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16. *Some Features of Recent Seismic Activity in and near Japan (2) Activity before and after Great Earthquakes.*

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Abstract

Regularities in space and time distributions of recent seismic activity in and near Japan are discussed from the standpoint that the earthquake occurrences are a dynamical process. The recent seismic activity in the Japanese region is interpreted as four great earthquakes or earthquake groups and their fore- and aftershock sequences in a broad sense. Each series shows the following typical pattern: In the period (several～twenty years) just before a great event, the area where the great event occurs is abnormally calm and its surrounding wide area becomes markedly active (the foreshock activity in a broad sense). With the great event, the above-mentioned doughnut pattern of the seismic activity disappears and then the area in and near the focal region of the great earthquake becomes active (the aftershock activity in a broad sense). The area and the duration in which the foreshocks or aftershocks in a broad sense occur are very large in comparison with those in a strict sense. The regularity mentioned above may give a clue to predict the next great earthquakes. As another regularity, the migration process of the focal regions of major earthquakes in the Japanese region is again discussed. These regular features in the earthquake occurrences may be interpreted as those of fracture phenomena from the view-point of the fracture theory of earthquakes.

1. Introduction

According to the fracture theory of earthquakes as discussed by Mogi (1967), earthquakes occur by fracture of the earth's crust (including the upper mantle) and the probability of earthquake occurrence is a function of the stress (σ) and the fracture strength (S) which depends on the mechanical structure of the earth's crust. When σ and S are nearly constant in a considered period, earthquake occurrence will be stationary in time. In many previous studies, the seismicity of wide areas has been discussed from this standpoint. However, the generation of an earthquake causes more or less some changes in σ and S. In particular, the changes should be remarkable for large earthquakes, as seen typically in their aftershock phenomena. In this case, the seismic activity cannot be fully understood as a stationary process, but it should be discussed as a dynamical process.

From this point of view, the recent seismic activity in and near Japan was discussed in a preceding paper (Mogi, 1968e). It was found that great earthquakes in the Japanese region occurred to fill gaps of the seismic activity before them, as pointed out by Fedotov (1965) in Kamchatka-northeastern Japan, and that no large earthquakes with magnitude 7 and over occurred during about thirty years before these great earthquakes. In this paper, a systematic change of the seismic activity before and after great earthquakes is discussed in detail. According to the result, recent activity in the Japanese region appears to be a dynamic process related only to the four greatest earthquakes or earthquake series. Another regularity related to a dynamical feature of seismic activity is the migration phenomenon. Some cases showing clear migration are also discussed in this paper.

2. Procedure of investigation and materials used

The procedure of investigation and the earthquake data used in this paper are similar to those of the preceding paper (Mogi, 1968e). The seismic activity is discussed based on the distribution maps of focal regions of earthquakes with magnitude 6 and over for each period, although larger earthquakes ($M \geq 7$) only were located in the preceding paper. According to the previous paper, the distribution of earthquake energy density is approximately shown by the distribution of focal regions of major earthquakes. A focal region of an earthquake was indicated by a circle with a diameter calculated from the following equation (Utsu, 1961),

$$\log D = 0.5M - 1.8,$$

where D is the diameter of circle in kilometer, based on the hypothesis that the aftershock area corresponds to the focal region. For great earthquakes, observed aftershock areas are indicated as their focal regions. It should be noted that the areal density of earthquake energy in the focal region is higher in greater earthquakes.

The present discussion is limited to shallow earthquakes of focal depths of 100 km or less. When focal depths are unknown, they were assumed to be shallow ones. In fact, focal depths of most earthquakes were shallower than 60 km.

Earthquake data were adopted from *the Magnitude Catalogue of Major Earthquakes Which Occurred in the Vicinity of Japan (1885-1950)* by Japan

Meteorological Agency or JMA for the period (1885-1925), *Catalogue of Major Earthquakes in and near Japan (1926-1956), (1957-1962)* and *(1963-1967)* by JMA and the preliminary seismological report by JMA for the period (1926-1968). The present discussion is mainly based on recent seismic data which are more accurate.

3. Linear location and systematic displacement of focal regions of large earthquakes

According to the fracture theory of earthquakes, specific features corresponding to those of fracture generation or propagation may be expected in earthquake occurrences. Two such features are linear location and systematic displacement of earthquake epicenters.

(i) Linear distribution of earthquake epicenters

It is frequently pointed out that the focal regions of major earthquakes locate linearly along some tectonic structures. Very typical examples are seen in great fault regions in California and Turkey (e.g. Richter, 1958). In both regions, most of the major earthquakes have occurred on a long fault or its branches. In the Japanese region, also, there are some cases showing linear locations of earthquake epicenters which can be connected to known geological structures, but their lengths are small in comparison

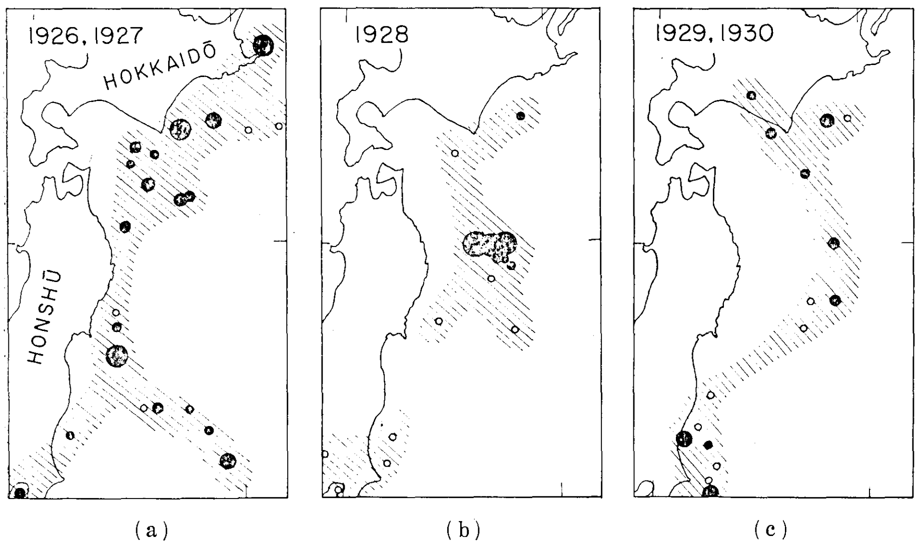


Fig. 1. Space distributions of focal regions of earthquakes in and around northeastern Japan in the successive periods (1926-1927), 1928 and (1929-1930). closed circle: $M \geq 6.0$; open circle: $5.7 \leq M < 6.0$.

to that of the San-Andreas fault in California (e.g. Kishimoto et al, 1966). However, the distribution of earthquakes in and near Japan is generally different from that in California and Turkey. The most active areas are located in belts along the Pacific coast of the Japanese islands (e.g. Mogi, 1968e). These belts are frequently wide and epicentral locations in the belts are complex, so they cannot be connected to a single fault. Such a typical case is seen in the outer seismic belt in northeastern Japan, which is one of the most active regions in the world. In this region, earthquake epicenters occasionally occur along a curved line, but this pattern changes rapidly. Figure 1 shows an example in which the pattern changed from (a) to (c) during five years interval. Such behavior seems to suggest a complex fracturing process in this highly active region.

