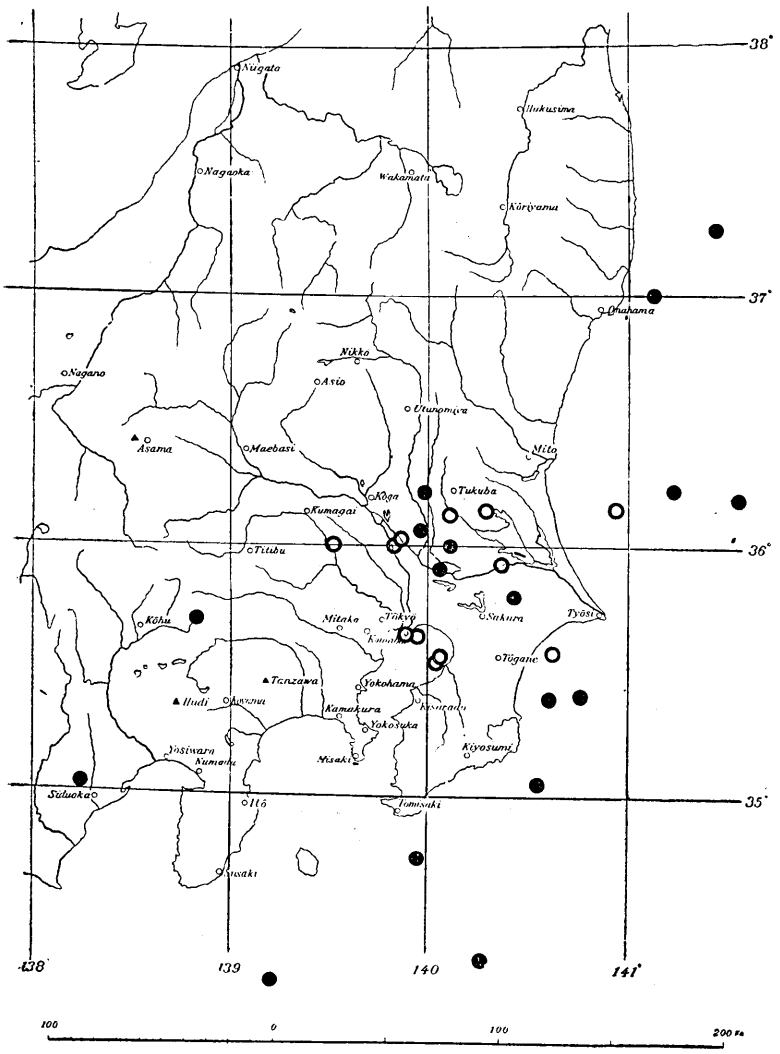


Fig. 1. Epicenters of the earthquakes that occurred in 1936.
Open circles are earthquakes of the first half of the year and closed circles earthquakes of the second half of the same year.

