BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 47 (1969), pp. 429-451

18. *Relationship between the Occurrence of Great Earthquakes and Tectonic Structures.*

By Kiyoo MOGI,
Earthquake Research Institute.

(Read Sept. 17, 1968.—Received March 19, 1969.)

Abstract

The tectonic relief on the focal regions of great shallow earthquakes in the circum-Pacific belt and its surrounding regions is discussed in relation to the generation mechanism of great earthquakes. In Part I, relationship between the tectonic relief and the occurrence of the great earthquake (namely the great fracture) is discussed according to aftershock locations. The result shows that a great fracture suddenly occurs in a unit area or its complex which is bounded by structural discontinuities, such as faults, ridges and trenches. In a sequential occurrence of great earthquakes, a subsequent great fracture propagates from the margin of the adjacent fractured area. In Part II, the tectonic features of the focal regions of the great shallow earthquakes are discussed in their broader aspects. According to the result, most great earthquakes occur in the tectonically limited regions, characterized mainly by topographical depression: About 64 percent of great earthquakes continuously occurred in ocean-facing slopes of deep sea trenches, about 26 percent occurred in local depressions, such as troughs and ends of trenches, and some singular places in tectonic structures, and only about 8 percent occurred in other tectonic areas. These results seem to give some important information on the earthquake generation mechanism.

Introduction

In previous papers (Mogi, 1968abc), some special features in the occurrence of great earthquakes, such as the migration phenomenon of epicentral regions and the development of aftershock regions, have been investigated. These results provided some important information on the mechanism of earthquake generation.

In this paper, the tectonic relief on the focal regions of great shallow earthquakes is disccussed in relation to the occurrence of great earthquakes. According to the fracture theory of earthquakes (Mogi, 1967), shallow earthquakes occur by fracture of the earth's crust, and so the occurrence and the propagation of fracture should be affected by the mechanical structure in the focal region. The effect is discussed by studying locations of aftershocks which suggest the fracturing process in the focal region of great earthquakes (Part I). The occurrences of such great fractures of the earth's crust (namely, great earthquakes) are the result of active tectonic movements, and at the same time they cause remarkable crustal deformations. Therefore, the tectonic relief in the focal regions of great shallow earthquakes may show some special features. This problem is discussed in Part II.

The relationship between the tectonic structure and locations of small or major earthquakes has been recently discussed by some investigators (e.g. Den, 1968; Suzuki, 1968). About great earthquakes, Den (1968) suggested that aftershock epicenters of Japanese earthquakes have a relation to deep sea terraces. But further systematic discussions on great earthquakes have not been made until now.

Part I Aftershocks of great shallow earthquakes and tectonic structures

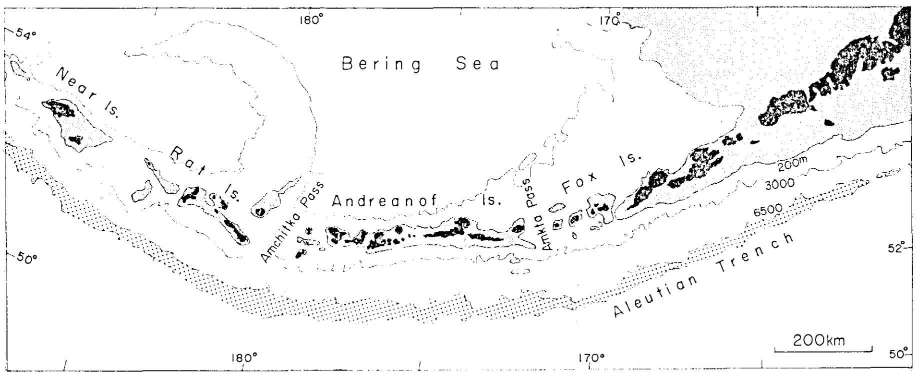
As mentioned above, the study of aftershock occurrence may provide a clue for making clear the dynamic process in the focal region of great shallow earthquakes. The aftershock area just after the great earthquake corresponds to the fractured area at the time of the main shock, namely the focal region where the strain energy released by the main shock was accumulated (Mogi, 1968b). Therefore, the effect of the tectonic structure upon the occurrence of the great earthquake can be deduced from space and time distributions of aftershock epicenters. It is very interesting to know, from the standpoint of the fracture theory of earthquakes, how the development of the aftershock area is affected by structural discontinuities, such as fault zones. Several examples showing the noticeable effect of the tectonic structures are described in the following sections.

Earthquake data were adopted from *the Seismological Bulletin of USCGS* for Aleutian earthquakes, the earthquake list by Duda (1963) for the Chilean earthquake and *the Seismological Bulletin of the Japan Meteorological Agency* or *JMA* for Japanese earthquakes. Topographical maps were adopted from *the Bathymetric Chart of the Adjacent Seas of Nippon* by the Japanese Hydrographic Office or JHO for the Japanese region and *the World Atlas* by the Chief Administration of Geodesy and Geography or CAGG, USSR for other regions.

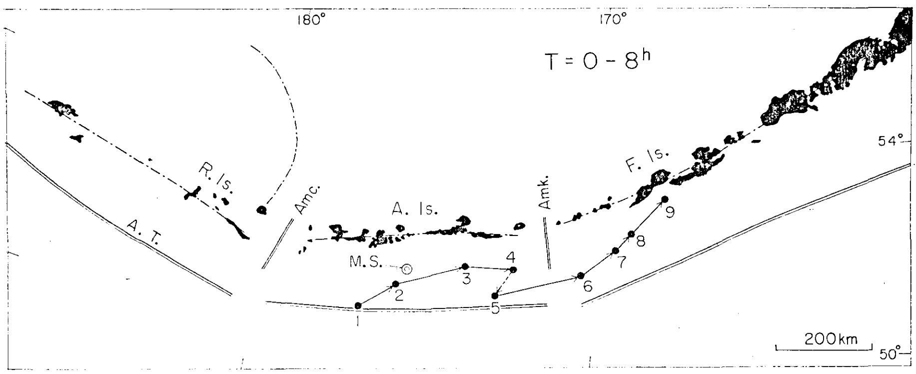
1. Andreanof (Aleutian) earthquake of March 9, 1957

In the previous paper (Mogi, 1968b), successive migration of epicenters of major aftershocks just after the Andreanof earthquake was pointed out and it was suggested that the discontinuity in this migration process may be due to a structural discontinuity. Now, the successive development of the aftershock region is discussed in relation to tectonic structures in and around the focal region of the great earthquake.

Figure 1a shows the topography of the Aleutian Island arc. This main structure is characterized by its circular shape. According to a detailed investigation, however, the island arc is not exactly circular, but it consists of three linear segments bounded by two discontinuities transverse to the arc structure, which are located near the Amchitka



(a)



(b)

Fig. 1. (a) Major topographic features of the Aleutian Island arc.
(b) Structural division of the Aleutian region on the basis of the island chain, the axis of the Aleutian trench, and the Amchitka and the Amkta passes. double circle: epicenter of the Andreanof earthquake of 1957; numbered closed circles: major aftershocks just after the main shock, showing migration.

and the Amkta passes. The three linear segments are also seen in the trend of the Aleutian trench parallel to the island chain. From these tectonic features, the seismic active area including the focal region of this earthquake may be divided into three rectangular blocks bounded by the island chain, the axis of the Aleutian trench and the above-mentioned two passes, as shown in Fig. 1b.

The main shock occurred in the central region of the Andreanof Island block, and its aftershocks occurred in this block and the western part of the adjacent block (the Fox Island block). Numbered solid circles in Fig. 1b show the epicenters of major aftershocks just after the main shock whose migration process was discussed in the previous paper (Mogi, 1968b). The migration branch starts from a region near the epicenter of the main shock and terminates at the region where a marked earthquake swarm occurred a few months before. Fig. 1b shows that the above-mentioned discontinuous process from No. 4 aftershock to No. 5 is certainly related to the Amkta pass discontinuity.

