BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 46 (1968), pp. 53-74

4. *Migration of Seismic Activity.*

By Kiyoo MOGI,

Earthquake Research Institute.

(Read April 25, 1967.—Received Nov. 18, 1967.)

Abstract

Local migration of the seismic activity before and after the great Sanriku earthquake of March 3, 1933 in northern Japan is described. This remarkable migration pattern in the most active seismic zone in the world is compared with that of the Anatolia earthquakes accompanied by successive development of a great faulting system. The global migration of the epicentral regions of the greatest earthquakes during the last 30 years is summarized. The two northward migration branches in the western part of the circum-Pacific belt and in the Sumatra-Burma-Kansu-Baikal seismic zone and the one southward branch in the south-eastern part of the circum-Pacific belt, which are confirmed by certain evidence, suggest a clockwise rotational migration pattern in the circum-Pacific belt and the surrounding area or a worldwide migration pattern from the equatorial region to the pole regions. These migration patterns may provide an important suggestion on the mechaism of earthquake generation.

1. Introduction

The object of the present investigation is to study a regularity in spatial and temporal distributions of earthquakes, particularly the systematic migration of epicentral regions. Up to the present time, many statistical studies have suggested migration and divergence of the seismic activity in certain regions [*Wadati*, 1926; *Terada and Miyabe*, 1928; *Imamura*, 1946; *Inouye*, 1948; *Homma and Nagahashi*, 1952; *Duda*, 1963; *Iida*, 1966]. Very Local divergence of epicentral regions has been certainly observed in some aftershocks and earthquake swarms [*Nasu et al*, 1931; *Murauchi*, 1949; *Katok*, 1966]. However, in the case of migration in larger scale, which is very interesting in relation to the mechanism of earthquake generation, many data in previous works were inadequate to conclude the suggested migration patterns. In these circumstances, this subject seems to have been left behind in modern seismology because of the lack of convincing evidence. However, whether or not great earthquakes occur with regularity in space and time may provide very important information on the mechanism of earthquake generation and the possibility of statistical prediction of the occurrence of great earthquakes.

In general, uncertainty in previous studies principally comes from insufficient data, complex distributions of earthquakes in space and time, and high background noise. Now, it is most important to find the convincing cases showing migration of seismic activity without any uncertainty. In this paper, some remarkable migrations of epicentral regions of great or greatest earthquakes are described based on the systematic analysis of the published earthquake data.

The earthquake sequence in Anatolia since 1939 is one of the most convincing cases, and has been fully discussed by other investigators [*Pamir and Ketin*, 1941; *Ketin and Roesli*, 1953; *Richter*, 1958]. The local migration pattern before and after the great Sanriku earthquake of March 3, 1933 in northern Japan, described in this paper, is another one. These two cases, in different tectonic regions, alpide and circum-Pacific arc areas, are compared in this paper. Futhermore, another finding from this study is global migration of the seismic activity during the last 30 years. Recent change in the seismicity of the world seems to be attributed to this migration pattern.

2. Procedure of investigation and materials used

As will be seen in later discussions, a remarkable regularity in spatial and temporal distributions of large or largest earthquakes is found in some cases, while no distinct mirgation in that of smaller earthquakes for the same cases is to be found. Therefore, the analysis of the number of earthquakes containing smaller ones cannot give a significant result about this problem. The random occurrence of smaller earthquakes may be partly due to incompleteness of the data. Furthermore, it may be also attributed to the following reason: if migration of seismic activity takes place by the transmission of energy, the regularity may be reflected in the occurrence of the largest earthquakes which account for a large percentage of the total seismic energy in a region, rather than that of small earthquakes of which the total energy is less important. The lowest magnitude over which migration was found is different for different cases, probably dependent on the background seismic activity.

For our purpose, it may be preferable that the released seismic energy is analyzed quantitatively. However, such quantitative analysis seems to have less significance, because uncertainty in magnitude determination seriously affects the result. Therefore, in this paper, epicenters of large or largest earthquakes with magnitudes larger than a certain limit occurring in successive time intervals are systematically described. The epicentral regions of these large earthquakes correspond to seismically active regions where a large part of the total seismic energy in the investigated area was released. This procedure is also affected by the uncertainty in magnitude determination. In fact, the magnitude for the same earthquake is determined differently by different methods, the difference being particularly conspicuous between the surface- and body-wave magnitudes. This kind of error is not appreciable within small areas, but may be considerable in the worldwide comparison. To avoid this uncertainty, the analysis of global migration has been made independently on the two different data by different methods of magnitude determination.

Earthquake data for the sequence before and after the great Sanriku earthquake of 1933 in Japan were taken from *the Catalogue of Major Earthquakes which Occurred in and near Japan (1926～1956)* by *the Japan Meteorological Agency* or *JMA* [1958]. The magnitudes of earthquakes in this catalogue correspond to the original ones in *Seismicity of the Earth* by *Gutenberg and Richter* [1954].

As mentioned above, the global migration problem is discussed in parallel based on the two different data from the following sources: The earthquake list (*Table R*) in *Rikanenpyō* (*Science Calender, Tokyo Astronomical Observatory*), edited by *Kawasumi* [1965] and *Hagiwara* [1967], which is mainly based on *Seismicity of the Earth* by *Gutenberg and Richter* [1954], and the earthquake list (*Table D*) in *Survey of Earthquakes in Period 1897～1964* by *Duda* [1965], which is partly the same as the earthquake list in *Elementary Seismology* by *Richter* [1958]. The magnitudes in Table R correspond to original ones by *Gutenberg and Richter* [1954], and those in Table D are the magnitudes revised by considering body waves. The latter magnitudes are frequently higher than the former for great earthquakes. The lower limit of the earthquake magnitudes in the present investigation is 8.2 for Table D and 8.0 (7.5 in one case) for Table R.

3. Migration of seismic activity before and after the great Sanriku earthquake in north-eastern Japan (1930～1935)

3-1. *Previous works*

Previous studies on migration of the seismic activity in the north-eastern part of the outer seismic belt in Japan have been made by *Wadati* [1926], *Imamura* [1946], and *Homma and Nagahashi* [1952]. Among them, Homma and Nagahashi studied most systematically the change in the spatial distributions of earthquake epicenters in and near Japan during the period 1926～1948 and they pointed out several migration patterns of seismic activity. One of them approximately coincides with the migration pattern described in this paper, but unfortunately their results seem to be too indistinct to conclude a definite migration pattern. The difference between their results and the present results is attributed to the following difference of the procedure of analysis: Homma and Nagahashi used the number of major felt earthquakes including smaller earthquakes (magnitude $M=4\sim5$), but the present analysis has been made for larger earthquakes ($M\geq5.6$). As will be mentioned below, the epicentral region of larger shallow earthquakes ($M\geq5.6$) systematically migrated in the period and the region concerned, but smaller earthquakes randomly occur without any systematic regularity. Accordingly, it is easily supposed that the regularity in larger earthquakes was masked by the inclusion of smaller ones.