The present study suggests a noticeable linear location of major earthquakes including several earthquakes which caused damage, such as the Kita-Izu and the Imaichi earthquakes. Epicenters of shallow earthquakes ($M \geq 6$) of focal depths less than 30 km, which occurred in northeastern Japan during the period (1926–1967), are shown by closed circles in Fig. 2. In this figure, the linear location of earthquake epicenters in the hatched zone ($\overline{ab}$), which is about 500 km long, is indicated. Furthermore, earthquake epicenters east of the Pacific coast of Honshū form a wide active zone parallel to the $\overline{ab}$ trend, and there is a marked non-active zone between these two active ones. As mentioned later, the earthquake series that occurred on the $\overline{ab}$ line shows a systematic migration from south to north. Thus, it may be concluded that the linear location of this earthquake series is not incidental, but it has a tectonic significance. The $\overline{ab}$ trend which crosses the Honshū arc at Sanriku and is nearly continuous to the Kurile arc does not strictly coincide with known geological structures, but it seems

Table 1. List of earthquakes showing migration in northeastern Honshū (along the $\overline{ab}$ line).

Name of Earthquake	Year	Date (J.S.T.)	Epicenter		Depth	Magnitude
			(°N)	(°E)	(km)	
Kita-Izu	1930	Nov. 26	35.1	139.0	0∼5	7.0
Yamanashi-tōbu	1931	June 11	35.4	138.9	0∼5	6.0
Saitama-nanbu	1931	June 17	35.8	139.3	0	6.3
Nishi-Saitama	1931	Sept. 21	36.1	139.2	10∼20	7.0
Tajima	1943	Aug. 12	37.3	139.8	15	6.1
Imaichi	1949	Dec. 26	36.7	139.7	0∼30	6.4
Imaichi	1949	Dec. 26	36.7	139.7	0∼30	6.7
Shiroishi	1956	Sept. 30	37.95	140.55	20	6.1
Miyagiken-hokubu	1962	April 30	38°44′	141°08′	0	6.5

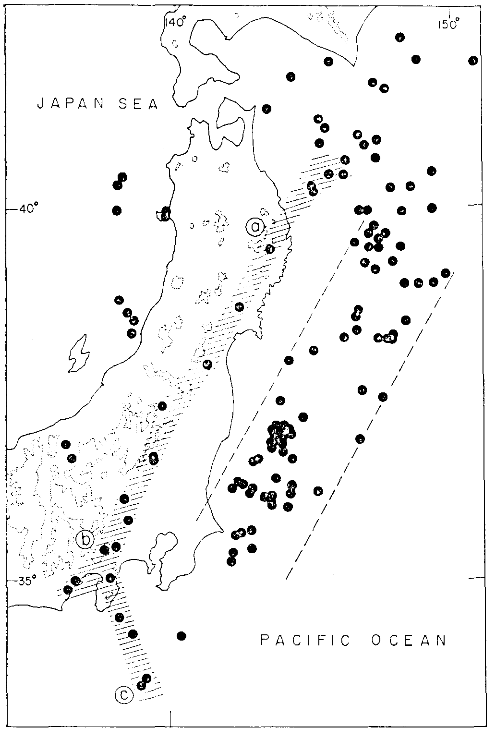


Fig. 2. Epicentral distribution of earthquakes, of which magnitudes are greater than 6.0 and focal depths are less than 30 km, in and around the northern Part of Honshū during the period (1926–1967). Linear location of epicenters in the hatched zone $\overline{ab}$ is remarked. dotted curves in the land area: topographic contour lines (1000m).

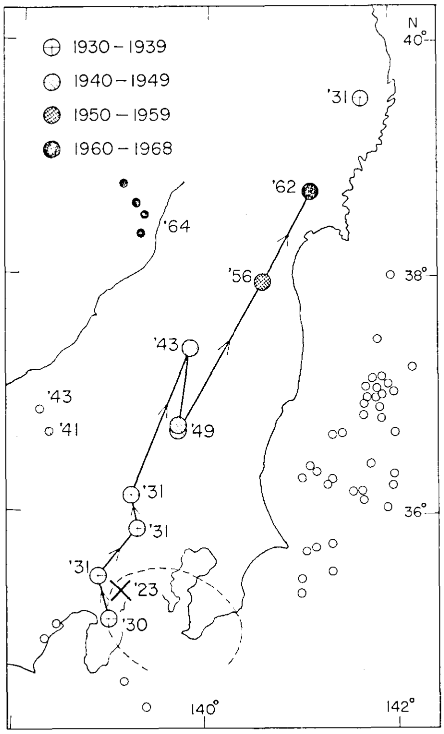


Fig. 3. Epicentral distribution of earthquakes ($M \geq 6.0$, focal depths$<$30 km) showing migration in northeastern Japan (large circles). Numerals indicate years. small circle: other earthquakes ($M \geq 6.0$, focal depths$<$30km) which occurred in the region during the period (1930–1967). cross mark and broken curve: epicenter of Kwantō earthquake 1923 and its focal region.

to correspond nearly to the eastern boundary of the mountainous region of Honshū. The parallel pattern in the $\overline{ab}$ trend is seen only at the surface layer with depths less than 30 km, and it is appreciably different from the pattern of epicentral locations of deeper earthquakes.

(ii) Migration of seismic activity

Under some stress distributions, the fracture propagates successively in one direction from a starting point. Therefore, it is expected that the migration of seismic activity takes place in some cases. However, we have only a very few examples showing clear migration, as mentioned in a previous paper (Mogi, 1968a), and so it is very important for investigation of this phenomena to find more examples. In the previous paper, systematic displacement of active area during the period (1930–1935) in northeastern Japan was pointed out. In addition, three cases in which a migration process is seen, are described below.

(a) *Earthquake series from the Kita-Izu earthquake to the Miyagiken-hokubu earthquake along the $\overline{ab}$ line (1930–1962)*

This earthquake series along the $\overline{ab}$ line in Fig. 2 shows migration feature, as shown in Fig. 3. Several major earthquakes, including the Kita-Izu earthquake of 1930 (M=7.0), the Nishi-Saitama earthquake of 1931 (M=7.0), the Imaichi earthquake of 1949 (M=6.7), the Shiroishi earthquake of 1956 (M=6.1) and the Miyagiken-hokubu earthquake of 1962 (M=6.5), of which magnitudes are greater than 6.0 and focal depths are less than 30 km, systematically occurred along the $\overline{ab}$ line from south to north. The migration path is about four hundred kilometer and the mean velocity is about 12 km/year (Fig. 4). It is very interesting that migration branch started from the epicentral region of the great Kwantō earthquake of September 1, 1923, which is the greatest one in this region during recent years. This fracturing process shown by the migration branch may be interpreted as a branch of the great fracture of 1923.

(b) *A series of large earthquakes including the Sanriku-oki earthquake of 1933 (1931–1938)*

All large earthquakes with magnitude 7.5 and over in northeastern Japan during the thirty-two years period (1924–1951) occurred within the eight years interval before and after the Sanriku-oki earthquake, and their focal regions systematically moved from north to south, as shown in Fig. 5. This migration branch partly overlaps that mentioned in the preceding paper (Mogi, 1968a), but it is different from the previous one in a later stage. The focal regions of the Sanriku-oki earthquake of 1933, the Kinkazan-oki earthquake of 1936 and the Fukushima-oki earthquake of 1938 are nearly continuous and they suggest a successive progression of a great fracture. This earth-

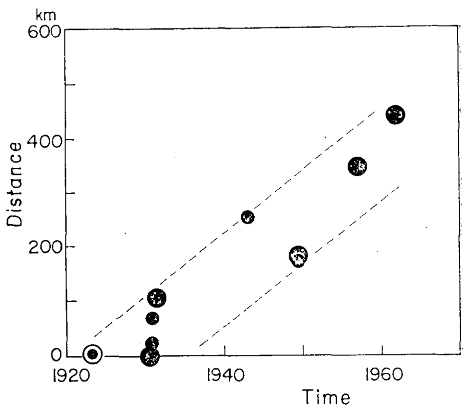


Fig. 4. Distances from the epicenter of the Kita-Izu earthquake of 1930 to each epicenter of the earthquakes along the $\overline{ab}$ line as function of time. double circle: Kwantō earthquake of 1923.