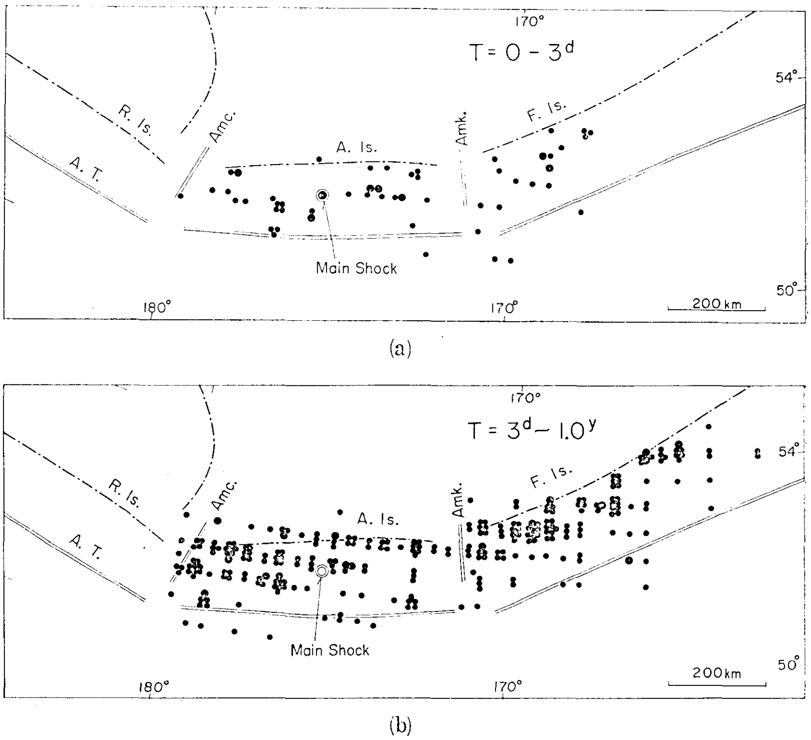


Fig. 2. (a) Aftershock epicenters during three days period just after the Andreanof earthquake of March 9, 1957.
(b) Aftershock epicenters during one year period after the earthquake, except for the first three days.

The space distribution of aftershocks during three days just after the main shock and during one year after the main shock, except for the first three days, are shown in Figs. 2 a and b, respectively. In an initial stage, the aftershock region was located around the above-mentioned migration path and then developed to the western boundary (the Amchitka pass) of the Andreanof Island block, by which the aftershock area was sharply limited through the whole period (cf. Jordan and Lander, 1965). In the Fox Island region which has no definite eastern boundary, the active area gradually spread eastward.

The successive development of the active area after the Andreanof earthquake is summarized in Fig. 3. The last stage (5) in this figure shows that the Rat Island earthquake of 1965 occurred in the adjacent block eight years after the Andreanof earthquake. In this case, it is very suggestive that some foreshocks and the main shock of the Rat Island earthquake occurred close to the western margin of the aftershock area of the Andreanof earthquake and its aftershock region developed westwards to another discontinuity. The above-mentioned process of the successive occurrence of earthquakes is interpreted as the discontinuous propagation of fracturing caused by sharp discontinuities suggesting fault zones transverse to the island arc structure.

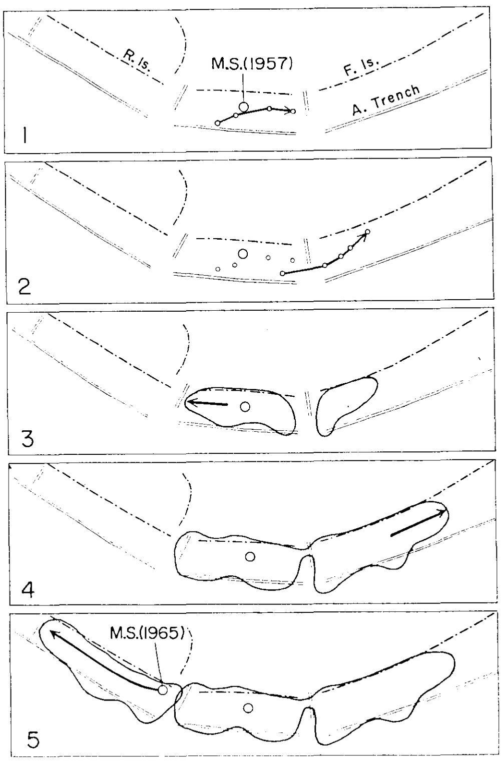
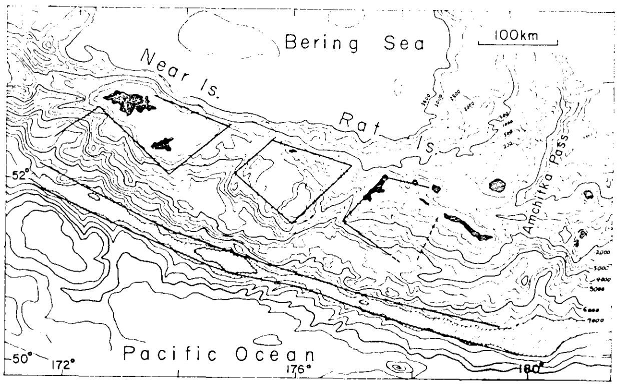


Fig. 3. Development of the aftershock region in successive periods. (1): 0～5 hours; (2): 5～8 hours; (3): 8 hours～3 days; (4): 3 days～1 year; (5): locations of the Rat Island earthquake of 1965 and its aftershock region.

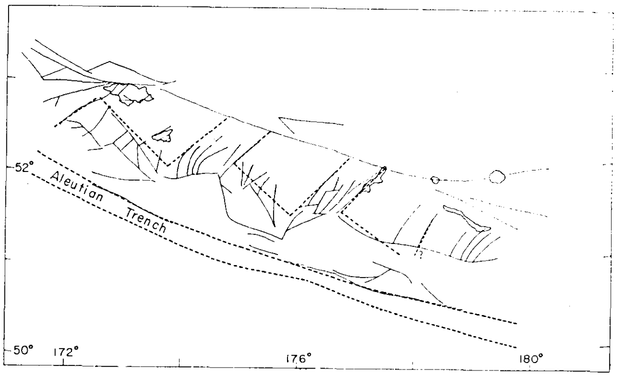
2. Rat Island (Aleutian) earthquake of February 4, 1965

As mentioned above, the Rat Island earthquake occurred in the block adjacent to the Andreanof Island block. The presence of the eastern and the western sharp margins of the aftershock area was pointed out by Jordan and Lander (1965). The source mechanism of this earthquake sequence was studied by Stauder (1968) and the successive development of the aftershock area was discussed by Mogi (1968b).