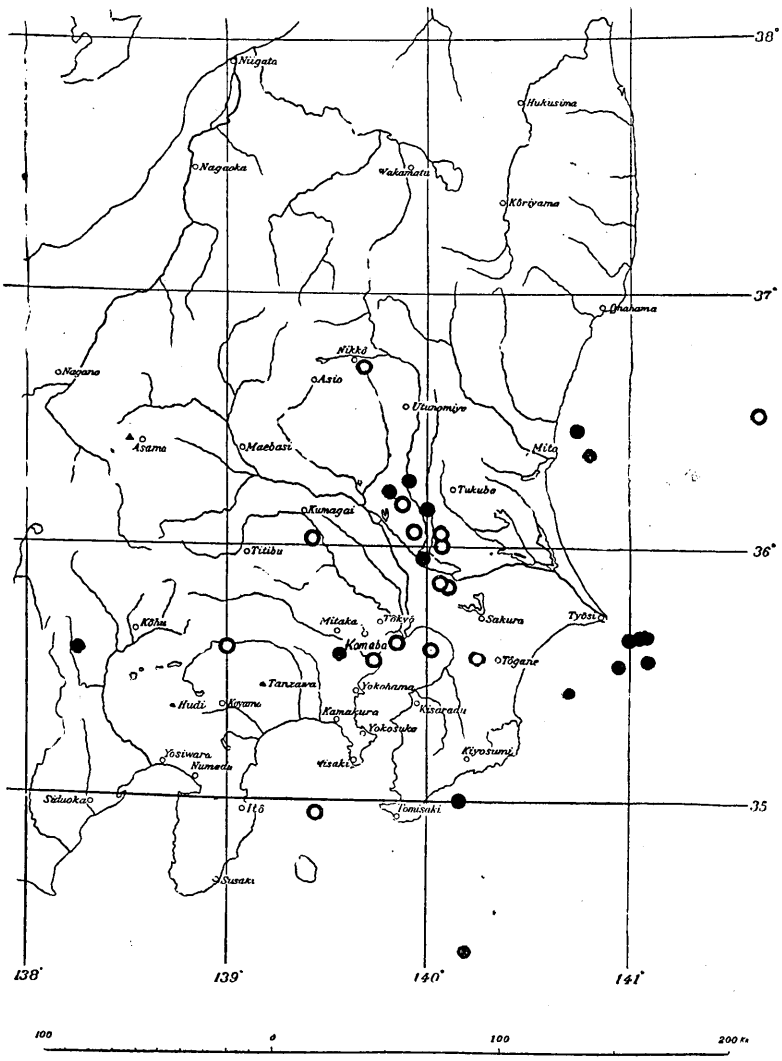


Fig. 2. Epicenters of earthquakes that occurred in 1937.

duration of its preliminary tremors exceeded 120 sec at all our stations, its origin was probably situated very far from the network of stations, so that the accurate position could not be determined by our network.

Of the sixteen shocks mentioned above, only two were in the Pacific Ocean, or to be more precise, in the sea off the northeastern coast of the Kwanto district.

In that region lying southwest of Mt. Tukuba, that is, on the river sides of Kinugawa and Tone, the earthquakes were always so active, that they were probably most densely distributed there. No marked change in the number of shocks could be seen; seven epicenters were distributed over this region.

During this period, three more shocks occurred in the Bay of Tokyo, the focal depths of which were 35, 40, and 50 km.

In the latter half of 1937, fourteen earthquakes were felt in Tokyo. What is remarkable is that six of them swarmed on the sea side near the cape of Inubozaki. The focal depths of these shocks were comparatively small, being estimated at between 30 and 40 km.

Two more shocks had their epicenters in the sea due east of Mito, where the earthquakes showed gradual increase in activity the following year, 1938.

### *Earthquakes in 1938.*

In the period from January to June 1938, the earthquakes in the northeastern sea of the Kwanto district, that is, in the open sea of Kasima and the sea off the coast of Iwaki Province, suddenly increased in number, nine of them having been felt in Tokyo. Of these, the one that occurred on May 23 was so strong that, at Tukuba, its intensity exceeded IV. Acceleration seismographs there showed that the maximum accelerations of the EW component and the vertical component were 27·0 gal and 29·0 gal respectively. Unfortunately, the NS component seismograph failed to give complete data.

The maximum displacements as observed in Tokyo were as follows; 60·3 mm in the NS component and 33·13 mm in the EW component. The periods of these waves were 8·8 and 9·9 sec respectively. The focal depth of this earthquake was worked out to be 80 km, being rather deep compared with the other shock that occurred in this region.

On the land side, one more remarkable earthquake occurred on Feb. 7. This earthquake had its epicenter northwest of Kumagai and a focal depth of 100 km. The intensity of the shock was estimated at IV in the City of Tokyo and its neighbourhood, for example, at Komaba and Mitaka. The maximum accelerations of the NS component, EW component, and the vertical component as measured at Hongo were 19·2, 27·6, and 6·8 gal respectively. The maximum displacements recorded at