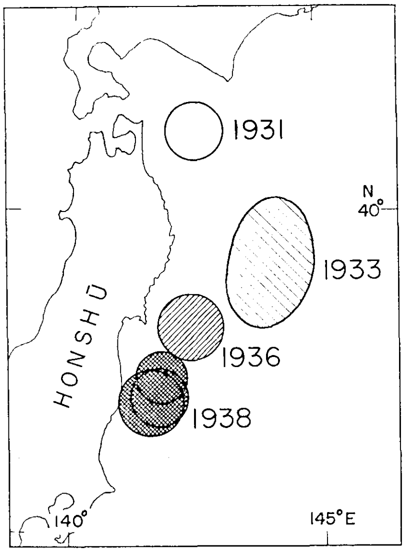


Fig. 5. Space distribution of focal regions of large earthquakes with magnitude 7.5 and over, which occurred in and around the northern part of Honshū during the period (1924–1951). Numerals indicate years.

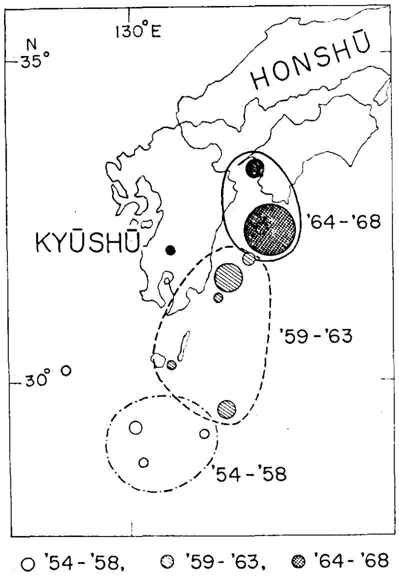


Fig. 6. Space distributions of focal regions of shallow earthquakes ($M \geq 6.0$) which occurred in the Hyūganada region and its adjacent area during the successive periods (1954–1958), (1959–1963) and (1964–1968).

quake series will be discussed again later.

(c) *Earthquakes in the Hyūganada region and its adjacent area during the period (1954–1968)*

This active zone corresponds to the northern part of the seismic belt along the Ryūkyū (Nanseishotō) arc. The focal regions in three successive periods are indicated by different symbols in Fig. 6. The successive displacement of active area from southwest to northeast along the seismic belt is indicated. The recent Hyūganada earthquake of 1968 ($M=7.5$) also belongs to this migration branch. About the period before 1954, it is difficult to point out such migration feature in this region.

Thus, the above-mentioned results including the previous one indicate that epicentral distribution of earthquakes sometimes show a clear migration feature, although it is not a commonplace event. This probably corresponds to the systematic propagation of fracture of the earth's crust under some stress distribution.

4. Seismic activity before and after great earthquakes

The energy released by a great earthquake is extremely large

(~10^{24}ergs.). For the occurrence of such a gigantic fracture, strain energy accumulation into a very wide area in a long term may be needed. This process should affect the seismic activity in and around the region, where a great earthquake will occur. If some special features in seismic activity before a great earthquake are found, they may give a key to predict the occurrence of great earthquakes. Until now, the in-

Table 2. List of large earthquakes in and near Japan during the period (1924-1968).

A. Western Japan ($M \geq 7.0$)

Name of Earthquake	Year	Date (J.S.T.)	Epicenter		Magnitude	Group
Tazima	1925	May 23	35.6°N	134.8°E	7.0	
Tango	1927	March 7	35.6	135.1	7.5	
Hyūganada	1941	Nov. 19	32.6	132.1	7.4	
Tottori	1943	Sept. 10	35.5	134.2	7.4	
Tōnankai	1944	Dec. 7	33.7	136.2	**8.0**	(b)
Mikawa	1945	Jan. 13	34.7	137.0	7.1	(b)
Nankaidō	1946	Dec. 21	33.0	135.6	**8.1**	(b)
Off Kii Penn.	1948	April 18	33.1	135.6	7.2	
Hidakagawa	1948	June 15	33.8	135.5	7.0	
Fukui	1948	June 28	36.1	136.2	7.3	
Yoshino	1952	July 18	34.45	135.80	7.0 (M_G)	
Hyūganada	1961	Feb. 27	31°36′	131°51′	7.0	
Kitamino	1961	Aug. 19	36°01′	136°46′	7.0	
Hyūganada	1968	April 1	32°17′	132°32′	7.5	

B. Eastern Japan ($M \geq 7.3$)

Name of Earthquake	Year	Date (J.S.T.)	Epicenter		Magnitude	Group
Off Aomori	1931	March 9	41.2°N	142.5°E	7.6	
Sanriku-oki	1933	March 3	39.1	144.7	**8.3**	(c)
Kinkazan-oki	1936	Nov. 3	38.2	142.2	7.7	(c)
Fukushima-oki	1938	Nov. 5	37.1	141.65	7.7	(c)
aftershock	1938	Nov. 5	37.15	141.7	7.6	(c)
aftershock	1938	Nov. 6	37.5	141.8	7.5	(c)
Off Aomori	1945	Feb. 10	40.9	142.1	7.3	
Tokachi-oki	1952	March 4	42.15	143.85	**8.1**	(a)
Bōsō-oki	1953	Nov. 26	34.3	141.8	7.5	
Sanriku-oki	1960	March 21	39.8	143.5	7.5	
Niigata	1964	June 16	38°21′	139°11′	7.5	
Tokachi-oki	1968	May 16	40°44′	143°35′	**7.9**	(d)
aftershock	1968	May 16	41°25′	142°51′	7.5	(d)

crease of seismic activity before a great earthquake has been supposed by many investigators. In a few cases, great earthquakes were certainly preceded by some foreshocks. In most cases, however, any marked foreshock activity could not be observed. The preceding papaer (Mogi, 1968e) showed that four recent great earthquakes in Japan occurred to fill gaps of seismic activity before these great earthquakes. Similar processes in the occurrence of great earthquakes were pointed out in other regions (Fedotov, 1965; Mogi, 1968c).

In the present paper, some special features of seismic activity before and after these great earthquakes are discussed in detail. Recent large earthquakes in the Japanese region are listed in Table 2. This table shows that the following four great earthquakes or earthquake series (a) (b) (c) and (d) were predominantly great events in the region during the last forty years.

(a) *The Tokachi-oki earthquake of March 4, 1952*

The main shock was located off the southeast coast of Hokkaidō. The space and the time distributions of aftershocks were discussed in the previous paper (Mogi, 1968b). Figures 7 a b c d show distributions of focal regions of earthquakes ($M \geq 6$) in northern Japan for the period (1934-1942), (1943-1951), 1952 and (1953-1959), respectively. In Figs. 7 a b d, the focal region of the Tokachi-oki earthquake of 1952 is shown by a broken curve and the active areas are hatched. These distribution maps suggest the following feature. During the nine years period just before the great earthquake, no major earthquakes occurred in the focal region of the great earthquake. Such low activity before the earthquake was already pointed out by Gotō and Sakai (1965), Inouye (1965), Utsu (1968) and Mogi (1968e) by different expressions. Another important feature just before the great earthquake is the increase of seismic activity in the surrounding wide area of the focal region of the great earthquakes. Thus, it should be noted that the pattern of a doughnut type of the active area is a special feature in the period just before the great earthquake in comparison with patterns in other periods (1934-1942) and (1953-1959).