Figures 4a and b show the submarine topography in this region and the fault system deduced from the topographical features by Gates and Gibson (1956), respectively. As pointed out by Gates and Gibson, wrench fault zones trending at angles of about 60° to the trench divide



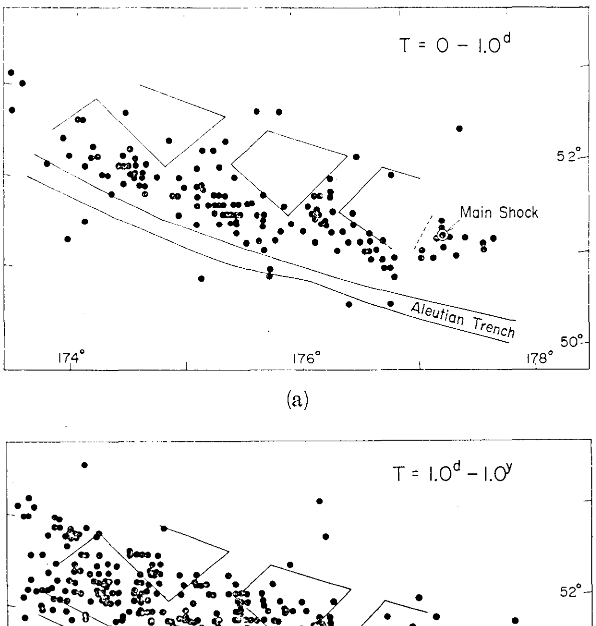
(a)



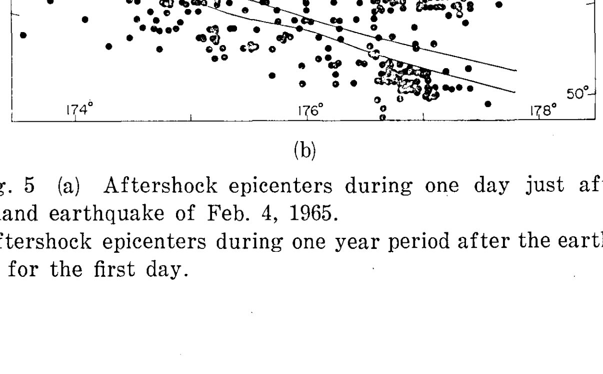
(b)

Fig. 4 (a) Submarine topography in and around the focal region of the Rat Island earthquake of 1965. The solid lines show simplified structural boundaries.
(b) The solid lines show fault systems deduced from the topographical features (Gates and Gibson, 1956).

this region into some fault blocks. Simplified structural boundaries are indicated in these figures. In Figs. 5a and b are shown the epicentral distributions of aftershocks during one day just after the main shock and one year after the main shock except for the first day, respectively. The aftershock area just after the main shock, which is thought to correspond to the fractured region directly related to the main shock, is located in a narrow zone beneath the ocean-facing slope of the trench, particularly between the blocks and the trench bottom (Fig. 5a). On the other hand, aftershocks in a later stage distribute in a wider zone covering the Aleutian trench, without any close relation to the above-mentioned fault block structure (Fig. 5b). The result may suggest the following fracturing process in the focal region. The main fracture progressed in a narrow zone between the island chain and the



(a)



(b)

Fig. 5 (a) Aftershock epicenters during one day just after the Rat Island earthquake of Feb. 4, 1965.
(b) Aftershock epicenters during one year period after the earthquake, except for the first day.

trench from east to west and the fracture pattern was appreciably affected by the pre-existing block structure. Thereafter, the fracturing area spread gradually and uniformly in the transversal direction, but the development of fracture along the island arc was limited by two sharp discontinuities, including the Amchitka pass.

3. Chilean earthquake of May 22, 1960

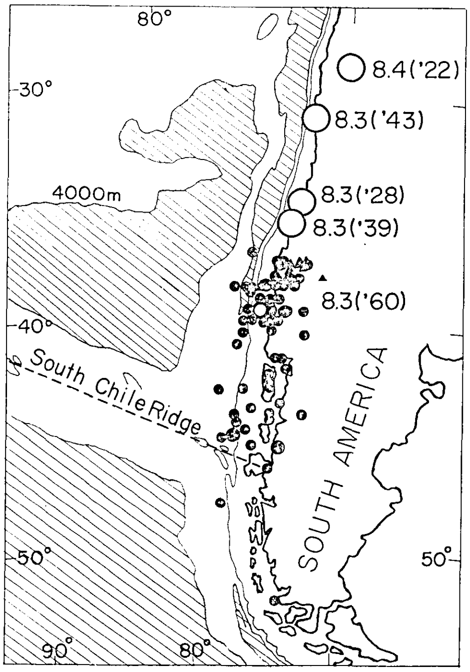


Fig. 6. Locations of the Chilean earthquake of 1960(small open circle), its foreshocks (closed triangles), and aftershocks (closed circles) are shown with the major submarine topography near the focal region. large open circles: epicenters of great earthquakes preceding the Chilean earthqurke of 1960; numerals: magnitude and year.

The process in the occurrence of the Chilean earthquake of 1960 is somewhat similar to that of the above-mentioned Rat Island earthquake. The focal region of the earthquake of 1960 adjoins the region where four great earthquakes occurred during the period (1922–1943), as shown in Fig. 6. A marked foreshock sequence of the earthquake of 1960 began to occur near the southern margin of the focal region of the earthquake of 1939, and the main shock of the earthquake of 1960 and its aftershocks occurred in the southern region along the Chile trench. In this case, it is noteworthy that the southern boundary of the aftershock region is located approximately at the south Chile ridge transverse to the Chile trench. This suggests that the fracture propagation from the margin of the 1939 earthquake along the Chile trench was stopped by the structural discontinuity, the south Chile ridge.

4. Tokachi-oki earthquake of March 4, 1952

The submarine topography in and around the focal region of this earthquake is shown in Fig. 7. The line (1) is a great submarine canyon and the line (2) is a submarine extension of Hidaka range. The curve (3) indicates a zone where the continental slope is particularly steep. They would be some sort of tectonic boundaries representing structural discontinuities. Figure 8 shows epicentral distributions of the main shock and its aftershocks during six days just after the main shock. In this figure, it is pointed out that the aftershocks occurred almost within an approximately rectangular area bounded by the above-mentioned structural discontinuities. Epicenters of aftershocks in a later stage are located in a wider area in the continental slope of the deep sea trench, without any close relation to the above-mentioned structural discontinuities (Fig. 8b).

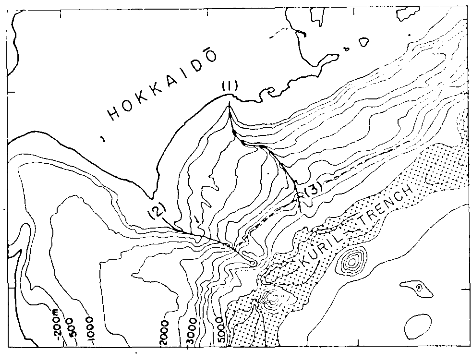
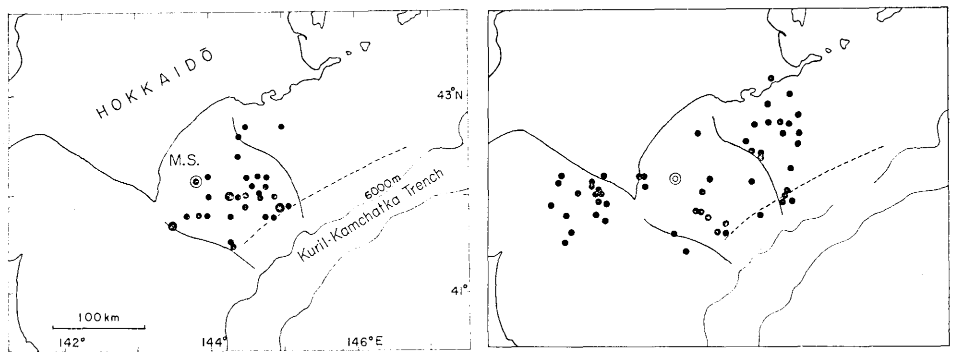


Fig. 7. Submarine topography in and around the focal region of the Tokachi-oki earthquake of 1952. (1), (2) and (3) indicate the possible structural discontinuities, expressed in major topography.