3-2. *Epicentral distributions of earthquakes in the successive periods*

Fig. 1 shows epicentral distributions of shallow earthquakes ($M\geq6$) which occurred in the north-eastern part of Japan and its vicinity during 1926～1965, together with the submarine topography. Large numbers of earthquakes occurred between the Pacific coast of Japanese islands and the Japan trench. The great Sanriku earthquake of March 3, 1933 occurred at the eastern boundary of this active zone, corresponding to the eastern wall of the Japan trench. The magnitude of the great Sanriku earthquake was 8.3 in the catalogue by *JMA* [1958] and 8.5 in *Seismicity of the Earth* by *Gutenberg and Richter* [1954]. The table in *Elementary Seismology* by *Richter* [1958] gives the largest value (8.9) by considering body-waves.

The earthquake sequence showing migration began to occur off the south coast of Hokkaidō in 1930. The epicentral distribution of earthquakes in successive time intervals during the period January 1, 1930 to September

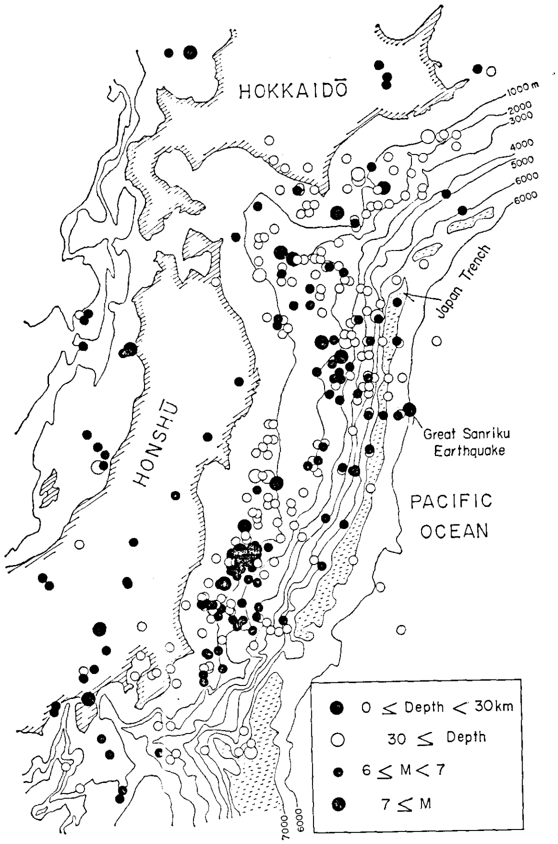


Fig. 1. Epicentral distribution of shallow earthquakes, which occurred in north-eastern Japan during the period 1926~1965, with the submarine topography.

30, 1935 are represented in Figs. 2a~e (Table 1). Large, intermediate and small circles indicate the following magnitude range: $M \geq 7$, $7 > M \geq 6$, $6 > M \geq 5.6$, respectively.

(1) *January 1, 1930~October 31, 1931.* Eight earthquakes including one large earthquake ($M=7.6$) occurred near the south coast of Hokkaidō. In this period, no earthquakes with the considered magnitude occurred in the south part of the considered area.

(2) *November 1, 1931~March 2, 1933.* Fourteen earthquakes occurred in this period. Most of the larger earthquakes occurred to the south-east of the active region in the preceding period. Three earthquakes

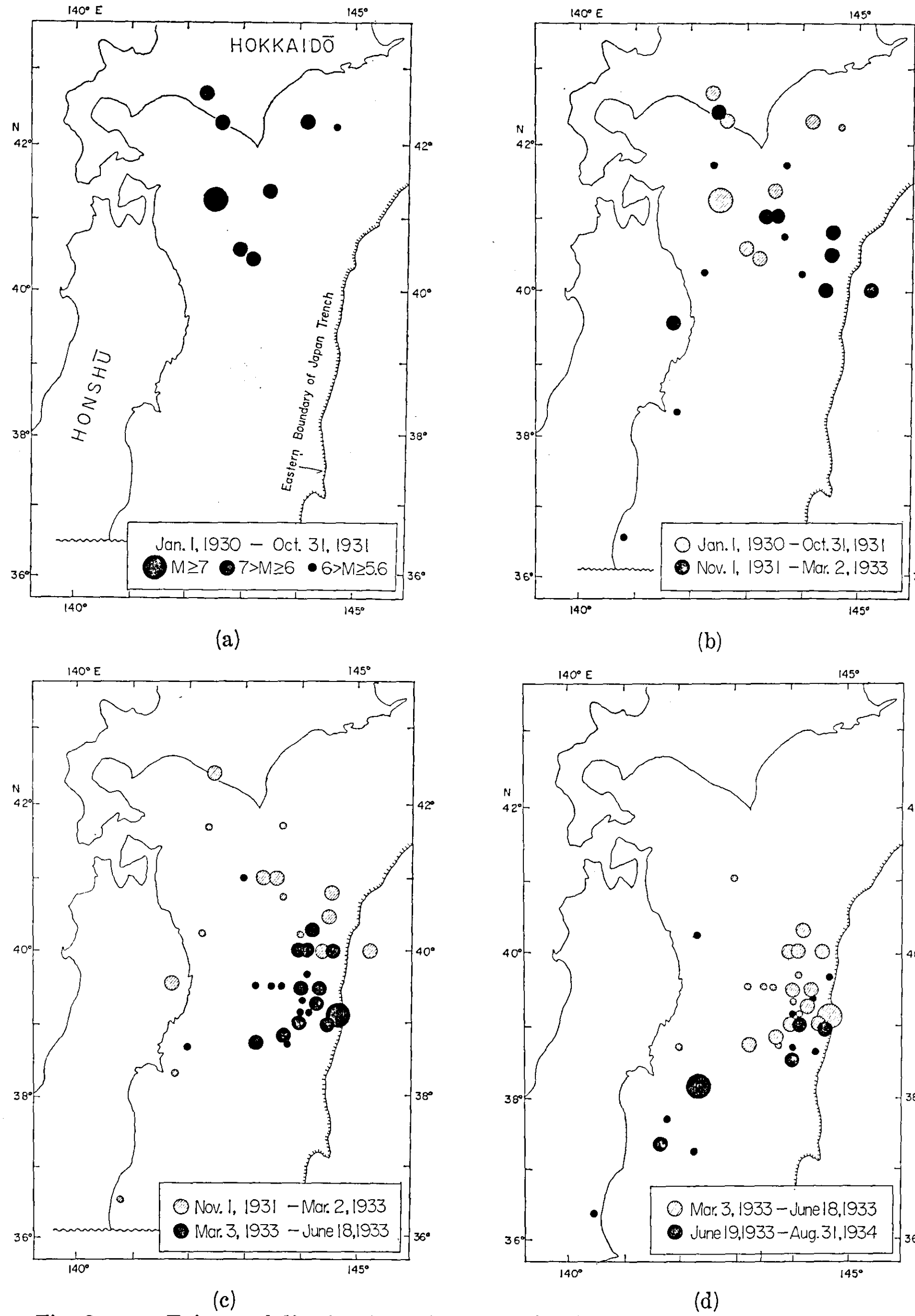
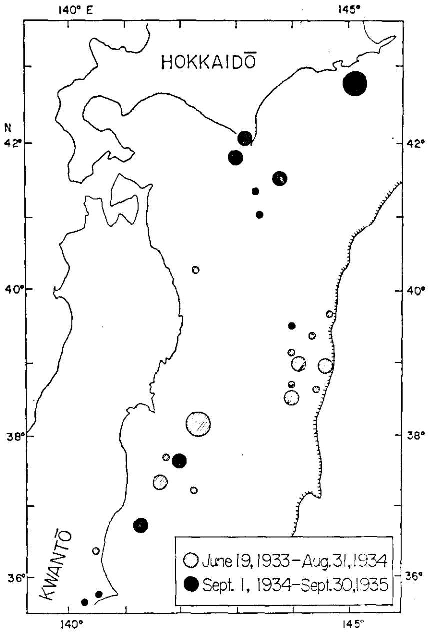