(b) *The Tōnankai earthquake of December 7, 1944 and the Nankaidō earthquake of December 21, 1946*

These two great earthquakes occurred off the south coast of the Kii peninsula. The space and the time distributions of their aftershocks were discussed in the preceding paper (Mogi, 1968b). Since their focal regions are continuous and the time interval between them was only two years, these two great earthquakes are regarded as a group in this

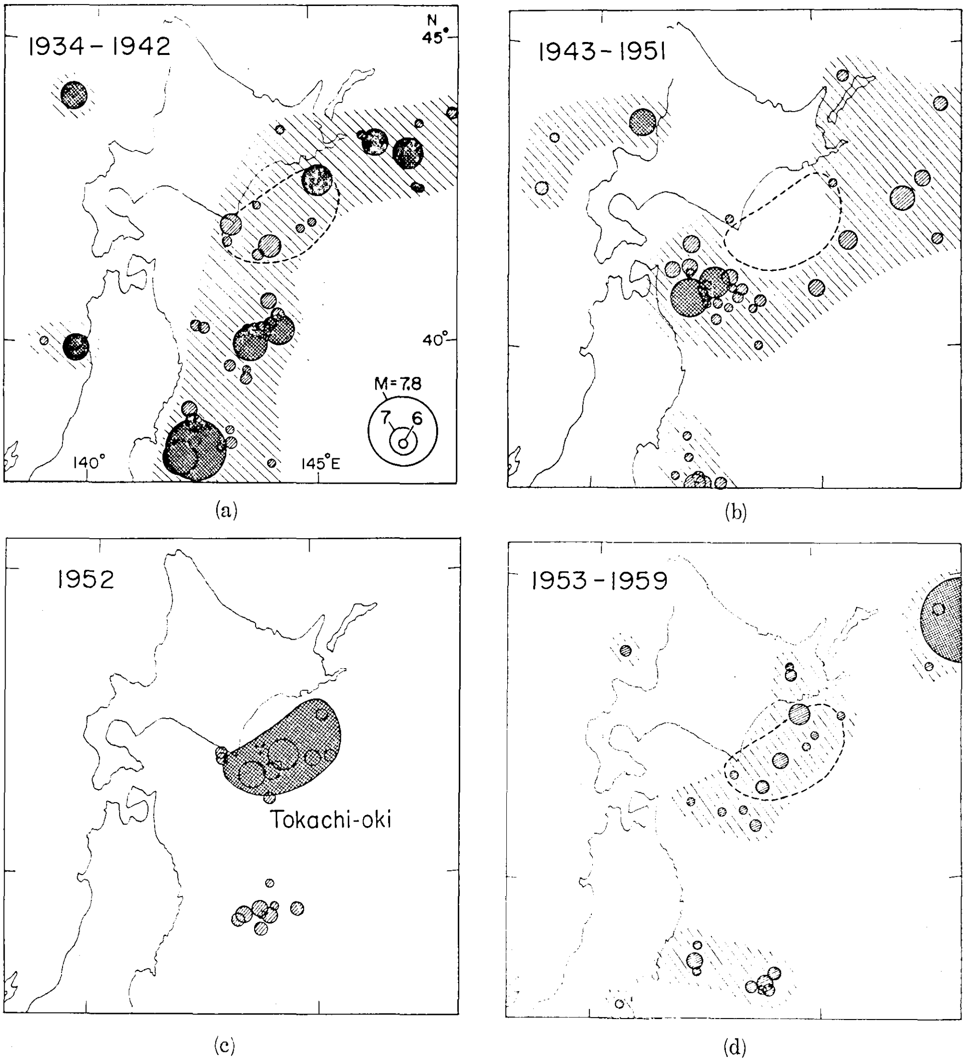


Fig. 7. Space distributions of focal regions of earthquakes with magnitude 6.0 and over, in and around the focal region of the Tokachi-oki earthquake of March 4, 1952. (a): 1934-1942; (b): 1943-1951; (c): 1952; (d): 1953-1959. broken curves in (a)(b)(d): focal region of the Tokachi-oki earthquake of 1952.

discussion. Figures 8 a b c d show the distributions of focal regions of major earthquakes in southwestern Japan for the periods (1910-1923), (1924-Nov. 1944), (Dec. 1944-1947) and (1948-1967), respectively. The focal regions of these great earthquakes are shown by a broken curve in Figs. 8 a b d. The seismic activity in the period (1910-1923) was not so high in southwestern Japan, and the active area was located in a wide zone throughout the focal region indicated by a broken curve.

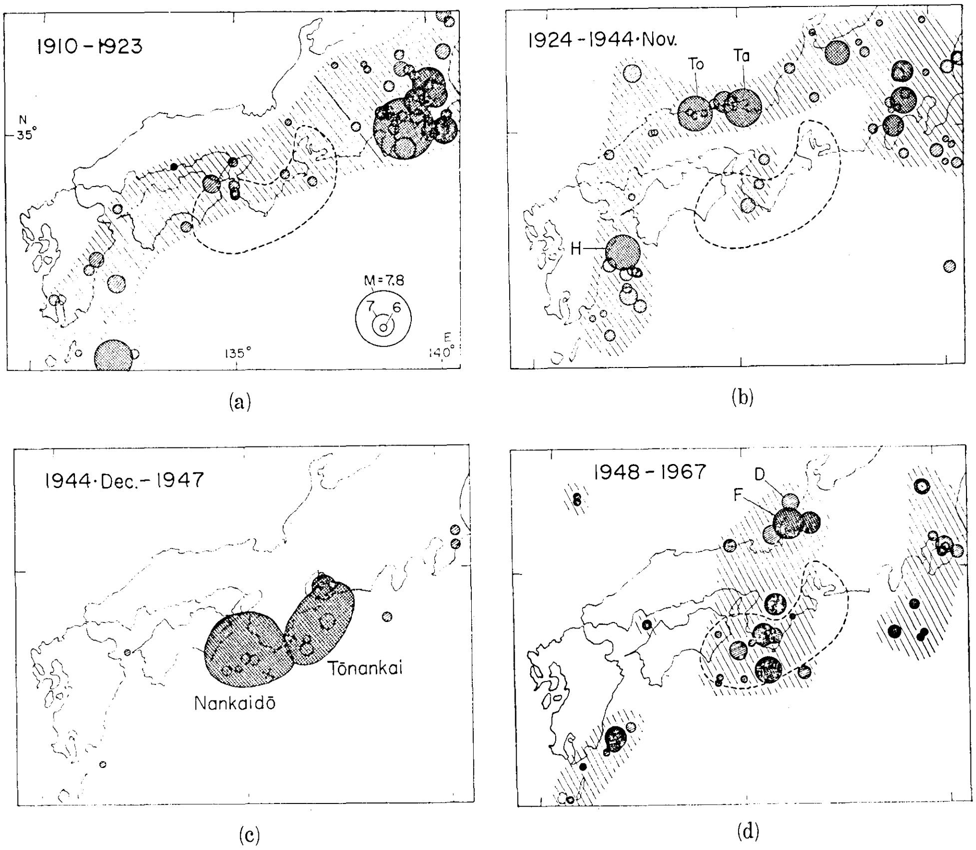


Fig. 8. Space distributions of focal regions of earthquakes with magnitude 6.0 and over, in and around the focal regions of the Tōnankai earthquake of Dec. 7, 1944 and the Nankaidō earthquake of Dec. 21, 1946.
(a): 1910-1923; (b): 1924-Nov. 1944; (c): Dec. 1944-1947; (d): 1948-1967. broken cureves in (a)(b)(d): focal regions of the Tōnankai-Nankaidō earthquakes. **Ta**: Tango earthquake of 1927; **H**: Hyūganada earthquake of 1941; **To**: Tottori earthquake of 1943; **F**: Fukui earthquake of 1948; **D**: Daishōji-oki earthquake of 1952.