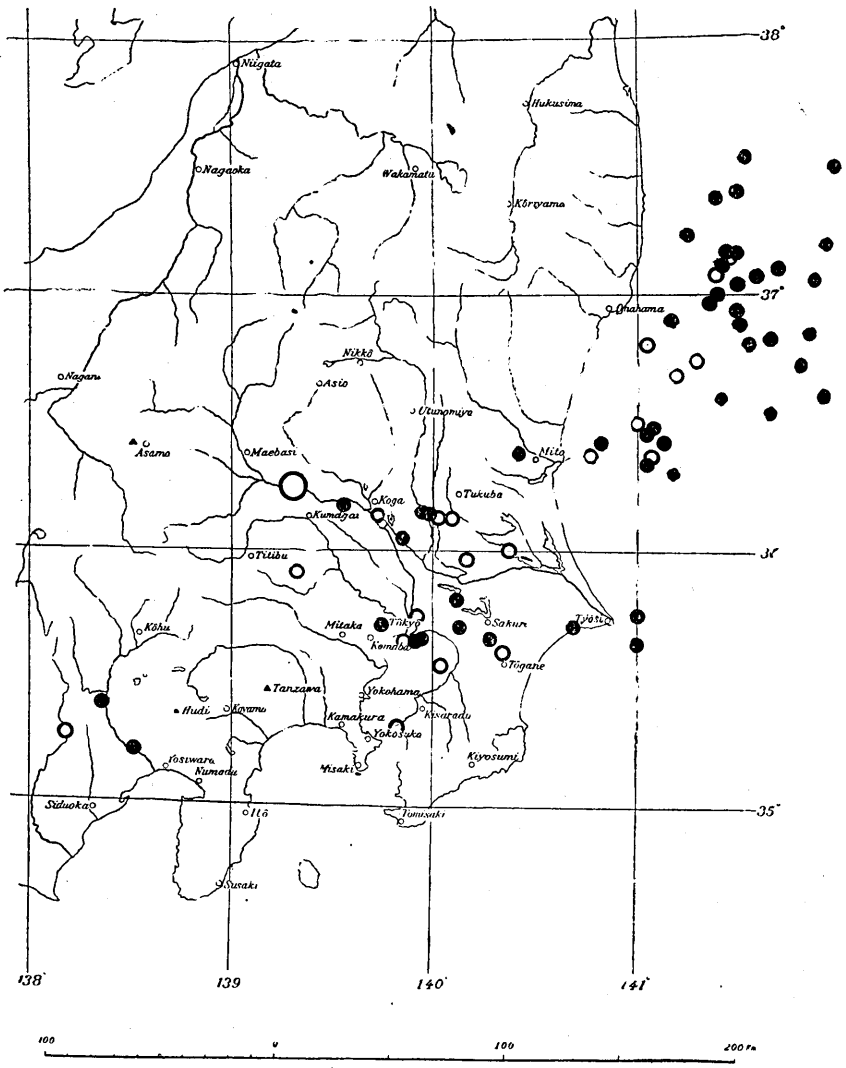


Fig. 3. Epicenters of earthquakes that occurred in 1938.

the same station were 25·6 mm in the NS component and 19·0 mm in the EW component. The initial motion of the earthquake registered by the displacement seismographs at Hongo were 1 $\mu$ southward, 2 $\mu$ eastward, and 14 $\mu$ upward. At Mitaka the vertical component of the initial motion predominated in magnitude, being 491 $\mu$ upward, while in the NS component it was 14 $\mu$ southward and 6 $\mu$ eastward respectively. This predominance in the vertical component motion might be caused by steepening in the angle of dip of the path of the rays along which the seismic waves proceed with increasing depth.

From our observations in the Kwanto district, the earthquakes that originated from depths, such as more than 100km, were not so numerous. In our previous paper, we maintained the existence of such earthquakes as would either be restricted to comparatively small regions or arranged in a narrow zone, which was amply proved by the earthquake of February 7.

In the latter half of 1938, earthquakes were most active in November, the sensible earthquakes in this month totalling 25, followed by December, in which month 12 shocks were felt in Tokyo. The total number of earthquakes in the latter half of this year reached 54, of which the number of those whose epicenters could be determined were 48.

A remarkable feature about the distribution of epicenters was that on the sea side, earthquakes clustered in two groups, the region occupied by the first group having as its approximate center a point, the coordinates of which were $\lambda=141{\cdot}7°\mathrm{E}$ $\varphi=37{\cdot}0°\mathrm{N}$, while the area occupied by the second group was much smaller than the former, and lay south of it and east of Mito.

Besides the earthquakes mentioned above, there were two shocks on the seaside near the cape of Inubo, where shocks were active in the latter half of 1937.

Of earthquakes belonging to the first group, the severest was that which occurred on November 5, its intensity at Tokyo being estimated at IV. The acceleration seismograms obtained at Hongo showed that the maximum accelerations of the NS–, EW–, vertical components were 32·3, 32·3, and 11·7 gal respectively. The maximum displacements registered there were 99·4 mm, with a period of 14·0 sec in the NS component, and 69·25 mm, with a period of 13·8 sec, in the EW component.

Because the earthquakes belonging to this group extended far beyond our network of stations, most of their focal depths either showed errors or were indeterminable, but from computations of the initial motions at individual stations, such as Hongo and Kamakura, it could be said that most of them originated from depths not greater than 50 km or more.