Fig. 2a~e. Epicentral distributions of earthquakes in north-eastern Japan in successive time intervals.



(e)

occurred at the Pacific coast of Honshū. In this period, the southern part of the considered area was also calm.

(3) *March 3, 1933～June 18, 1933.* The great Sanriku earthquake occurred at the south of the active region in the preceding period. The epicenter is situated at the eastern wall of the Japan trench. Directly after the great earthquake, numerous aftershocks followed it. Large aftershocks distribute in the two directions from the epicenter of the main shock, to the northwest and the southwest. These earthquakes in this period were situated on the south of the active region in the preceding period.

(4) *June 19, 1933～August 31, 1934.* The epicentral region in this period developed further in the southwest direction from the epicenter of the great Sanriku earthquake. This pattern coincides with one of the abovementioned branches of the aftershock region. In this period, the northern part of the considered area was very calm.

(5) *September 1, 1934～September 30, 1935.* The active zone in the preceding period developed again in the southwest direction. Two earthquakes occurred in the Kwantō region. During the later stage of this period, several earthquakes began to occur near the southeast coast of Hokkaidō after a long calm period.

Fig. 3 shows also systematic changes in latitude of earthquake epicenters in the considered area during the period 1930～1935.

From these results it may be concluded that the seismic activity certainly migrated from north to south during the period.

3-3. *Migration pattern of seismic activity*

Migration of the active centers in each time interval is summarized in Fig. 4. According to this figure, the active centers moved in the southeast direction from the south coast of Hokkaidō since 1930 and

Table 1. List of earthquakes occurred in north-eastern Japan (36.5°N~43°N) during 1930~1935.

Year	Date (J.S.T.)		Epicenter		Depth	Magnitude
			(°N)	(°E)	(km)	
1930	July	20	42.2	144.7	20	5.8
	Aug.	21	41 1/3	143 1/2	60	6.1
	Dec.	13	42 2/3	142 1/3	20~40	6.1
		24	42.3	144.1	20	6.5
1931	Feb.	17	42.3	142.6	40	6.8
	March	9	41.2	142.5	0	7.6
		10	40.5	143.0	20	6.0
		16	40.4	143.2	40	6.0
	May	15	41.0	143 1/3	20	5.7
	Nov.	4	39.5	141.7	0~10	6.1
1932	June	3	38.2	141.8	40	5.9
		3	40.2	142.2	40	5.7
		4	41.0	143.3	40	6.0
		30	40.2	144.0	60	5.8
	July	10	40	145 1/5	30	6.1
		16	41.7	142.3	40	5.6
	Sept.	3	41	143 1/2	50	6.6
		4	40.8	143.6	50	5.6
		5	41.0	143.1	40	5.8
	Nov.	26	42.4	142.4	40	6.8
	Dec.	20	41 2/3	143 2/3	20	5.8
1933	Jan.	4	40 1/2	144 1/2	0~40	6.4
		7	40.0	144.5	20	6.8
		8	40.8	144.5	40	6.2
	March	3	39.1	144.7	0~20	8.3
		3	40.0	144.0	s	6.5
		3	39.0	144.0	0	6.5
		3	40.0	144.5	40	6.0
		3	39 1/4	143 1/3	20	5.8
		3	39 1/2	144.0	60	6.7
		3	39 1/2	144 1/3	30	6.1
		3	39.1	144.0	30	5.8
		3	39.1	144.1	20	5.9
		3	39 2/3	144.1	30	5.6
		3	38 3/4	143 3/4	40	5.9
		4	38.8	143.7	30	6.0

(to be continued)

Table 1. (continued)

Year	Date		Epicenter (°N)	Epicenter (°E)	Depth (km)	Magnitude
1933	March	4	39 1/2	143 2/3	30	5.9
		4	39	144	20	5.9
		4	39 1/2	144.0	20	5.6
		8	38.7	143.2	20	6.3
	April	2	39 1/2	143.5	0	5.9
		2	39 1/2	144 1/4	20	5.8
		2	39 3/5	143 2/3	40	5.6
		9	39 1/4	144 1/3	40	6.2
		9	40 1/4	143 1/2	20	5.8
		9	40	144	0	6.0
		19	39.3	144.0	0	5.9
		23	39.0	144.5	0	6.4
	June	9	40.3	144.2	0	6.2
		13	38.7	142.0	40	5.8
		14	41	143	20	5.9
		19	38.1	142.35	20	7.1
	July	10	39	144 1/2	40~50	6.3
		21	38 1/2	144.0	60	6.2
	Aug.	7	39.7	144.6	60	5.8
		29	37.7	141.8	40	5.8
	Sept.	21	39.0	144.0	40~60	6.1
		21	38 2/3	144.0	40~60	5.8
		22	39.1	144.0	20	5.7
1934	Jan.	29	37.3	144 2/5	40	5.7
	Feb.	11	37.1	142 1/5	40	5.8
	April	7	37.3	141.6	60	6.5
	May	20	39.4	144 1/3	40	5.8
	July	12	38.6	144.4	60	5.9
	Aug.	3	40.2	142.3	10~20	5.9
	Oct.	6	41 1/2	143.8	40	6.1
		6	41 1/3	143 1/3	20~40	5.6
1935	March	31	37.6	142.0	50	6.3
	July	19	36.7	141.3	0	6.5
	Aug.	27	39.5	144.0	40	5.8
	Sept.	11	42.7	145.1	60	7.1
		18	42.0	143.1	30	6.8
		18	41.8	143.0	40	6.0
		19	41.0	143.4	40	5.6