However, in the period just before the great earthquakes (1924-Nov. 1944), the focal region of the great earthquakes was appreciably calm and the surrounding area became very active. The great earthquakes occurred to fill the gap of the seismic activity. After the great earthquakes, the doughnut pattern of the seismic activity disappeared and the active region was located in and near the forcal region of the great earthquakes.

The histograms of released earthquake energy in the focal region (A) of the great earthquakes and their surrounding area (B) are shown in Fig. 9. The activity in Region A during about twenty years before

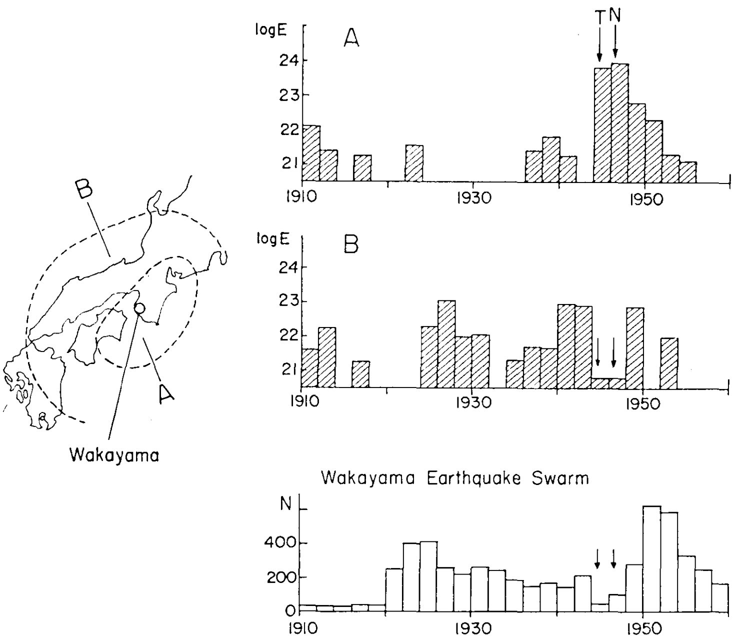
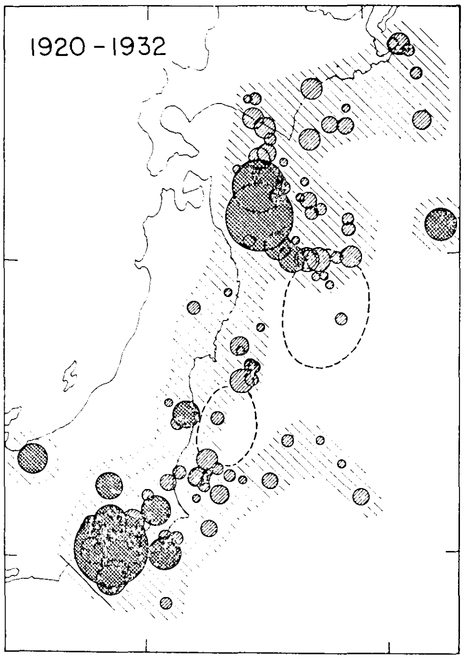


Fig. 9. Histograms of seismic energy release in Regions **A** and **B** (above) and frequency of local swarm earthquakes at Wakayama (below). **T**: Tōnankai earthquake; **N**: Nankaidō earthquake.

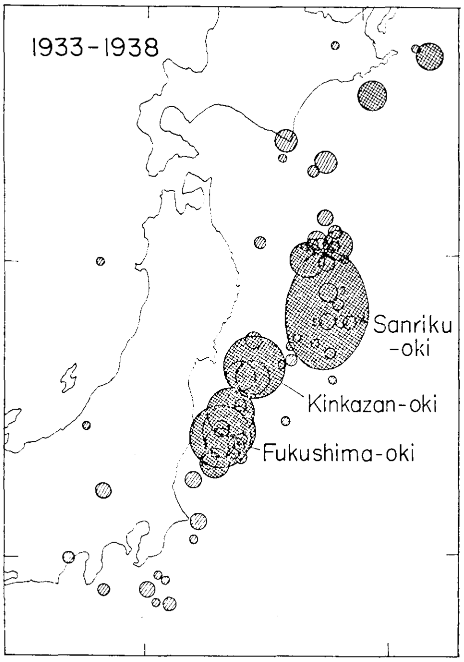
the great earthquakes was abnormally low, except for three earthquakes ($M \geq 6$) a few years before the great earthquakes. On the other hand, the activity in Region B increased compensatively during the twenty years period before the great earthquakes. Now, it is also an interesting fact that the temporal variation of the seismic activity in the surrounding region (B) is roughly similar to the frequency curve of local swarm earthquakes at Wakayama which is located in Region A (Fig. 9). That is, the number of earthquakes felt at the Meteorological Station of Wakayama markedly increased after 1920 and temporarily decreased during the period (1944–1946). It is probable that the swarm activity indicates the stress level in the considered wide area.

(c) *The Sanriku-oki earthquake of March 2, 1933, the Kinkazan-oki earthquake of November 3, 1936 and the Fukushima-oki earthquake of November 5, 1938*

The Sanriku-oki earthquake was one of the greatest earthquakes in the world. The magnitude of the Fukushima-oki earthquake was 7.7, but the total released energy including aftershocks, which were abnormally active, corresponds to that of an earthquake with magnitude 8.0. These



(a)



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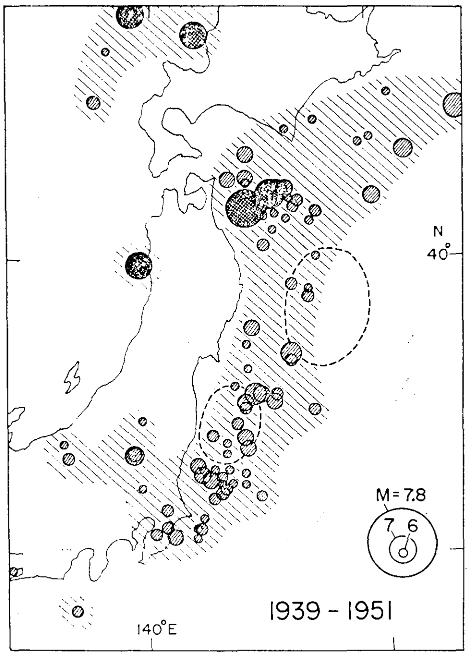
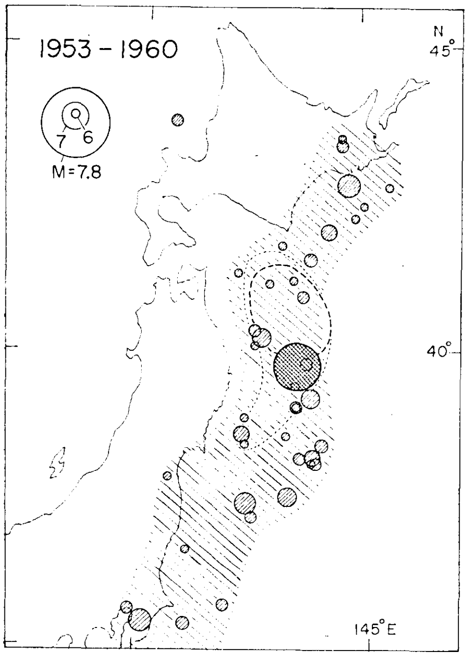
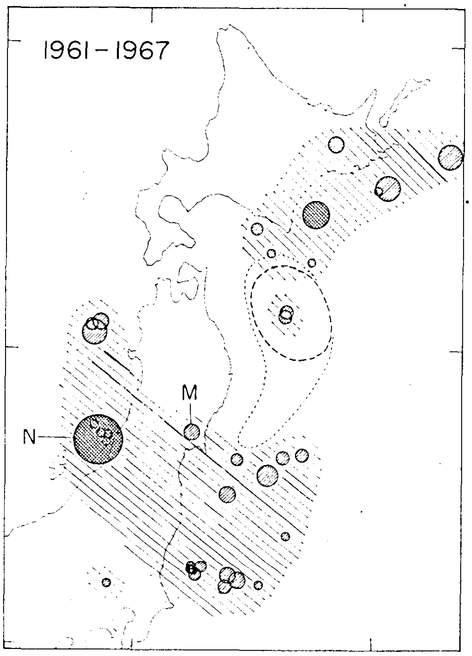