(a) (b)

Fig. 8. (a) Aftershock epicenters during six days period just after the Takachi-oki earthquake of March 4, 1952.
(b) Aftershock epicenters during one year period after the earthquake, except for the first six days.

5. Nankaidō earthquake of December 21, 1946

In Figs. 9 and 10 are shown the topographical map in and around the focal region of this earthquake and the epicentral distributions of the main shock and its aftershocks, respectively. Aftershock epicenters are located within the rectangular region surrounded by the topographic heights, probably structural boundaries, shown by solid lines in Fig. 9. Closed and open circles in Fig. 10 indicate aftershock epicenters in initial and later stages. In this case, also, the aftershock locations suggest that the great earthquake occurred by a sudden fracture within the above-mentioned topographic-structural unit area surrounded by structural boundaries.

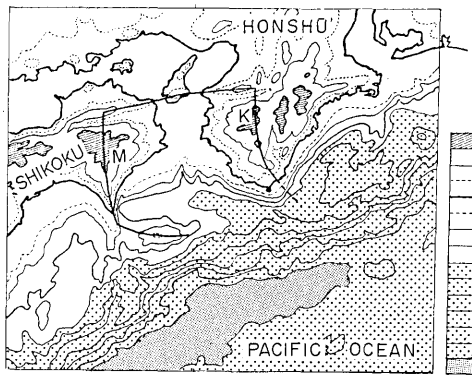


Fig. 9. Topography in and around the focal region of the Nankaidō earthquake of 1946. The solid lines show the supposed structural boundary. K: Kii peninsula; M: Muroto peninsula.

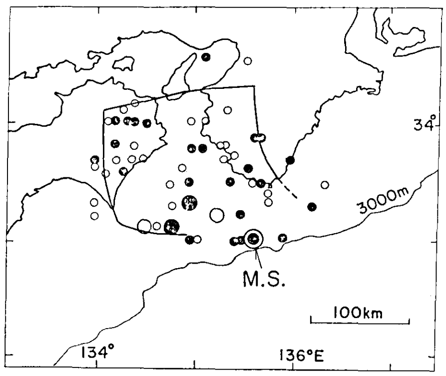


Fig. 10. Aftershock epicenters of the Nankaidō earthquake of Dec. 21, 1946. closed circle: aftershock during one month period after the main shock; open circle: aftershock during one year period after the main shock, except for the first month.

6. Discussion

According to the above-mentioned examples, aftershocks of great shallow earthquakes in the circum-Pacific belt occur along the trench and beneath its ocean-facing slope, and aftershock epicenters just after the main shock are located in the structural unit area surrounded by faults or other structural discontinuities, even in the case where the whole aftershock locations showed no appreciable relation to regional structures. The result suggests that a great earthquake occurs by a sudden fracture of the unit area or its complex along trenches which is bounded by structural discontinuities. It is very probable that the great earthquakes occur repeatedly in the same area with a long time interval, such as is suggested by the fact that the Tōnankai and the Nankaidō earthquakes occurred repeatedly in nearly the same areas with time intervals of one hundred years or so.

When two or more great earthquakes successively occur in areas adjacent each other, the generation of the following earthquake is affected by the preceding earthquake, as pointed out in the case of the Rat Island and the Chilean earthquakes. The process of the successive occurrence of foreshocks, a main shock and aftershocks in several cases is shown in Fig. 11. The following earthquake originates near the margin of the aftershock area of the preceding earthquake, and the aftershock area of the following earthquake develops in the direction opposite to the focal region of the preceding earthquake. Moreover, it is noticeable that some of the following earthquakes were preceded by foreshocks, which occurred near the margin of the preceding earthquake. This successive occurrence of great earthquakes can be interpreted as the successive propagation of a great fracture from a block to the adjacent block.

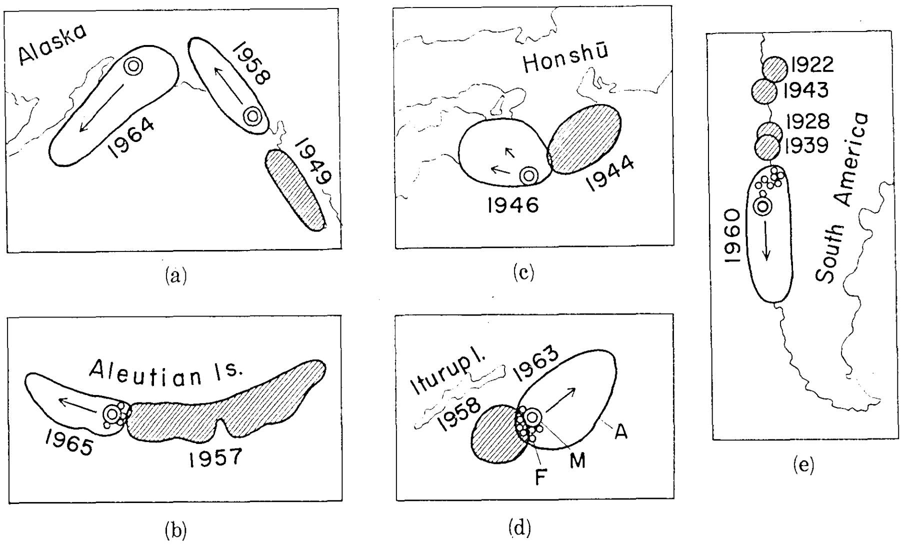


Fig. 11. The process of occurrence of great earthquakes which occurred in regions adjacent to focal regions of preceding great earthquakes. M: main shock; F: foreshock; A: aftershock region.

(a) Queen Charlotte Island earthquake of 1949, southeast Alaska earthquake of 1958 and Alaska earthquake of 1964.

(b) Andreanof Island earthquake of 1957 and Rat Island earthquake of 1965.

(c) Tōnankai earthquake of 1944 and Nankaidō earthquake of 1946.

(d) Iturup earthquakes of 1958 and 1963.

(e) Chilean earthquakes of 1939 and 1960.

Part II Tectonic feature in the focal regions of great shallow earthquakes

According to the theory that great shallow earthquakes occur by sudden great fracture caused by active tectonic movement, localities of great earthquakes should have a close relation to the tectonic relief which was surface expressions of active tectonic movements. The places where great shallow earthquakes occur may show a common feature in their major tectonic relief. As a first step in this problem, major topographic features of the focal regions of great shallow earthquakes in the circum-Pacific region and its surrounding areas are discussed in the following sections.

It is well known that the seismic active zones in the Pacific region are located along arc structures (cf. Gutenberg and Richter, 1954). Recently Isacks et al (1968), who promoted the new global tectonics, pointed out that the maximum size of earthquakes is greatest in the island arc regions among various tectonic regions. According to more detailed investigations, many great shallow earthquakes occur continuously along the very deep sea trenches. However, some great earthquakes are located at other places of which topographical features are discussed as follows.

1. Earthquakes in Japan and its vicinity

In this region, earthquake data were adopted from *the Seismological Bulletin of JMA*, *Rikanenpyō* (Kawasumi, 1961) and the earthquake list by Duda (1965), and submarine topographic maps were adopted from *the Bathymetric Chart of the Adjacent Seas of Nippon* by JHO. The epicentral distribution of great earthquakes ($M \gtrsim 7.7$) during the period (1890-1968) in the investigated area are shown in Fig. 12. As seen in this figure, great earthquakes in northeastern Japan are located uninterruptedly parallel to the axis of trenches which are the deepest ones, although a few large earthquakes in the earlier period were excluded in this figure because of uncertainty of their magnitudes. In the remaining areas, where the trenches are not so deep except for the Izu-Ogasawara arc region, great earthquakes are more sparsely located along the island arcs. The detailed topographies of their focal regions are shown in Figs. 13-17. The tectonic features of the localities of these great earthquakes are summarized as follows.