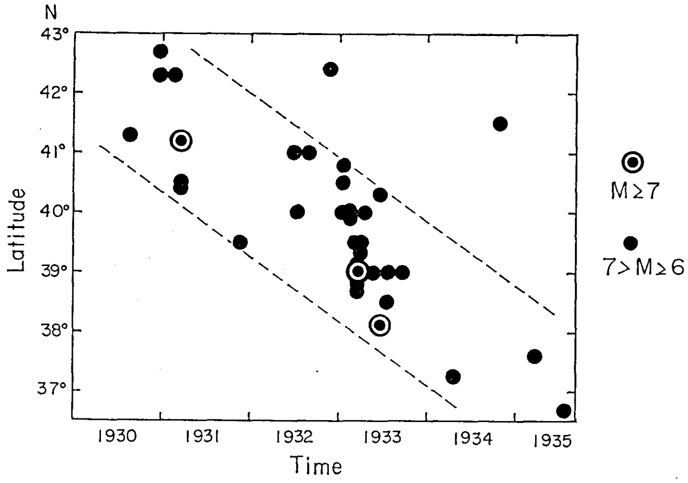


Fig. 3. Latitudes of earthquakes before and after the great Sanriku earthquake of 1933 as a function of time.

met with the Japan trench which is the eastern boundary of the outer seismic zone in Japan. On March 3, 1933, the great Sanriku earthquake occurred at the meeting place between the Japan trench and the migration path. After this great event, the direction of migration changed discontinuously toward the southeast. This pattern developed up to the Pacific coast of Kwantō, crossing the western slope of the Japan trench.

In Fig. 5, the areal density of epicenters of shallow earthquakes with the magnitude 6 and over occurring during the period 1926~1965 is indicated by contour lines and the epicenters of earthquakes ($M \geq 6$) in the abovementioned sequence showing migration are shown by closed circles. It is very interesting that the abovementioned migration path of seismic activity nearly coincides with the most active zone in this area during the period 1926~1965. The total distance in this migration was about 800 km and the average velocity of migration was about 150 km per year.

3-4. *Discussion*

Since earthquakes ($M \geq 5.6$) which do not belong to the investigated sequence showing migration were fortunately extremely rare in the area during the period 1930~1935, the simple migration of seismic activity may be concluded without any uncertainty. This migration pattern before and after the great Sanriku earthquake is appreciably different

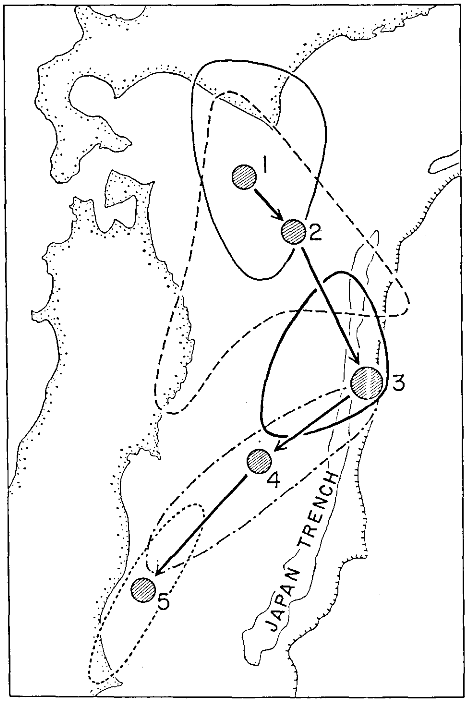


Fig. 4. Epicentral regions and active centers in each period.
1: January 1, 1930~October 31, 1931; **2**: November 1, 1931~March 2, 1933; **3**: March 3, 1933~June 18, 1933; **4**: June 19, 1933~August 31, 1934; **5**: September 1, 1934~September 30, 1935.

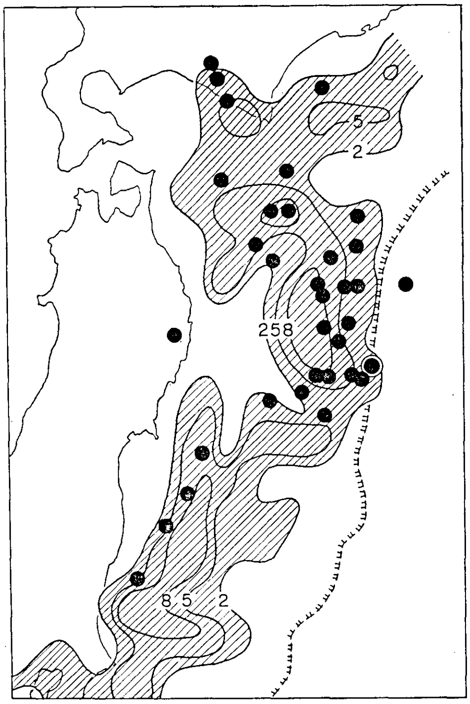


Fig. 5. Contour lines show the areal density of epicenters of shallow earthquakes with the magnitude 6 and over during the period 1926~1965. Closed circles show earthquakes ($M \geq 6$) in the investigated sequences denoting migration.

from that of the Anatolia earthquake sequence at some points.