(c)

Fig. 10. Space distributions of focal regions of earthquakes with magnitude 6.0 and over, in and around the focal region of the Sanriku-oki earthquake of 1933, the Kinkazan-oki earthquake of 1936 and the Fukshima-oki earthquake of 1938. (a): 1920-1932; (b): 1933-1938; (c): 1939-1951. broken curves in (a)(c): focal regions of the Sanriku-oki and the Fukushima-oki earthquakes.



(a)



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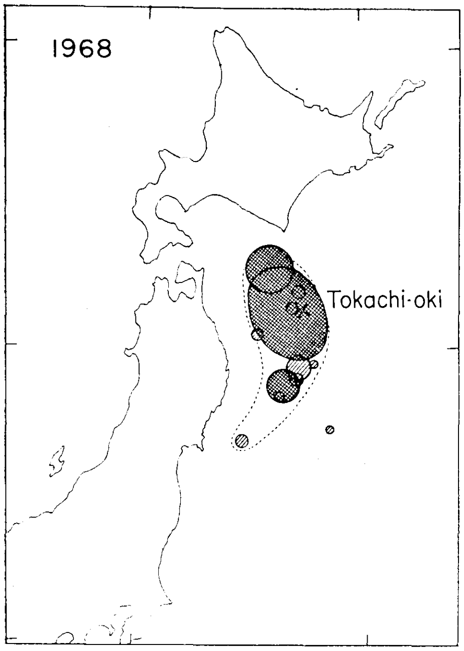

(c)

Fig. 11. Space distributions of focal regions of earthquakes with magnitude 6.0 and over, in and around the focal region of the Tokachi-oki earthquake of May 16, 1968. (a): 1953-1960; (b): 1961-1967; (c): 1968. broken curve: aftershock region a half day after the main shock; dotted curve: aftershock region three months after the main shock; **M**: Miyagiken-hokubu earthquake of 1962; **N**: Niigata earthquake of 1964.

three great earthquakes occurred successively in the six years interval, with clear migration feature, as mentioned in the preceding section, and their focal regions were nearly continuous. Therefore, these three great earthquakes are regarded as a group in this discussion. Figures 10 a b c show the distributions of focal regions of major earthquakes in northeastern Japan for the periods (1920-1932), (1933-1938) and (1939-1951). The focal regions of the Sanriku-oki and the Fukushima-oki earthquakes are shown by broken curves in Figs. 11 a c. Although a few earthquakes ($M \geq 6$) occurred before the great earthquake series in their focal regions, the activity in the focal regions was abnormally calm as compared with the adjacent regions which were very active. In this case, also, it is remarked that the calm area corresponding to the fccal regions is nearly surrounded by active areas. After the great earthquake series, the pattern did not show any remarkable relation to the focal regions of the great earthquakes.

(d) *The Tokachi-oki earthquake of May 16, 1968*

The magnitude of this earthquake was estimated at 7.9 by JMA, 8.2 by Pasadena and 8.4 by Palisades. In the preceding paper (Mogi, 1968e), it was pointed out that the focal region estimated from the aftershock area just after the main shock is adjacent to the focal regions of the Sanriku-oki earthquake of 1933 and the Tokachi-oki earthquake of 1952, and the focal region of this earthquake occurred to fill a gap in the seismic activity in the preceding forty-five years. Figures 11 a b c show the distributions of focal regions of earthquakes ($M \geq 6$) in northeastern Japan for the periods (1953-1960), (1961-1967) and 1968. In the period (1961-1967) just before the great earthquake, the focal region of the great earthquake was appreciably calm and the wide area surrounding the focal region was markedly active, as seen in the above mentioned other cases. In this case, precise seismic data in-

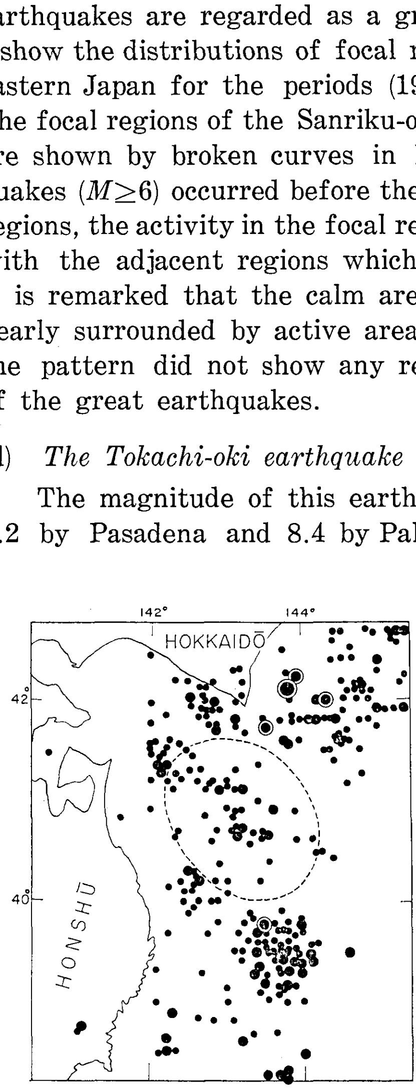

Fig. 12. Epicentral locations of shallow earthquakes in and around the focal region of the Tokachi-oki earthquake of 1968, during the twenty years interval preceding the earthquake of 1968. A broken curve shows approximately the focal region of the great earthquake. double circle: $M \geq 7.0$; large closed circle: $6.0 \leq M < 7.0$; small closed circle: $5.0 \leq M < 6.0$.

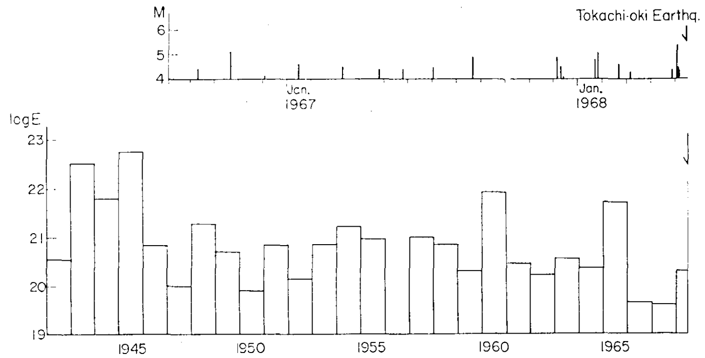

Fig. 13. Temporal variation of the seismic activity in the area indicated by a broken curve in Fig. 12 before the Tokachi-oki earthquake of May 16, 1968. M: magnitude; E: earthquake energy in ergs.

cluding smaller earthquakes are available and so a detailed investigation of the seismic activity before the great earthquake can be made. Figure 12 shows the epicentral locations of shallow earthquakes in and around the focal region of the earthquake of 1968 during the twenty years before it. Figure 13 shows the temporal variation of the seismic activity in the focal region. In this figure, an appreciable increase of the seismic activity just before the great earthquake is not seen, but the activity has rather decreased gradually since 1961, except for 1965 in which two major earthquakes ($M \geq 6$) occurred in the focal region. This result indicates that the foreshock activity in strict sense did not occur before this great earthquake.