On the other hand, the seven earthquakes belonging to the second group originated from depths between 40 and 60 km. In intensity, as felt in Tokyo, none of them exceeded II.

Two shocks were experienced west of Mt. Huzi. Their origins were comparatively shallow, their focal depths being 30 km.

A number of earthquakes had their epicenters near Tokyo and Tiba, the depths of most of which exceeded 50 km.

*Earthquakes in 1939.*

Tokyo felt 26 sensible earthquakes in the first half of this year, one of which was the strong earthquake of the Oga Peninsula, Akita Prefecture, that occurred on May 1. The intensity of this earthquake

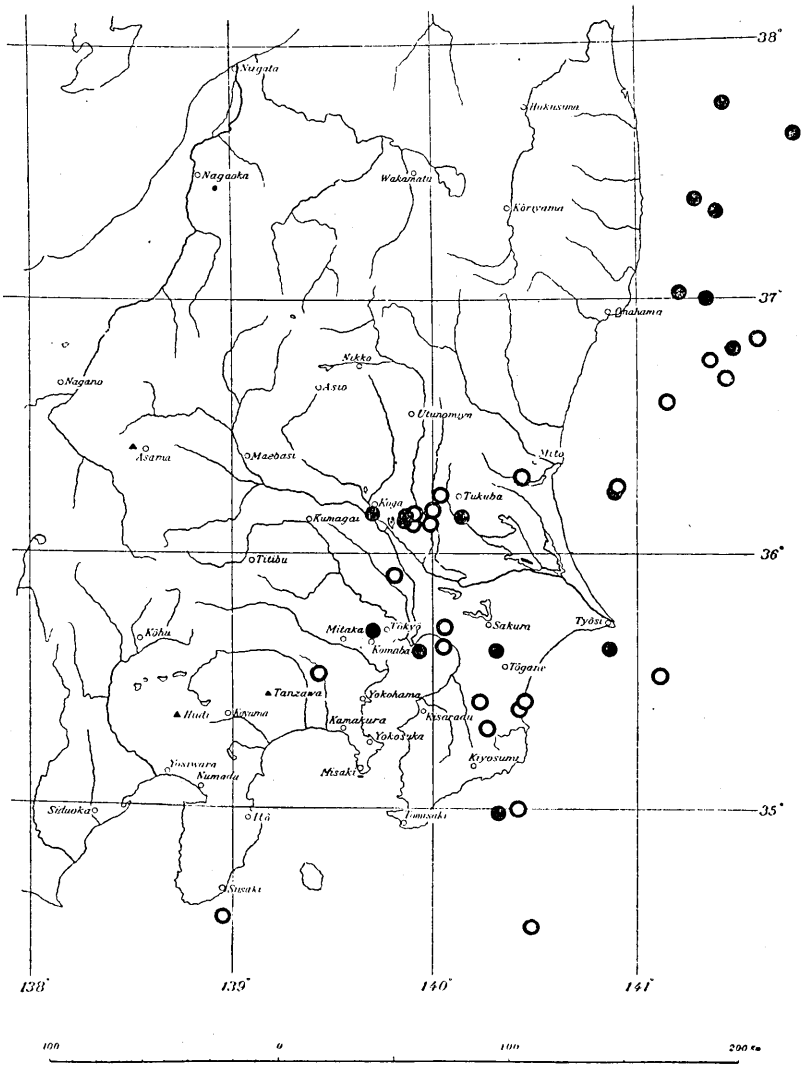


Fig. 4. Epicenters of earthquakes that occurred in 1939.

in Tokyo, however, did not exceed I (slight), the maximum accelerations of the NS component being 1·02 gal, the EW component 1·14 gal, and the vertical component 0·81 gal. The displacement seismograms gave

a maximum range of 20·00 mm, with a period of 7·28 sec in the NS component and that of 16·70 mm with a period of 8·0 sec in the EW component.

The following notes apply to seismic activities in the Kwanto district during this period.

The earthquakes were distributed in a region lying west of Mt. Tukuba and in the northeastern sea. As already mentioned, in the former region the earthquakes were constantly active, while in the latter region the activities were continuations of those in the previous year.

Another remarkable distribution in the epicenters was that four centers were found near the middle part of the Boso Peninsula, where it was found that these originated from comparatively shallow origins, their focal depths being less than 30 km.

In the latter half of 1939, eighteen earthquakes were felt. Upon comparing the distribution of the epicenters for this period with that for the earlier half of the same year, it was found that the seismically active center on the seaside migrated northward during the latter half of that year, because then the epicenters were mostly distributed north of latitude 37°, while in the earlier half they were distributed south of it.