In the Anatolia sequence [c.f. *Richter*, 1958], the largest earthquake (M=8.0) occurred at the initial stage (December 26, 1939) and several earthquakes successively occurred along a great fault system in the following years (Fig. 6). In Fig. 7, the distance from the epicenter of the great earthquake (39.5°N-38.5°E) to epicenters of each earthquake along the fault is plotted against time. The migration rate was high just after the great earthquake and then considerably decreased. The average rate is about 50-100 km per year. Their epicenters fall closely on the fault line. The westward migration of epicentral regions may

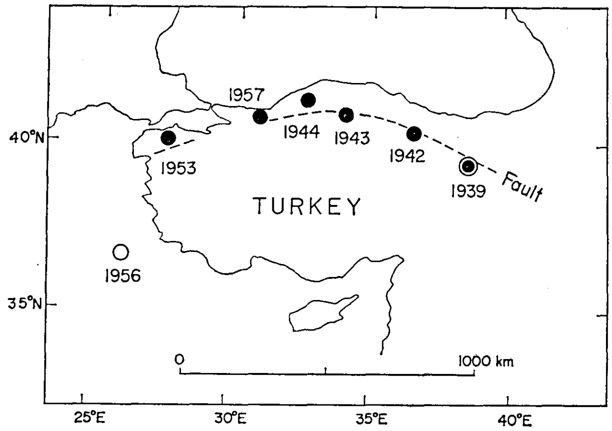


Fig. 6. Epicenters of earthquakes with magnitude 7 and over in Anatolia since 1939. Broken lines show simplified fault traces.

be attributed to the progressive development of the great fault system slightly curving around the northern margin of the Anatolia mass.

On the other hand, the pattern in the Sanriku sequence is more complex. The principal earthquake occurred at the middle stage and the direction of migration changed discontinuously before and after the great earthquake. The epicenters distributed in a wider zone around the migration path of the active centers. This migration pattern can not be explained as the successive development of a single fault system in block structures, but it does suggest the progressive pattern of the areal fracturing. This difference in migration pattern may be attributed to the difference of the mechanism of earthquake occurrence between the most active region in island arcs and the moderately active region with block structures.

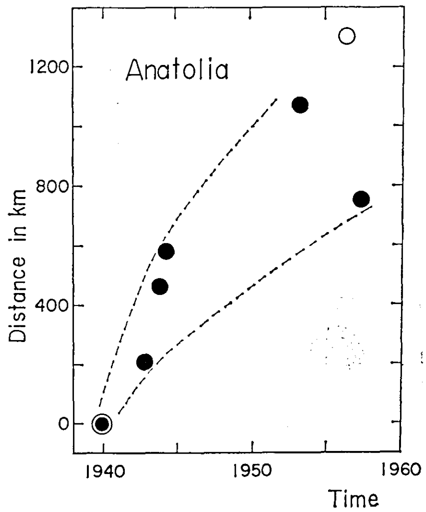


Fig. 7. Distances from the epicenter of the first great earthquake of December 26, 1939, in Anatolia to each epicenter of the following earthquakes along the fault system, as a function of time.

4. Global migration of seismic activity

4-1. *The period 1935～1964*

Fig. 8 shows the geographical distribution of epicenters of great earthquakes with magnitude 8.2 and over, during the period 1900～1964 (Table D). The majority of the great shallow earthquakes occur in the circum-Pacific belt. Most of the remaining great shallow earthquakes occur in the central area of Asia between the Alpide belt and the Pamir-Baikal seismic zone. *Duda* [1965] pointed out another branch of the seismic zone in this area, the Baikal-Kansu-Burma seismic zone, which is also suggested by the migration pattern mentioned below. This zone parallels the western part of the circum-Pacific belt passing through Japan, Formosa, Philippines and Celebes. The epicenters in the circum-Pacific belt form a linear structure. A chain line in Fig. 8 indicates the axis of this belt and numerals on the line show the distance (in km) measured along the chain line from Cape Horn in South America, which will be used in the following discussion. The present investigations of the distributions of shallow earthquakes in space and time suggest a systematic change of epicentral regions during the last 30 years.

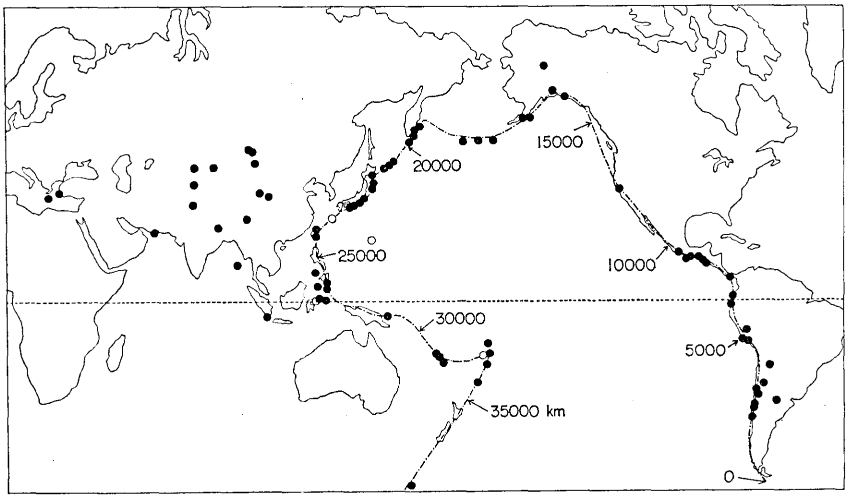


Fig. 8. Epicenters of great shallow earthquakes with magnitude 8.2 and over during the period 1900～1965 (Table D). Closed circle: focal depth≤100 km; open circle: focal depth>100 km. A chain line shows the axis of the circum-Pacific seismc belt and the numeral indicates the distance in km measured along the chain line from Cape Horn, South America.

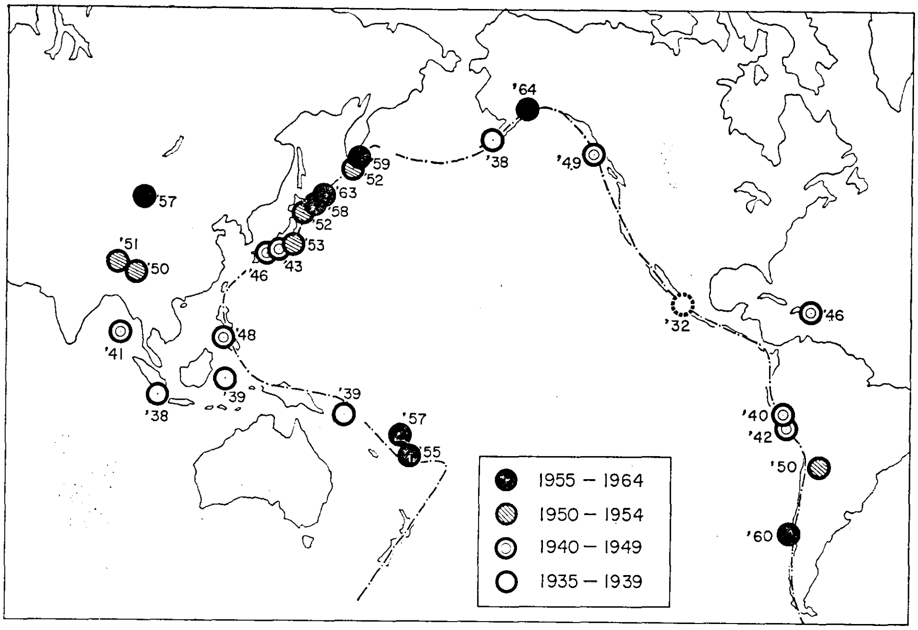


Fig. 9. Epicenters of great earthquakes with magnitude 8 and over in successive periods since 1935 (Table R). Numerals indicate years.