5. The dynamic process in seismic activity

The above-mentioned results suggest a typical process in the seismic activity before and after a great earthquake or earthquake series, as follows. In the initial stage, the active area lies within a belt, without any close relation to the focal region of the great earthquake. Certain years before the great earthquake, the pattern of the seismic activity changes markedly. The focal region of the great earthquake becomes considerably calm, but the area surrounding the focal region becomes highly active. Occasionally major earthquakes will occur in the focal region a few years before a great earthquake. With the occurrence of the great earthquake, the above-mentioned doughnut pattern of the seismic activity disappears and aftershocks follow. A number of years after the great earthquake, the pattern returns to the initial one.

The increased activity in the surrounding area before the great earthquake may be regarded as a foreshock activity in a broad sense.

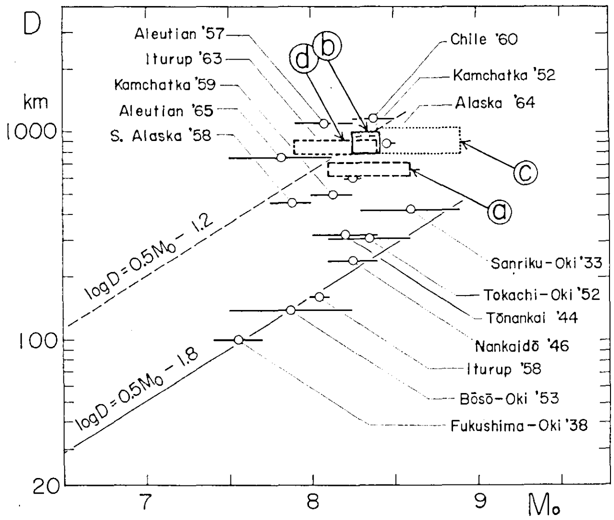

Fig. 14. Comparison in length of the aftershock area (circle with bar) and the foreshock area in a broad sense (rectangle). D: length of area; M_0: magnitude of main shock; **a**: Tokachi-oki earthquake of 1952; **b**: Tōnankai-Nankaidō earthquakes; **c**: Sanriku-oki, Kinkazan-oki and Fukushima-oki earthquakes; **d**: Tokachi-oki earthquake of 1968.

From this point of view, the Tottori earthquake of 1943 ($M=7.4$), the Hyūganada earthquake of 1941 ($M=7.4$) and even the Tango earthquake of 1927 ($M=7.5$) are foreshocks of the Tōnankai-Nankaidō earthquakes, and the Niigata earthquake of 1964 ($M=7.5$) and the Miyagiken-hokubu earthquake of 1962 ($M=6.5$) also may be foreshocks in a broad sense of the Tokachi-oki earthquake of 1968. The size of foreshock area in the present hypothesis may be thought to be unexpectedly large. Certainly the area is very much larger than known aftershock regions of these earthquakes. However, the previous discussion about the size of aftershock areas showed that the aftershock areas of Japanese great earthquakes are considerably smaller than those of earthquakes of the same magnitude in other regions, such as Aleutian and Alaska (Mogi, 1968b). Figure 14 shows that the above-mentioned foreshock area is rather comparable to the aftershock area in other regions. Therefore, it is probable that the great earthquakes affect the seismic activity in such a wide area before their occurrence, and so it is reasonable that the increase of activity in the surrounding area before the great earthquakes is regarded as the forerunning phenomenon of the great earthquakes in a broad sense.

From this view point, the aftershock activity in a broad sense also should be considered. That is, the Fukui earthquake of 1948 ($M=7.3$) and probably the Daishōji-oki earthquake of 1952 ($M=6.8$) may be regarded as aftershocks of the Tōnankai-Nankaidō earthquakes.

The time interval, in which the foreshock (also aftershock) activity in a broad sense continued, was about twenty years for the Tōnankai-Nankaidō earthquakes (1944–1946), and about ten years for the Tokachi-oki earthquake of 1952. This time interval may be longer in the less active region (southwestern Japan) than in the highly active region (northeastern Japan). This could be due to the different stress rate in these regions.

According to the above-mentioned discussion, the effective area of the Tōnankai-Nankaidō earthquakes covers the whole area of southwestern Japan, and the activity related to the great earthquakes continued for about a fifty year interval. Therefore, the recent seismic activity since 1924 in southwestern Japan can be understood as a dynamic process, including foreshock and aftershock series in a broad sense, of the Tōnankai-Nankaidō earthquakes. Furthermore, a large part of recent major earthquakes in and near Japan may be regarded as foreshocks or aftershocks, in a broad sense, of the above-mentioned four great earthquakes or earthquake series.

The above-mentioned seismic process before the great earthquake may be understood as a fracturing process under a stress wihch continues to increase in and around the focal region of the great earthquake, as follows. In an initial stage, local fractures occur in the stressed region. If the fracture strength of the focal region is higher than other regions, the activity in the focal region decreases at an elevated stress, and the surrounding area becomes very active, up to the occurrence of the main fracture, namely the great earthquake, at the focal region. With the main fracture, the fracturing activity in the surrounding area suddenly decreases. The compensative occurrence of fractures in adjacent regions was pointed out in a laboratory fracture experiment (Mogi, 1968d). Furthermore, the decrease of fracturing activity (at the elevated stress) just before the main fracture was also frequently observed in fracture experiments on brittle materials with low degree of heterogeneity.

Although the main fracture in the above-mentioned four great earthquakes or earthquake series were not preceded by marked local fractures at the central region, a few great earthquakes, such as the Chilean earthquake of 1960, were preceded by foreshocks in a strict sense. This difference in foreshock activity may be dependent on the structures of the earth's crust in the region, and so this may be a regional characteristic, as pointed out for smaller earthquakes in and near Japan in a previous study (Mogi, 1963). Although a very few data only are available for great earthquakes, the situation may be analogous to that in the smaller ones.

6. Seismic activity in future

The occurrence of an earthquake more or less affects the mechanical state of the earth's crust by causing changes in stress and structure. This effect is larger in greater earthquakes. The preceding discussion showed that the great earthquakes seriously affect the seismic process in very wide regions, and the process in relation to the great earthquakes continues for an appreciably long time interval in comparison to the time interval in which the seismicity is discussed in many cases. This result suggests that the seismic activity cannot be adequately described as a stationary process, but it should be analysed as a dynamical process. Particularly, it is noteworthy that the important features of the seismic activity in the Japanese region can appear to have a close relation to the occurrence of great earthquakes. If the typical process of an earth-

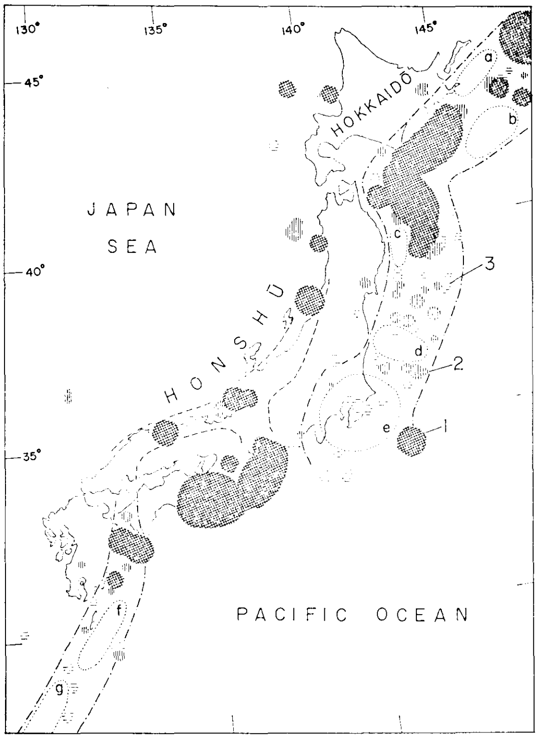

Fig. 15. **1**: focal region of large earthquakes ($M \geq 7.0$) wihch occurred during the recent thirty years interval; **2**: focal region of earthquakes ($6.0 \leq M < 7.0$) which occurred during the recent ten years interval; **3**: focal region of earthquakes ($6.0 \leq M < 7.0$) which occurred during the recent twenty years interval, except for **2**; area surrounded by chain or broken curves: seismic active regions during the recent fifty years interval.

quake occurrence is made clear from this point of view, some information for the future seismic activity may be obtained, as tried by Fedotov (1965) and the present writer (Mogi, 1968e).