Generally speaking, the recent earthquakes of the Kwanto district so far mentioned were mostly distributed east of the region just mentioned. By drawing a line corresponding to longitude 139·5° it will be found that the epicenters of the earthquakes are densely distributed east of it, whereas they are rare west of it.

Another noteworthy point is that, on the land side, the active region may be bordered by a line that passes through Mito in an E–W direction. Excepting the one that occurred near the Oga Peninsula on May 1, 1938, in that region lying north of this line, no sensible earthquake occurred during the period in question. This earthquake, which was especially severe, originated some distance away from the Kwanto district.

It must be remembered that the distribution, as mentioned above, was restricted to earthquakes of recent years, with the result that earthquakes of a different period will show different distribution. For example, the adjacent region lying west of the meridian line just drawn, namely, that covering the greater part of the two Prefectures of Kanagawa and Saitama, the Bay of Sagami, and the northeastern part of the Idu Peninsula, became very active during the ten years or so following the great earthquake of 1923. We may recall that numerous aftershocks of this great earthquake occurred, the countless shocks of the

so-called "Ito earthquake-swarms" of 1930, the destructive earthquake of the same year, and the strong earthquake of Saitama in 1932.

From these facts it may be concluded that, at present, seismic activity in the Kwanto district is limited to its eastern part, the active center in the last recent few years having migrated eastward or northeastward.

*Annual changes in seismicity in various parts of the Kwanto District.*

For the purpose of studying the annual changes in seismic activity in various parts of this district, the following eight regions were selected;

(1) Tokyo Bay
(2) Sagami Bay
(3) The provinces of Sagami and Kai
(4) The Boso Peninsula
(5) The sea off the coast of Kuzyukuri
(6) The sea south of Katuura
(7) The Kasima Sea
(8) The basin of the River Kinu.

The boundaries of these regions, as shown in Fig. 5, being merely for convenience, may have no definite meaning, either geologically or geographically. Table II contains a count of the annual number of earthquakes that originated in the respective regions between 1924 and 1939.

Table II. Annual numbers of earthquakes and their means for five years.

| Region | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A, M / Year | A | M | A | M | A | M | A | M | A | M | A | M | A | M | A | M |
| 1924 | 11 | | 2 | | 12 | | 5 | | 1 | | 0 | | 0 | | 5 | |
| 1925 | 6 | | 2 | | 1 | | 4 | | 1 | | 0 | | 2 | | 8 | |
| 1926 | 7 | 8·6 | 2 | 1·6 | 2 | 5·6 | 9 | 6·2 | 1 | 1·0 | 1 | 0·4 | 2 | 3·0 | 10 | 11·4 |
| 1927 | 6 | 8·4 | 2 | 1·8 | 10 | 4·6 | 6 | 6·2 | 0 | 1·4 | 1 | 0·4 | 6 | 3·6 | 12 | 11·6 |
| 1928 | 13 | 8·4 | 0 | 2·2 | 3 | 4·8 | 7 | 6·2 | 2 | 2·4 | 0 | 0·4 | 5 | 4·8 | 22 | 11·4 |
| 1929 | 10 | 7·8 | 3 | 2·4 | 7 | 5·0 | 5 | 5·2 | 3 | 3·0 | 0 | 0·8 | 3 | 5·8 | 6 | 11·8 |
| 1930 | 6 | 7·8 | 4 | 2·0 | 2 | 4·9 | 4 | 5·2 | 6 | 3·8 | 0 | 0·6 | 8 | 5·4 | 7 | 13·0 |
| 1931 | 4 | 6·2 | 3 | 2·4 | 7 | 3·8 | 4 | 4·0 | 4 | 4·6 | 3 | 1·0 | 7 | 7·0 | 12 | 11·2 |
| 1932 | 6 | 5·2 | 0 | 2·2 | 1 | 2·8 | 6 | 4·2 | 4 | 4·4 | 0 | 1·8 | 4 | 7·8 | 18 | 12·4 |
| 1933 | 5 | 6·0 | 2 | 2·0 | 2 | 3·8 | 1 | 4·6 | 6 | 3·8 | 2 | 3·2 | 13 | 7·0 | 12 | 14·4 |
| 1934 | 5 | 6·0 | 2 | 1·4 | 2 | 1·6 | 6 | 3·8 | 2 | 3·6 | 4 | 3·2 | 7 | 6·2 | 13 | 13·4 |
| 1935 | 10 | 5·2 | 3 | 1·6 | 3 | 1·6 | 6 | 2·8 | 3 | 4·0 | 7 | 3·4 | 4 | 5·8 | 17 | 12·0 |
| 1936 | 4 | 5·2 | 0 | 1·2 | 0 | 1·2 | 0 | 3·2 | 3 | 3·2 | 3 | 3·0 | 3 | 8·4 | 7 | 11·2 |
| 1937 | 2 | 4·6 | 1 | 0·8 | 1 | 1·0 | 1 | 2·8 | 6 | 3·4 | 1 | 2·8 | 2 | 8·6 | 11 | 10·8 |
| 1938 | 5 | | 0 | | 3 | | 3 | | 2 | | 0 | | 26 | | 8 | |
| 1939 | 2 | | 0 | | 1 | | 4 | | 3 | | 3 | | 8 | | 11 | |