Earthquakes with focal depths greater than 150 km are omitted in this discussion. Fig. 9 represents the epicentral distributions of great earthquakes ($M \geq 8$) in successive periods since 1935, based on Table R. Activity in the western part of the circum-Pacific belt and the Sumatra-Burma-Kansu zone successively migrated from south to north. In the last ten years, five great earthquakes occurred at the northern part of these seismic belts. It is very interesting that migration took place simultaneously in both belts. Another branch in the southeastern part of the circum-Pacific belt seems to show the southward migration with some irregularity. Before the investigated period (1935~1964), a great earthquake occurred on the Pacific coast of Mexico in 1932, which is the only great earthquake occurring in the area during the period 1930~1934. This may belong to the abovementioned earthquake sequence showing migration.

Fig. 10 is another expression showing the location of migration of epicentral regions as a function of time. The ordinate shows the distance (in km) measured along the axis of the circum-Pacific belt from Cape Horn in South America. Circles show earthquakes within the narrow

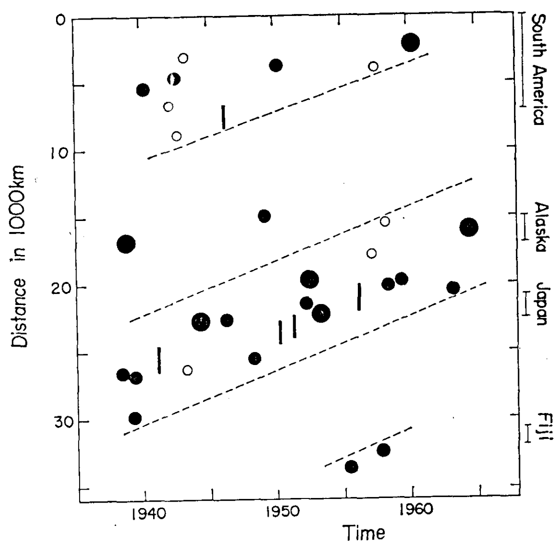


Fig. 10. Distribution of great shallow earthquakes ($M \geq 7.9$) in space and time since 1935 (Table R). The distance in the ordinate is measured from the southern end of South America (Cape Horn) along the axis of the circum-Pacific belt. Circles show earthquakes within the narrow zone of the circum-Pacific belt and vertical bars show earthquakes in surrounding regions, including the Burma-Kansu seismic zone. Large closed circle: $M \geq 8.3$; small closed circle: $8.0 \leq M < 8.3$; open circle: $M = 7.9$; bar: $M \geq 8.0$.

belt and vertical bars show earthquakes in the surrounding regions, including the Burma-Kansu seismic zone. This figure also indicates that epicentral regions have migrated in two groups along the circum-Pacific belt, although a few earthquakes occurred in isolation.

Fig. 11 indicates epicentral distributions of earthquakes with magnitude 7.5 and over in the central area of Asia in successive time intervals during the period 1935~1964 (Table R). As will be seen from this figure, epicentral regions of smaller earthquakes ($7.5 \leq M < 8.0$) migrated successively from south to north simultaneously with those of the greatest earthquakes in this area and the western part of the circum-Pacific belt. This migration pattern reaches to the Caspian Sea. In this figure, the Sumatra-Burma-Kansu-Baikal seismic zone is very clearly marked. According to those investigations, the lowest magnitude over which migration was found was 7.5 in this zone, but 7.9~8.0 in the circum-Pacific belt. This difference between both seismic zones may

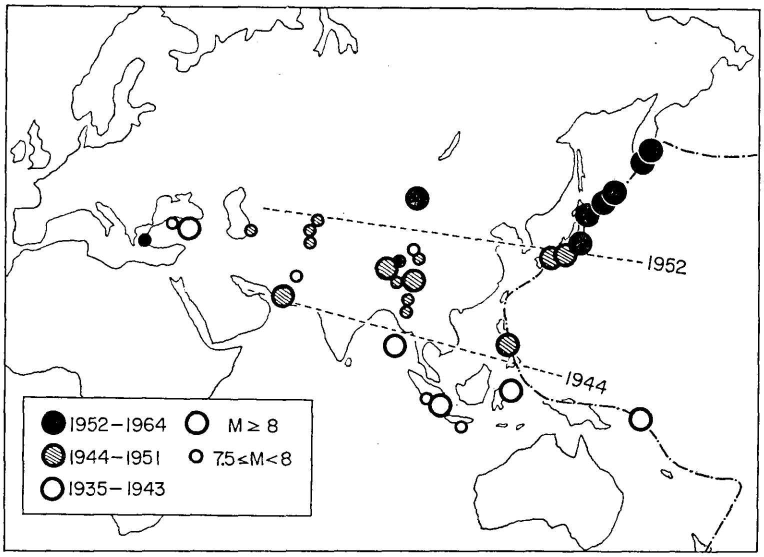


Fig. 11. Epicenters of earthquakes with magnitude 7.5 and over in successive time intervals during the period 1935~1964 (Table R). For the circum-Pacific belt, smaller earthquakes ($7.5 \leq M < 8$) are exclude.

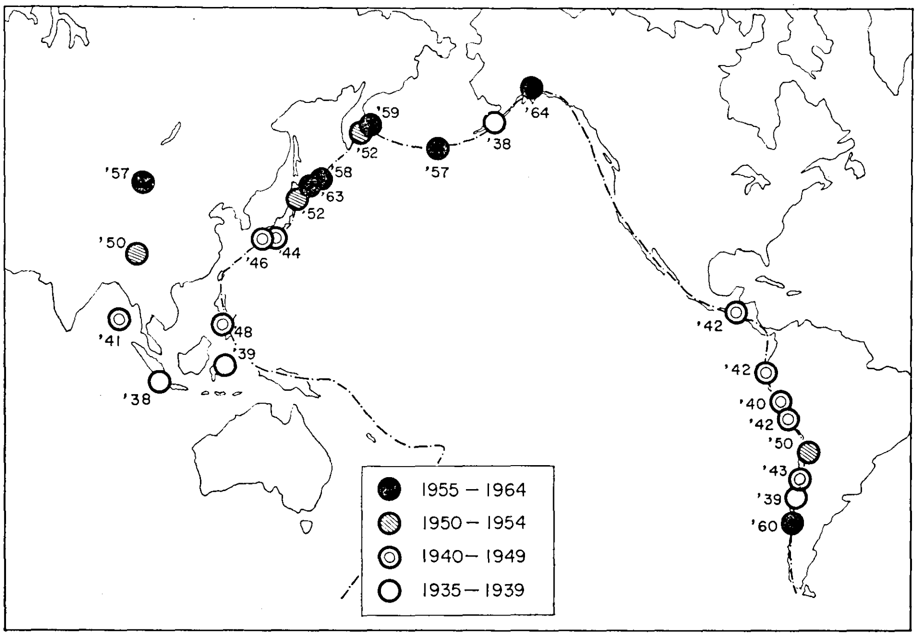


Fig. 12. Epicenters of great earthquakes with magnitude 8.2 and over in successive time intervals during the period 1935~1964 (Table D). Numerals indicate years.