The above-mentioned discussion and the discussion in the preceding paper (Mogi, 1968e) suggest the following regularities on the occurrence of great earthquakes: (1) A great earthquake occurred to fill a gap in the seismic activity during the preceding years. (2) In the recent four great Japanese earthquakes, no large earthquakes with magnitude 7 and over occurred during the thirty years period before the great earthquakes. (3) The occurrence of the great earthquake is preceded by a marked calmness in the focal region and an increase of the seismic activity in the surrounding area. In Fig. 15, the focal regions of large earthquakes with magnitude 7 and over during the recent thirty years period are shown by cross-hatched area **1** and the focal regions of major earthquakes with magnitude 6 and over during the recent ten years period and the ten years before the period are shown by the hatched area **2** and **3**, respectively. The areas surrounded by chain and broken lines are the regions where large or major earthquakes occurred frequently during the recent fifty years period. If the above-mentioned regularities are applied to future activity, it is deduced that no great earthquakes will occur in the areas marked by **1** and **2**. Therefore, remarkable gaps within the areas surrounded by chain or broken lines are noted as areas where great or large earthquake may occur in future. Some of them are indicated by dotted curves. In this figure, a marked gap in the Kwantō region is also noticeable, as pointed out in the preceding paper (Mogi, 1968e). It should be noted that the present discussion is very approximate, because the above-mentioned regularities have not been deduced from a sufficiently large number of cases. Exceptional cases may be expected with some probability, since the state of the stress and structure of the earth's crust is very complex.

Appendix

In the preceding paper (Mogi, 1968e), the seismicity in and near Japan was discussed based on the seismic data during the last eighty years period. In the paper, the zonal distribution of the seismic active areas along the arc systems was pointed out. Figure 16 shows the seismic zoning which was described in the paper. The outer seismic zone, the inactive zone and the inner seismic zone run parallel to the trend of the deep sea trench, and the complex pattern of the seismic feature in the Japanese region is interpreted as a complex of those of the Kuril, the Honshū, the Ryūkyū and the Izu-Ogasawara arc systems. However, the

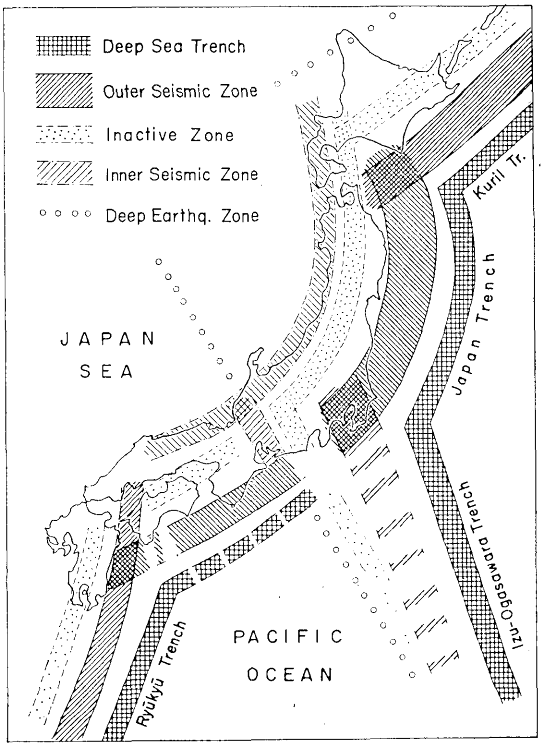

Fig. 16. Seismic zones in and near Japan, based on the distribution of seismic energy released by shallow earthquakes.

following facts should be noticed: (1) These arcs are different from each other in seismotectonic features. For example, the Kuril arc and the northeastern part of the Honshū arc are more active than the southwestern part of the Honshū arc and the Ryūkyū arc, as suggested by the higher seismic activity and the deeper trenches, and the Izu-Ogasawara arc, of which higher activity is also suggested by its deep trench and the high seismic activity at deep regions, is characterized by its very low seismic activity at shallow depths. (2) The areas where two seismic zones meet are the most active regions, such as the region off the south coast of Hokkaidō, the Kwantō district and the region off the east coast of southern Kyūshū. The higher activity in the northeastern part of the outer seismic zone along the Honshū arc may be attributed to interaction with the other two active arcs, the Kuril and the Izu-Ogasawara arcs.

The above-mentioned seismic zoning and characterization may be useful for discussions of a future seismic activity.

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16. 近年における日本の地震活動の二三の特徴

(2) 特に大地震前後の活動

地震研究所 茂 木 清 夫

一つの地震の発生は，多かれ少なかれ，地殻応力の解放と地殻の構造状態の変化（破壊）をもたらし，その後の地震活動に何らかの影響を与えるものであり，とくに大きい地震ではその影響が著しいはずである．従って，地震活動の本質は，単に定常的なものとしてではなく，時間的・空間的に変化しつづけるものとして，動的な取扱いによって明らかにされると思われる．このような観点から，前回の報告にひきつづいて，最近の日本及びその周辺の地震活動にみられる時間的・空間的規則性を論じた．その結果を次に要約する．

（1） 規則性として，地震の線状配列及びいくつかの震源移動の例が指摘された．特に，1930 年以降，深さ 30 km 以浅の地震（M≥6）が伊豆から仙台を結ぶ一つの直線上に配列し，北伊豆地震 (1930)，西埼玉地震 (1931)，今市地震 (1949)，白石地震 (1959)，宮城県北部地震 (1962) と北々東に規則的に移動したことが見出されたが，このような顕著な例によって，震源移動の事実はますます確かなものとなったといえる．特に，この場合，その出発点が，1923 年の関東大地震の震源域

にあることは注目すべきことである．このような規則性は，破壊の伝播の特徴として理解することができる．
(2) 近年（1930年以降）日本周辺に発生した最大級の地震若しくは地震のグループは4回あるが，その前後の活動には，次のような規則的過程が指摘される．即ち，大地震の発生の前数年乃至20年間，大地震の震源域となる地域の地震活動がかえって低下し，それをとりまくドーナッツ状の周辺地域の活動が増大する（広義の前震活動）．大地震の発生と共に，ドーナッツ状の活動域は消滅し，震源域及びその隣接地域の活動増加（広義の余震活動）を経て，定常状態に復帰する．
(3) これらの広義の前震又は余震活動の空間的・時間的ひろがりは，従来考えられてきたものに較べて著しく大きいが，大地震の影響範囲として十分考えられるひろがりである．近年の主な地震のほとんどは，これらの4つの大地震（又は大地震のグループ）及びその広義の前震又は余震と見ることができる．
(4) 前回及び今回指摘された地震発生の規則性をもとに，近い将来期待される地震活動の分布を推定することができる．