(a) *Kwantō earthquake of September 1, 1923* (Fig. 13)

The magnitude of this earthquake was estimated 7.9 by JMA, 8.2

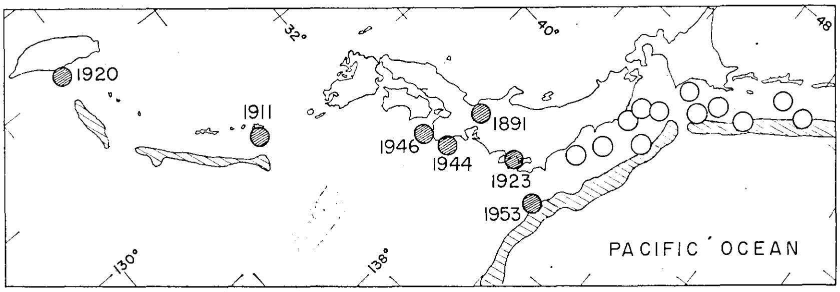


Fig. 12. Epicentral distribution of great shallow earthquakes (M≳7.7) in the Japan-Taiwan region. Open and hatched circles indicate the types **A** and **B**, respectively.

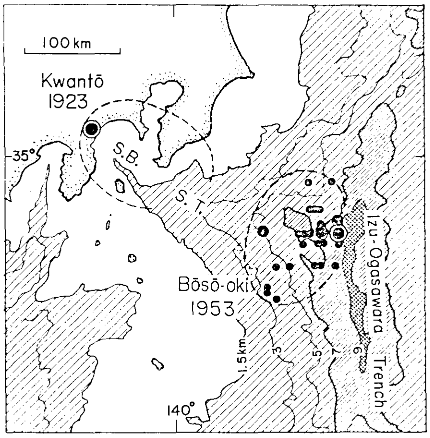


Fig. 13. Submarine topography in and around the focal regions of the Kwantō earthquake of 1923 and the Bōsō-oki earthquake of 1953. S. B.: Sagami bay; S. T.: Sagami trough; double circle: main shock; closed circle: aftershock.

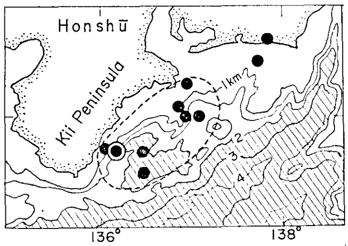


Fig. 14. Submarine topography in and around the focal region of the Tōnankai earthquake of 1944. double circle: main shock; closed circle: aftershock.

by Duda (1965) and 8.1 by Kanamori and Miyamura (1968). The focal region deduced from aftershock epicenters and the source area of the tsunami (Hatori, 1966) is located at Sagami bay (S. B.) which continues to the Sagami trough (S. T.) which is a branch of the Izu-Ogasawara (Izu-Bonin) deep sea trench. The marked subsidence of the sea bottom in Sagami bay at the time of the Kwantō earthquake was reported (JHO, 1925; Mogi, 1959).

(b) *Bōsō-oki earthquake of November 26, 1953* (Fig. 13)

The magnitude of the earthquake was estimated 7.5 by JMA, and 8.0 by Duda (1965). The focal region deduced from the aftershock area and the source area of the tsunami (Hatori, 1966) is characterized

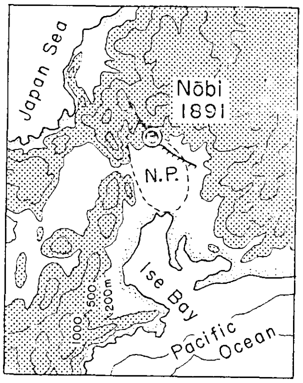


Fig. 15. Topography in and around the focal region of the Nōbi earthquake of 1891 with locations of the earthquake epicenter and fault. double circle: main shock; dotted curve: aftershock area; N.P.: Nōbi plain.

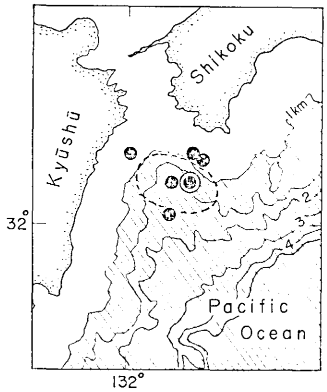


Fig. 16. Submarine topography in and around the focal region of the Hyūganada earthquake of 1968. double circle: main shock; closed circle: aftershock.

by the local depression where the Sagami trough crosses the western slope of the Izu-Ogasawara trench. No great earthquake has not been reported along Izu-Ogasawara trench proper, except for this region.

(c) *Tōnankai earthquake of December 7, 1944* (Fig. 14)

The magnitude of the earthquake is 8.0 by JMA and 8.1 by Duda (1965). The focal region deduced from aftershock epicenters and the source area of the tsunami (Hatori, 1966) coincides with the topographical depression southeast of the Kii peninsula.

(d) *Nankaidō earthquake of December 21, 1946* (Fig. 9)

The magnitude of the earthquake is 8.1 by JMA and 8.2 by Duda (1965). The focal region suggested by the epicentral distribution of aftershocks is located in the topographical depression surrounded by the Kii and the Muroto peninsulas, as pointed out in Part I.

(e) *Nōbi earthquake of October 24, 1891* (Fig. 15)

The magnitude was estimated at 8.0 by Muramatsu (1962). The epicenter of the main shock and the earthquake fault are located at the northeastern margin of the Nōbi plain (N. P.) and many aftershocks occurred under the Nōbi plain. As seen in Fig. 15, the deduced focal region is also characterized by the topographical depression.

(f) *Hyūganada earthquake of April 1, 1968* (Fig. 16)

This earthquake is not plotted in Fig. 12, because the magnitude was estimated 7.5 by JMA, although this is one of the largest shocks in the Hyūganada region. The focal region deduced by the source area of the tsunami (Kajiura et al, 1968) and aftershock epicenters is located in the depression on the continental slope off the Bungo channel between Shikoku and Kyūshū.

Great earthquakes ($M \gtrsim 8$) which occurred since 1900 in the Ryūkyū-Taiwan region were only two, except for deep ones (Fig. 17a). These two great earthquakes occurred along the Nanseishotō trench, but at structurally special regions.

(g) *Earthquake of June 15, 1911 near the Amami-ōshima* (Fig. 17c)

The magnitude is 8.2 (Rikanenpyō) and 8.7 (Duda, 1965), and the focal depth is about 160 km (Duda, 1965). The epicenter is located near the northern end of the deepest region in the Nanseishotō (Ryūkyū) trench, where a transcurrent fault seems to cross the trench (Konishi, 1965).