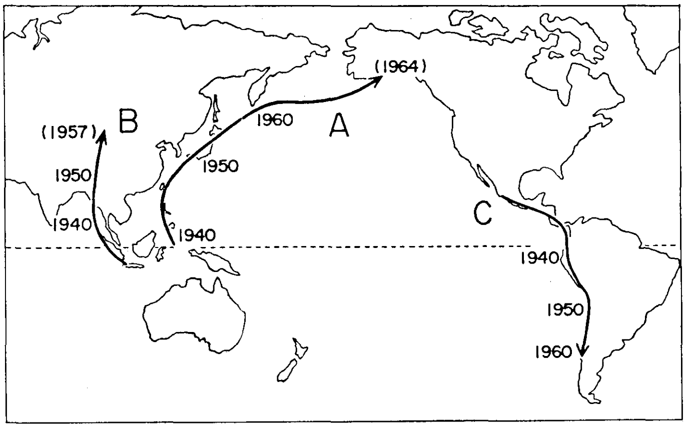


Fig. 13. Summarized global migration patterns of seismic activity during the last 30 years.

be related to the fact that the background seismic activity is higher in the circum-Pacific zone than in the central part of Asia.

As mentioned above, the magnitude for the same earthquake is sometimes different in different tables. To avoid errors from uncertainty in magnitude determination, the earthquake data in Table D [*Duda*, 1965] have also been analyzed, in which the magnitude is given with Richter's revised scale considering body waves. The epicentral distributions of great earthquakes with magnitude 8.2 and over based on this table are represented in Fig. 12. The same migration patterns noted in Fig. 9 can also be clearly seen in this figure. The agreement of both results gives evidence of high reliability of the present conclusion.

The three migration patterns, mentioned above, are summarized in Fig. 13. They suggest the clockwise rotational migration of seismic activity in the circum-Pacific belt and the surrounding areas. On the other hand, these patterns may be arranged as the changes in latitude of great earthquakes. Fig. 14 shows the latitude of earthquakes as a function of time in each branch (Table R). Latitude increases simultaneously from zero both in the northern and southern hemispheres. Accordingly, the observed result can be arranged as a worldwide migration from the equatorial region to the pole regions during the last 30 years.

4-2. *The period 1900∼1934*

As mentioned above, the global migration of seismic activity during the last 30 years is strongly suggested. Now, it is very interesting

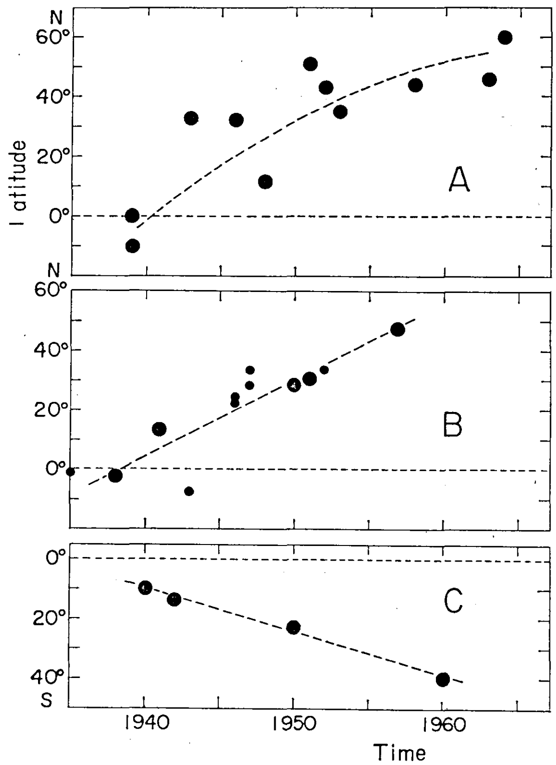


Fig. 14. Latitudes of earthquakes as functions of time (Table R). **A**: western part of the circum-Pacific belt; **B**: Sumatra-Burma-Kansu seismic zone; **C**: south-western part of the circum-Pacific belt. Large circle: $M \geq 8.0$; small circle: $7.5 \leq M < 8.0$.

whether or not this pattern is a part of a long-term migration system. Fig. 15 shows epicentral distribution in space and time during the period 1900~1964 based on Table D, which seems to contain the most complete list of earthquakes during the period 1900~1934. The ordinate of this figure is the distance along the circum-Pacific belt, as in Fig. 10. Earthquakes are limited to the great shallow ones which occurred in the circum-Pacific belt. The migration of seismic activity during the period 1935~1964 can also be clearly seen, but the epicentral distribution in the preceding period is not continuous with the migration pattern of the period 1935~1964 and is more complex. This complexity may be related to the fact that the seismic activity was extremely high at

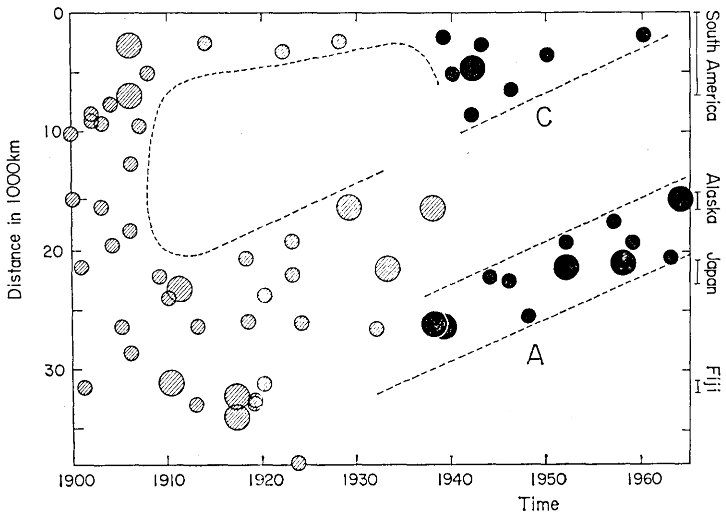


Fig. 15. Distribution of great shallow earthquakes ($M \geq 8.2$), which occurred in the circum-Pacific belt during the period 1900∼1964, in space and time (Table D). The distance in the ordinate is measured from the southern end of South America along the axis of the circum-Pacific belt. **A** and **C** correspond to the migration branches in Fig. 10 and broken lines show the boundary between active and inactive regions. Large circle: $M \geq 8.5$; small circle: $8.2 \leq M < 8.5$.