A=Annual number, M=Means for five years.

For our present purpose, however, it is better to take the overlapping means of these annual numbers. In doing so, the curves for the annual numbers may be smoothed, thus bringing out the general features of the seismic activity more clearly. In taking these overlapping means, care was taken to see that the divisions of years in which the means were taken did not extend to more than five, as otherwise the smoothed curves thus drawn might become too flat to show the actual tendencies. Thus the means of the annual numbers of five years were taken, this division being best suited to our present work.

By using these values of M, eight curves were drawn for the eight regions just mentioned, as in Fig. 6, in which three kinds of curves will be seen. The curves of the first kind descend, showing gradual decrease in activity with time, such as in the cases of Tokyo Bay, the Provinces of Sagami and Kai, and the Boso Peninsula all being regions affected by the great earthquake of September 1, 1923. According to Prof. A. Imamura[4] and Prof. Saem. Nakamura,[5] a number of conspicuous aftershocks followed this great earthquake. The epicenters of these aftershocks were distributed in the Bay and on the land of Sagami, densely, especially in the latter. On the other hand, a dense distribution of epicenters may be seen in the Boso Peninsula, where, however, the shocks were not so conspicuous as those in the former regions, although they were very numerous.

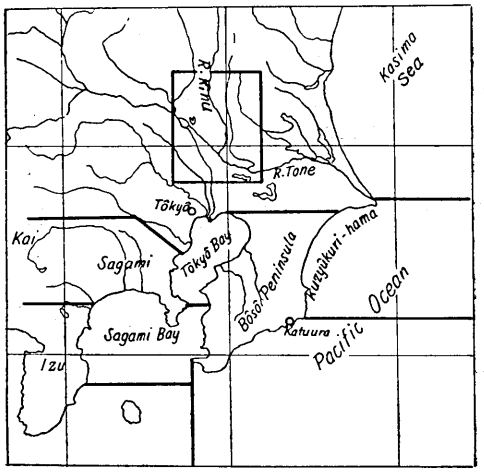

Fig. 5. Boundaries of the regions.

The curves of the second kind are those that begin as ascending curves, as in the case of the sea off the coast of Kuzyukuri, the sea to the south of Katuura and the Kasima Sea. The curves for the former two seas showed downward tendencies after they passed their maximum point, that is, they gradually declined in activity in recent years. In the case of the sea east of Kuzyukuri, the maximum was

4) A. IMAMURA, "The Great Kwanto (S. E. Japan) Earthquake on Sept. 1, 1923." *Report Imp. Earthq. Inv. Comm.*, No. 100, A. 1925.

5) Saemontaro NAKAMURA, "The Great Earthquake of S. E. Japan on Sept. 1, 1923," *ditto.*

in 1931, while in that of the sea south of Katuura, it was in 1935.

The curve for the Sea of Kasima, although somewhat undulatory, shows gradual increase in activity that lasted up to 1936, the year of its maximum.

Lastly, in curves of the third kind, no such clear tendencies as in the previous cases can be seen. These curves show that, notwithstanding the changes in seismic activity that may be seen from time to time, on the whole they are not marked. The typical curve was that for the region of the River Kinu. As often mentioned, earthquakes in this region were the most frequent in the Kwanto district. As shown in Table II, the annual number attained in 1928 a maximum of 22, whereas, in 1924, it was the minimum. The overlapping means, however, ranged between 14·40 and 10·80. The general tendency, as represented by using these overlapping means, suggests that the mean activity reached maximum in 1933, after which it slightly declined. Roughly speaking, the same degrees of activity were found at the beginning and the end of the period now under consideration.