(h) *Earthquake of June 5, 1920 off the east coast of Taiwan* (Fig. 17b)

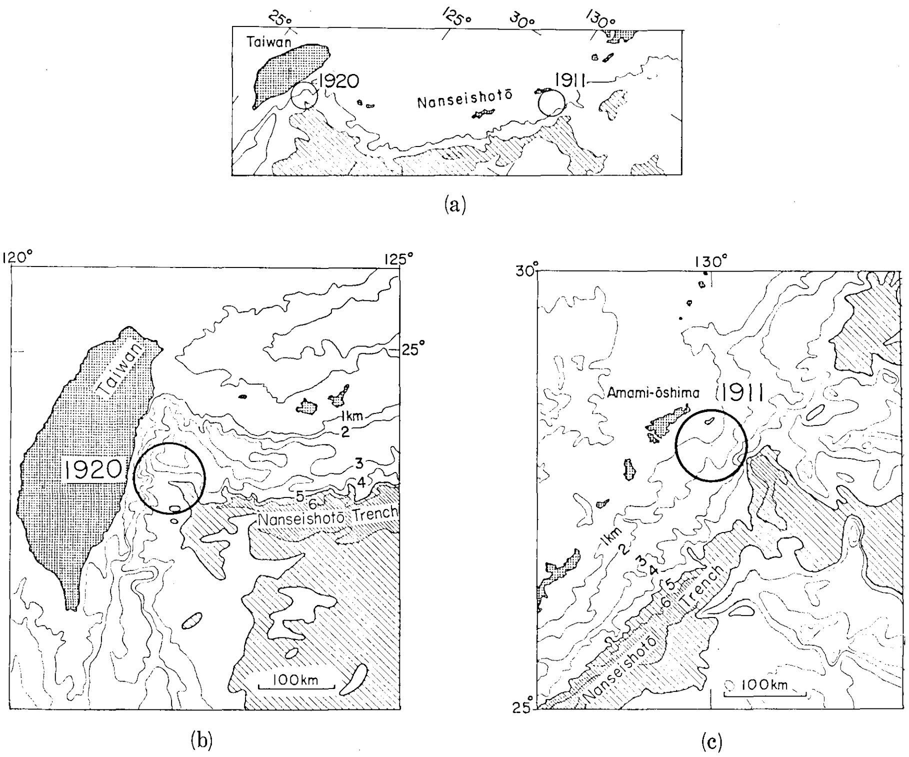


Fig. 17. Submarine topography in and around the focal regions of the great earthquake of 1911 near Amami-ōshima and the great earthquake of 1920 east of Taiwan.

The magnitude of the earthquake is 8.3 (Duda, 1963). The epicenter is located close to the western end of the Nanseishotō trench.

In these cases, it can be pointed out as a common feature that these great shallow earthquakes occurred at local depressions, such as bays, troughs and ends of trenches. These earthquakes (Type **B** in the next section) are indicated by hatched circles in Fig. 12. As a conclusion, the general feature in the major relief of the focal regions of great shallow earthquakes in the whole Japan-Taiwan region is characterized by *topographical depressions*, such as deep sea trenches and troughs.

2. Earthquakes in the Pacific region and its surrounding areas

For other Pacific regions and the surrounding areas, earthquake data were adopted from the earthquake list given by Duda (1965) and the topographical features were mainly studied based on *the World Atlas* by CAGG.

The above-mentioned tectonic feature of the focal regions found in the Japan-Taiwan region is also pointed out in these regions. That is, a large part of great earthquakes occurred continuously along very deep and long trenches, and the rest occurred at local depression or singular places in major relief features. Some examples of the later cases are shown in Figs. 18-20.

(*a*) *Earthquake of August 4, 1946 in the Puerto Rico trench* (Fig. 18)

This earthquake, which is the only one with magnitude 8 and over in this region since 1900, is located at the western end of the Puerto Rico trench.

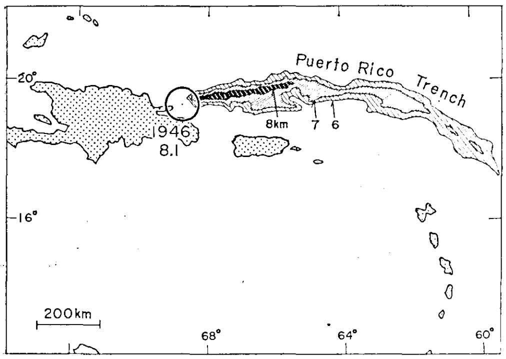
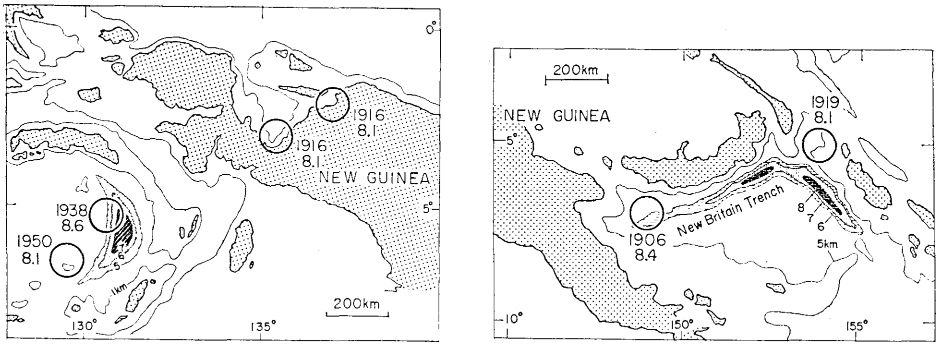


Fig. 18. Submarine topography in and around the Puerto Rico trench and epicentral location of the great earthquake of 1946.

(*b*) *Earthquakes in and around New Guinea* (Figs. 19ab)

In this region, six great earthquakes have occurred since 1900. Figs. 19 a and b show their epicentral locations and the submarine topography



(a) (b)

Fig. 19ab. Submarine topography around New Guinea and epicentral locations of great earthquakes in this region. Numerals indicate years and magnitudes.

in the region. In these figures, it is remarked that these focal regions are also located in or near troughs, bays and the end of a short trench.

(c) *Earthquakes in Central and South America* (Fig. 20)

In this region, many great shallow earthquakes occurred along the Pacific coast. Deep sea trenches, which runs parallel to the coastal line, are discontinuous. Several earthquakes are located in the ocean-facing slope of the deep sea trenches, but several other earthquakes occurred at the places where oceanic ridges or fracture zones meet the active continental margin.

Thus, in relation to the feature of major relief, the occurrence of great shallow earthquakes in the Pacific area may be divided into the following three or four cases as the first approximation.

(1) Many great earthquakes occur uninterruptedly in the ocean-facing slopes of very deep and long trenches (Type **A**).

(2) Great earthquakes occur sparsely at special places in relief features. Some of them occur at local depressions, such as troughs and ends of short trenches (Type **B**) and others occur at intersecting points between oceanic ridges or fracture zones and island-arc-like structure (Type **B′**).

(3) Some earthquakes occur in other regions (Type **C**).

According to the preliminary examination of 72 great shallow earthquakes in the circum-Pacific region and its surrounding areas since 1900, the above-mentioned Type **A**, (**B**+**B′**), and **C** were about 64%, 26%, and 10%, respectively. The epicentral locations of great earthquakes of these types are shown in Fig. 20. Although this classification is accompanied by some uncertainties, due to inaccuracy of epicentral locations and to ambiguity in characterization of relief features, it may

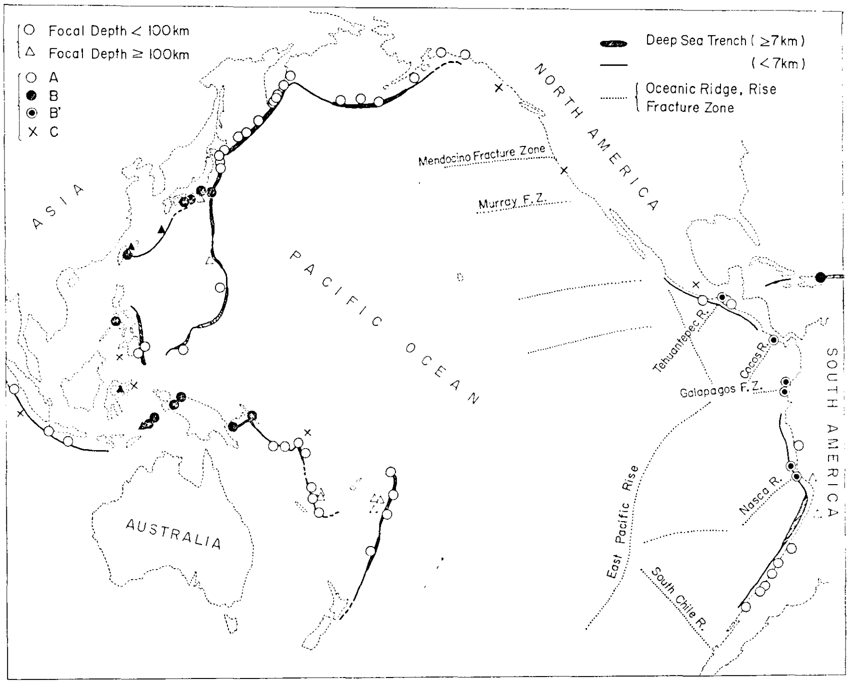


Fig. 20. Locations of epicenters of great earthquakes, deep sea trenches and oceanic ridges. A: earthquake along deep sea trenches; B: earthquake located at bays, troughs and ends of trenches; B′: earthquake located at the intersecting points between oceanic ridges and island-arc-like structure; C: earthquake located at other regions.