the beginning of this century and gradually decreased until the present time, as pointed by *Duda* [1965]. However, some regularities can be noted even in the period before 1934. Fig. 16 shows epicentral distribution in successive time intervals during the period 1897∼1930. Although epicenters were spread out in a wide area, seismic activity migrated from north to south. Further, in Fig. 15, the boundary between the active and inactive regions in the northern part of the circum-Pacific belt also shifted from west to east during the period 1910∼1930. Thus, although the distributions of epicenters in space and time during the period is too complex to be ascribed to any simple migration pattern, they suggest that the greatest earthquakes did not occur independently.

4-3. *Discussion*

As mentioned before, the local migration in Japan and Anatolia may be reasonably explained as successive development of faulting or fracturing of the earth's crust. However, the abovementioned global migration of seismic acivity is difficult to interpret with known mechanisms. A large part of the seismic energy in the world during the last 30 years was released in the abovementioned regular pattern. Since such global long-term migration cannot be the results of secondary causes, such as triggering actions, the present result suggests the global transmission of the main part of the energy source, such as the slow propagation of stress waves in plastico-elastic media. If the global migration in the recent years is accepted, we can draw the following conclusions:

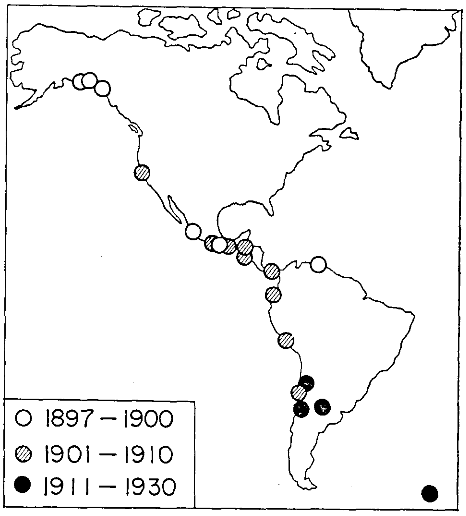


Fig. 16. Epicenters of great earthquakes ($M \geq 8.2$) in America in successive time intervals during the period 1897~1930 (Table D).

(1) The seismic activities in each region were not independent, but had a close relation with each other, particularly within each branch of migration.

(2) The seismic energy was supplied not only from the deep region directly under the seismic region, but also in lateral directions from distant areas.

(3) The velocity of migration was considerably large, 150 to 270 km per year, so that this transmission of seismic activity is not attributable to thermal processes, such as conduction or mantle convection, but may be due to mechanical processes, as mentioned above. This result supports mechanical theories on earthquake generation mechanisms, such as the fracture hypothesis [*Mogi*, 1967], better than the phase change hypothesis [*Evison*, 1963], in which thermal processes are important.

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4. 地震活動の移動

地震研究所 茂木清夫

地震の震源域が時間と共に系統的に移動する場合があるかどうかという問題は，地震の発生を予測する問題にも関連して，古くから多くの人によって論じられてきた．余震域の拡大の様な，比較的短期間の局地的な移動については，2，3のかなり明瞭な移動の例が報告されているが，最も興味ある所の大きい地震の大規模な移動に関しては，これまでいくつかの報告例があるにも拘らず，その資料は，移動を結論するには不十分な場合が多く，移動が確実に結論され得る例は非常に少ない．従って，この問題については，確実に震源域の移動を結論出来る例を出来るだけ多く見出して，その移動特性を明らかにすることが重要である．

本論文では，次に述べる，1933年3月3日の三陸沖大地震前後約6年間の移動及び過去30年間の巨大地震の震源域の世界的規模における移動について論ずる．

(1) 1933年の三陸沖大地震前後の移動

M が 5.6 乃至6以上の比較的大きい地震に注目すると，その活動域が 1930年1月から約6年間の間に，北海道南岸沖から関東地方東岸まで次第に南下したことが結論される．特に，その活動中心に注目すると，先づ，北海道南岸沖から南東方向に移動し，それが日本海溝に達する所で三陸沖

大地震が発生し，その後，方向を南西にかえて関東地方東岸に達した．この移動経路は，この地域のサイスミシテイの最も高い地帯と一致している．この地域で，ほかの期間については，この様な明瞭な活動域の系統的移動は認められなかった．

(2) 巨大地震の大規模な移動

M が8前後乃至それ以上の巨大地震の震源域が，1935 年以後の 30 年間に系統的に移動したことを結論した．(M が更に小さい地震については，観測洩れがあるため定量的解析が無理なことと，総地震エネルギーへの寄与が小さく，常時活動の一部を含む等の理由から，大地震に見られる様な規則性は期待されないので，今回の取扱いからのぞかれたが，実際その起こり方は不規則である．) 結論が，M の決定の不確定さに影響される可能性があるので，二つの異なる方法 (表面波と実体波を用いる方法) によって求められた M の表にもとづいて独立に解析してその結果がほとんど変らないことを確めた．この結論によると 1935 年から 30 年間に，(A) インドネシア→日本→カムチヤッカ→アラスカ，(B) スマトラ→ビルマ→バイカル，及び (C) 中米→ペルー→チリの三つの移動系列が認められ，これは環太平洋地震帯に沿う時計回りの方向の移動と見ることも出来るし，また，赤道から南北の極方向に向かう移動と見ることも出来る．いづれにせよ，これらの最近の巨大地震の発生は，各々独立に起こったと見るよりも，世界的規模をもった一つの移動形式にしたがって起こったと見られる．1935 年以前の地震については，その資料の信頼性に問題が残るけれども，上述の様な明瞭な傾向は認められないことから，この様な移動のパターンは永続的なものではないと推定される．

以上の結果に，1939 年以後の Anatolia 地震の例を加えると，もはや地震の震源域の大規模な移動の可能性は否定出来ない．地震の起こり方のこの様な特徴は，地震発生機構を考察する場合の重要な手掛りを与えると思われる．