*Distribution of Earthquakes of rather deep origin.*

Here, the words "rather deep" mean about 100 km below the surface of the earth.

During the period from 1924 to 1939, there were only nine earthquakes whose focal depths were deduced as being 100 km or more, the

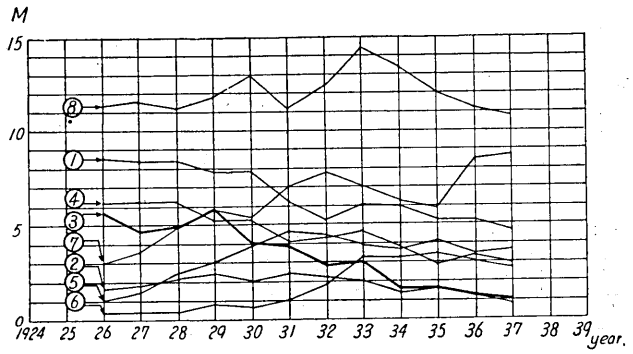


Fig. 6. Curves showing general tendencies of earthquake activity in various regions. (1=Tokyo Bay, 2=Sagami Bay, 3=The Provinces of Sagami and Kai, 4=Boso Peninsula, 5=The Sea off the coast of Kuzyukuri, 6=The Sea south of Katuura, 7=The Kasima Sea, 8=The Basin of the River Kinu.)

epicenters of which are indicated by crosses in Fig. 7. As will be seen from this figure, most of them are distributed in the western part of the Kwanto district, namely, three near Kumagai, one northwest of