safely be concluded that most of great shallow earthquakes in the circum-Pacific region occurred only at very limited places, such as the regions along very deep trenches or the special places mentioned above.

3. Earthquakes along the northern part of the Chile trench and the Izu-Ogasawara trench

As mentioned above, very deep trenches are accompained by uninterrupted locations of great shallow earthquakes. However, there are a few exceptional cases. One of such cases is the northern part of the Chile trench. Figure 21 shows epicentral distributions of major earthquakes in the investigated region in South America. Larger circles indicate great earthquakes ($M \geq 8.0$) during the period (1900–1968) and smaller earthquakes ($7.0 \leq M < 8.0$) during the period (1935–1964). The difference in period is due to the different accuracy of the available data in the earlier period. Open, semi-closed and closed symbols indicate the focal depth (0∼100 km), (101∼300 km) and (301 km∼), respectively.

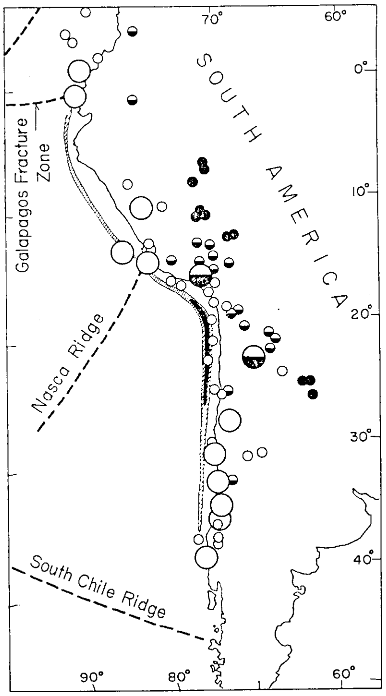


Fig. 21. Locations of earthquake epicenters, the deep sea trench and oceanic ridges in the Pacific region of South America. large circle: M≥8.0 (1900-1968); small circle: 7≤M<8 (1935-1964); open circle: h (focal depth) <100 km; semi-closed circle: 100≤h<300km; closed circle: h≥300 km.

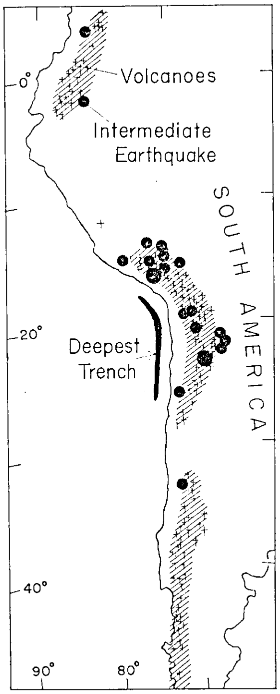


Fig. 22. Locations of epicenters of intermediate earthquakes (100≤h<300 km) (closed circles) and areas where many volcanoes are located (hatched area).

In this figure, it is pointed out that none of the greatest shallow earthquakes occurred along the deepest trench from southern Peru to northern Chile. On the other hand, the earthquake activity at deep or intermediate regions was particularly high in the continental side of this zone. Therefore, it is suggested that the low activity in the shallow region is compensated by the high activity in the deep region. In Fig. 22, the region where many volcanoes are located (Katsui, 1968) is shown together with epicentral distributions of large earthquakes with intermediate focal depths. Although Sugimura (1966) argues that the spatial distribution of the intermediate earthquakes is compensative to that of active volcanoes in this area, Fig. 22 shows that their distributions are rather duplicate. In particular, it is very suggestive for tectonics in this region that intermediate earthquakes, volcanoes and a very deep trench are located in this limited sector where the trend of the arc structure changes markedly.

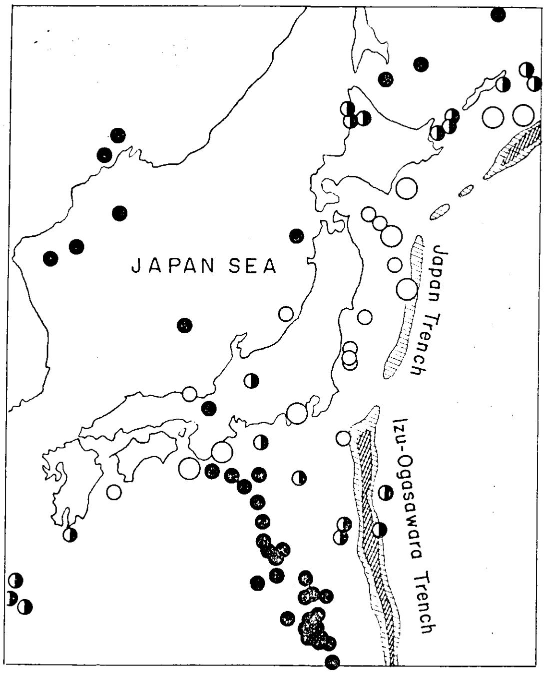


Fig. 23. Locations of major deep earthquakes with magnitude 6 and over during the period (1951–1965) (after Katsumata, 1966) and shallow large earthquakes of magnitude 7.5 and over during the period (1920–1968). open circle: h (focal depth) <120 km; semi-closed circle: $120 \leq h \leq 300$ km; closed circle: $h > 300$ km.

Another region showing the above-mentioned exceptional feature is the Izu-Ogasawara (Izu-Bonin) trench, which is one of the deepest trenches (Fig. 23). As pointed out in a previous paper (Mogi, 1968d), the seismic activity at shallow depths is markedly lower along the Izu-Ogasawara trench than other deep trenches. At deeper regions, however, the seismic activity is very high along the Izu-Ogasawara trench (Katsumata, 1966), as seen in Fig. 23. These features are also seen along the Mariana trench which is the southern extension of the Izu-Ogasawara trench. Table 1 shows the ratio of the energy of intermediated and deep earthquakes to that of shallow earthquakes, in each seismic region of the circum-Pacific belt, calculated from the table of seismic energy by Duda (1965). The abnormally large value of this ratio and the extremely low activity at shallow depths in the Izu-Mariana region is remarkable in this table. These special features seem to be related to the fact that the Izu-Mariana arc is the only one that is situated on the ocean floor surrounded by the circum-Pacific arc systems.

Table 1. Ratio of the seismic energy of the intermediate and the deep earthquakes to that of the shallow ones in different regions of the circum-Pacific seismic belt.

*Region	*Seismic energy released by shallow earthquakes (focal depth ≤ 65 km) per 1° of the belt (10^{23} ergs/degree)	(Energy of intermediate and deep earthquakes) / (Energy of shallow earthquakes)
Izu-Mariana	0.51	5.33
Aleutian-Alaska	6.45	0.11
Japan-Kuril-Kamchatka	15.88	0.25
Philippines-w. New Guinea	7.32	0.40
e. New Guinea-New Hebrides	5.02	0.40
Tonga-New Zealand	3.64	0.29
South America	8.60	0.17
North America	4.15	0.06

*) Duda (1965)

4. Concluding remarks

From the above-mentioned discussion, it is concluded that great shallow earthquakes in the Pacific region occurred almost solely in the limited regions along the arc structures, characterized by long or short topographical depression for most cases and by intersection of oceanic ridges or fracture zones and the arc structures for some cases. These focal regions are sometimes bounded by structural discontinuities. Therefore, if the above-mentioned regularity is established, it is possible to qualify the places, where great shallow earthquakes occur, from the major relief features.

The fact that most great shallow earthquakes occurred at depressions suggests the mechanism that the great shallow earthquakes occur by sudden fracture caused by the down-going movement of the earth's surface layer, which may be attributed to the down-going mantle convection. This mechanism seem to be directly supported by other evidence from the crustal movements associated with the occurrence of great earthquakes (e.g. Plafker, 1965) and the source mechanism of great earthquakes in the circum-Pacific belt (e.g. Stauder, 1968). On the other hand, the concentrated occurrence of great earthquakes at intersecting points of oceanic ridges or fracture zones and arc structures, probably be interpreted by the mechanism in which the higher stress is applied concentrically at such singular places. The main results of the present paper on the major relief features in the focal regions of great earthquakes are in good agreement with the currently promoted global tectonics (e.g. Isacks et al, 1968).

Acknowledgements I wish to thank Dr. Kazuaki Nakamura for critically reading the manuscript and valuable comments, and Dr. Akio Mogi for helpful suggestions on the submarine topography.

References

DEN, N., 1968, Submarine topography and distribution of epicenters of shallow earthquakes, *Geophys. Bull. Hokkaido Univ.*, **20**, 111-124.

DUDA, S. J., 1963, Strain release in the circum-Pacific belt, Chile: 1960, *Jour. Geophys. Res.*, **68**, 5531-5544.

DUDA, S. J., 1965, Secular seismic energy release in the circum-Pacific belt, *Tectonophysics*, **2**, 409-452.

GATES, O. and W. GIBSON, 1956, Interpretation of the configuration of the Aleutian ridge, *Bull. Geol. Soc. Amer.*, **67**, 127-146.

GUTENBERG, B. and C. F. RICHTER, 1954, Seismicity of the earth, Princeton Univ. Press., Princenton, N. J.

HATORI, T., 1966, Vertical displacement in a tsunami source area and the topography of the sea bottom, *Bull. Earthq. Res. Inst.*, **44**, 1449-1464.

ISACKS, B., J. OLIVER and L. R. SYKES, 1968, Seismology and the new global tectonics, *Jour. Geophy. Res.*, **73**, 5855-5899.

Japanese Hydrographic Office, 1925, Report on the depth change of the sea in Sagami-nada and its vicinity by the great earthquake of 1st. September, 1923, *Shinsai-Yobo-Chosakai-Hokoku*, 100 (乙), 61.

JORDAN, J. N. and J. F. LANDER, 1965, Aftershocks of the 4 February 1965 Rat Island earthquake, *Science*, June, 1323-1325.

KAJIURA, K., I. AIDA and T. HATORI, 1968, An investigation of the tsunami which accompanied the Hiuganada earthquake of April 1, 1968, *Bull. Earthq. Res. Inst.*, **46**, 1149-1168

KANAMORI, H. and S. MIYAMURA, 1968, Read at the monthly meeting at the Earthq. Res. Inst.

KATSUI, Y., 1968, Andes no Kazan (Volcanoes in Andes), *Chiri*, **13**, 7-13.

KATSUMATA, M., 1966, Seismic activities in and near Japan (1), *Zisin*, (ii), **19**, 237-245.

KAWASUMI. H. (ed.), 1961, Rikanenpyō (Science Calendar, Tokyo Astronomical Observatory), Maruzen, Tokyo.

KONISHI, K. 1965, Geotectonic framework of the Ryukyu islands (Nansei-shoto), *Jour. Geol. Soc. Japan*, **71**, 437-457.

MOGI, A., 1959, On the depth change at the time of Kanto earthquake in Sagami bay, *Hydrographic Bull.*, no. **60**, 52-60.

MOGI, K., 1967, Earthquakes and fractures, *Tectonophysics*, **5**, 35-55.

MOGI, K., 1968a, Migration of seismic activity, *Bull. Earthq. Res. Inst.*, **46**, 53-74.

MOGI, K., 1968b, Development of aftershock areas of great earthquakes, *Bull. Earthq. Res. Inst.*, **46**, 175-203.

MOGI, K., 1968c, Sequential occurrences of recent great earthquakes, *Jour. Phys. Earth*, **16**, 30-36.

MOGI. K., 1968d, Some features of recent seismic activity in and near Japan (1), *Bull. Earthq. Res. Inst.*, **46**, 1225-1236.

MURAMATSU, I., 1962, Magnitude of the Nōbi earthquake, Oct. 28, 1891, *Zisin*, (ii), **15**, 341-342.

PLAFKER, G., 1965, Tectonic deformation associated with the 1964 Alaska earthquake, *Science*, **148**, 1675-1687.

STAUDER, W., 1968, Mechanism of the Rat Island earthquake sequence of February 4, 1965, with relation to island arcs and sea floor spreading, *Jour. Geophys. Res.*, **73**, 3847-3858.

SUGIMURA, A., 1966, Complementary distributions of epicenters of mantle earthquakes and of loci of volcanoes in island arcs, *Zisin*, (ii), **19**, 96-106.

---

18. 大地震の発生と地体構造との関係

地震研究所　茂　木　清　夫

大地震の起こり方の特徴についてこれまでいくつかの調査を行なってきたが，本報告では，地体構造，とくに長期の地殻変動のあらわれとみられる変動地形（断層や海溝）との関係について述べる．第 I 部では，大地震のときの大規模破壊の過程を反映しているとみられる余震の起こり方と構造との関係を述べ，第 II 部では，このような大地震の起こる場所の地体構造上の特徴を論ずる．今回の調査は，太平洋地域及びその周辺に限られている．次にその結果を要約する．

第 I 部　大地震の余震と地体構造

アリューシャン，チリ，日本の大地震の余震の起こり方は，震源域の断層や海溝の分布と密接な関係を示し，次のような過程が推定される．即ち，大地震の際の大規模破壊は，既存の構造上の不連続線で境された単一若しくは複合ブロックで起こり，このブロックは海溝の陸側斜面にあって海溝にまたがらない．一つのブロックの破壊につづいて隣接ブロックの破壊が起こる場合が多く，その際破壊は既破壊ブロック寄りから進行する．

第 II 部　浅い大地震の震源域の地体構造上の特徴

この様な大地震（又は大規模破壊）の起こり方を地体構造との関連の上からみると，約 64% の大きい地震が大海溝の陸側斜面に連続的に分布し (Type A)，約 26% が小規模海溝の末端や局所的深まりなどに起こり (Type B)，その他の地域に起こったもの (Type C) は僅かに 10% にすぎない．即ち，大地震のほとんどは，Type A 及び B に属するもので，その発生地域は極めて限定され，凹地形という共通の特徴が指摘される．南米の北部チリ海溝及び伊豆・マリアナ海溝では例外的に浅い大地震が少ないが，ここではそれを補うように深い地震活動が活発である．

以上，大地震の震源域は，大局的にも，局部的にも，地体構造と密接な関連を示し，これが大地震の発生機構を研究する上の重要な手掛りとなると思われる．

以上