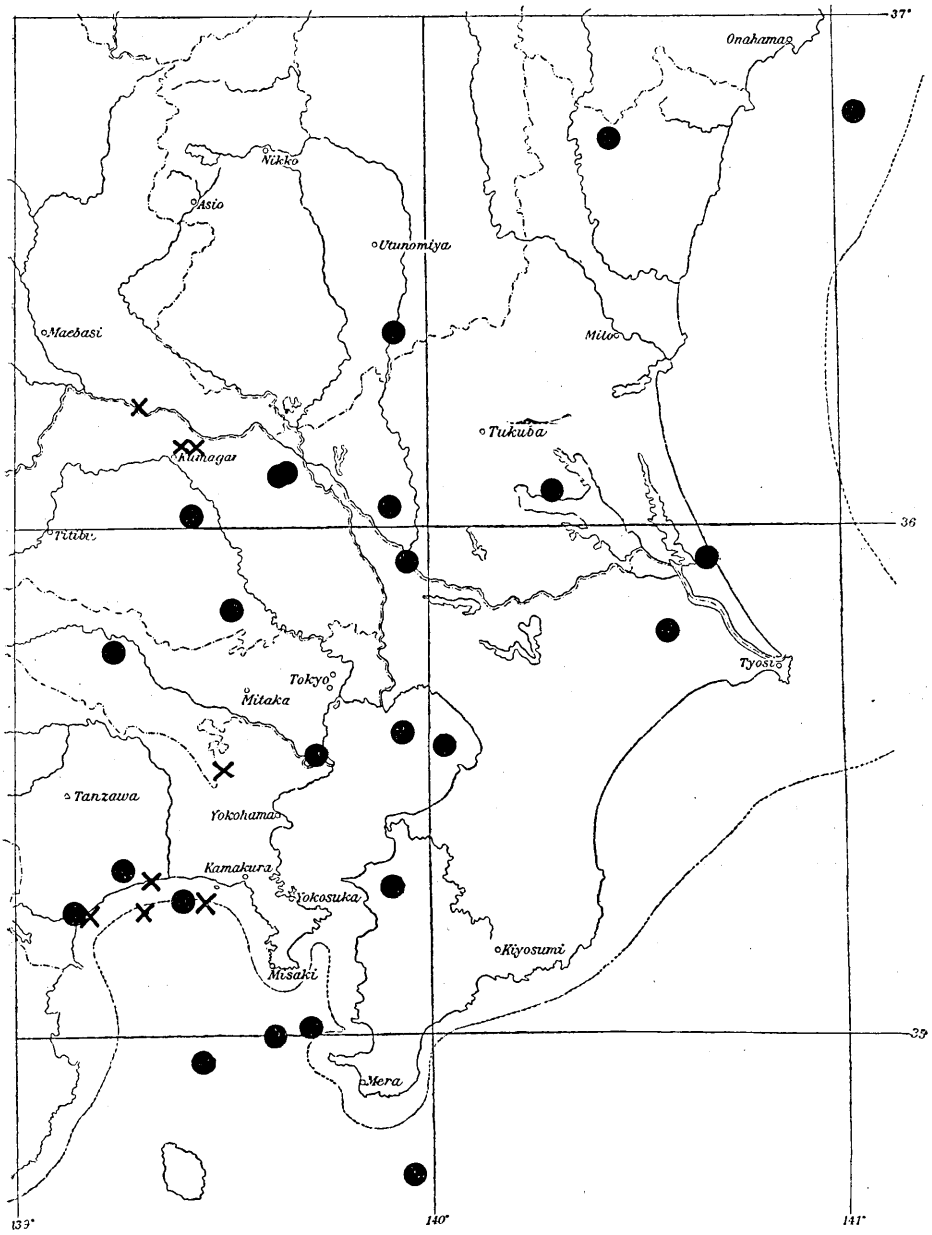


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Fig. 7. Epicenters of earthquakes of rather deep origin.

Crosses are earthquakes whose focal depths exceeded 100 km, shaded circles shocks whose focal depths were 80~100 km.

Yokohama, and four in the northern part of Sagami Bay. There is another one in the sea off the southern cape of the Boso Peninsula.

Although there were only a few epicenters of these shocks, there must be a zone or belt running in a N–S direction, or to be more precise, in a NNW–SSE direction, on which these epicenters ought to be distributed. As a matter of fact, the existence of such an earthquake belt can be deduced from the interesting studies of Dr. K. Wadati[6] and Dr. H. Honda,[7] which extended to the distribution of earthquakes in Japan as a whole, classifying the shocks according to their focal depths. The results show that besides the belt of deep seated earthquakes, there exist two other belts, from one of which originated earthquakes of rather deep origin, the focal depths ranging between 240 km and 100 km, and from the other, earthquakes of comparatively shallow origins less than 100 km. The former passes through the Kwanto district in the direction just mentioned, the epicenters of which, as indicated by crosses, being probably distributed in this belt. The other belt, which runs nearly parallel with the former, also passes through the eastern part of the same district.

In view of these facts, it may be concluded that earthquakes of rather deep origin occurred in the western part of the Kwanto district, while in the eastern part of it they were very rare.

For reference, the epicenters of shocks whose focal depths were deduced by computations to be 80～100 km are shown in Fig. 7. As to their epicenters, it was also found that they are mostly distributed in the western part of the district now under consideration.

*Acknowledgement.* We wish to record here our great indebtedness to the various observers, whose arduous labours provided the valuable data for the present work.

6) K. WADATI, "On the Activity of Deep-focus Earthquakes observed in the Japan Islands and Neighbourhoods." *Geophys. Mag.*, 8 (1934～1935), 305～325.

7) H. HONDA, *Kensin-Ziho*, **11** (1940), No. 2, 183～216.

# 26. 最近に於ける關東地方の地震に就いて

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此の論文には前年發表せる論文の續きとして主として昭和 11 年から同 14 年に至る期間に於いて起つた東京有感程地震に就いて述べてある．これらの地震の分布を半年毎に區切つて考へ，その結果から地震活動區域の移動狀態を推察したのである．これの說明に供するため各期間に起つた地震に就いて略述しておいた．

關東地方の地震を更に區別し，或る定まつた區域內に於ける地震活動の消長を見ることにした．この目的のため東京灣，以下 8 區域を選び，大正 13 年から昭和 14 年に至る 16 年間の地震觀測結果を用ひて此區域に起つた地震回數の統計を取つた．

統計の方法としては移動平均法を用ひ地震活動の一般的狀勢を見ることにした．その結果，相模灣，相模甲斐地方，房總半島等關東大地震の餘震が比較的多かつた地方に於ては近年地震活動は順次減衰の傾向を示してゐるがこれと正反對の傾向を示してゐる地方もある．例へば鹿島灘の如きがそれである．尙ほ鬼怒川附近は地震の最も多い所であり，昭和 3 年には東京有感地震回數は 22 となり最大値に達した．

關東地方に發生する震原の稍深い地震（深さ 100 粁以上）の分布を見るに關東地方の西部に限られてゐる．此の種の地震が發生する地帶が本州を略南北の方向に橫斷して存在することは旣に知られてゐることであるが尙ほこの研究に依つてその存在を確めることが出來た．