第11卷 第4期 西北地震学报 Vol.11,No.4
1989年12月 NORTHWESTERN SEISMOLOGICAL JOURNAL Dec.,1989

MIGRATION AND DIFFUSION OF SEISMIC ACTIVITY OBSERVED IN THE JAPANESE ISLANDS

Akio Yoshida
(*Meteorological Research Institute, JMA 1—1, Nagamine, Tsukuba, Ibaraki 305 Japan*)
Kohji Hosono
(*Seismological Observatory, JMA 3511, Nishijo, Matsushiro, Nagano 381—12 Japan*)

Abstract

Migrations of seismic activity observed after large earthquakes which occurred in and near the Japanese Islands are investigated. A common feature of migrational phenomena in the six cases which are studied in this paper is that migration occurred along geological tectonic zones. Sometimes existence of active tectonic zone is reconfirmed by the appearance of migrational phenomena. Analogizing to plate boundary regions where seismic activity is known to migrate or diffuse along mechanically coupled plane, we can consider that inland active tectonic zones correspond to mechanically interacting boundaries of crustal blocks. It is likely that more than one type exist in miqrational phenomena.In the cases we investigated following characteristics are observed that velocity of migration is about several km/year,seismic gaps remain between focal regions of large earthquakes, and there are seismically active periods in each seismic belt. A possible mechanism of migration is successive break down of asperities in which tectonic stress concentrates by relative movement of crustal blocks.

1. Introduction

Large earthquakes seldom occur isolated from others, but most likely they occur successively in a region which constitutes a tectonic block or along boundaries of blocks in active periods. Further, seismic activity sometimes shows migrational tendency or diffusive pattern towards specific direction in each district. Such migrational phenomena are extensively investigated concerning large earthquake occurrence in the circum-Pacific seismic belt. Migration of seismic activity is also observed along inland large fault zone such as the northern Anatolian fault in Turkey, the San Andreas fault in California as well as some seismic belts in China. Concerning seismic activity in the Japanese Islands Mogi (1969) first recognized migration of large earthquakes in the Kanto-Tohoku districts after the occurrence of the 1923 Kanto earthquake, and now we have many reports of such phenomena including those observed in small earthquake activity.

Although migration and diffusion of seismic activity which we investigate in this paper are similar to the phenomena of extension of aftershock area, they also have different aspects such that they last more than several tens of years and reach to distance of several tens times of aftershock area and they usually have directionality. In the following we introduce some examples of such phenomena observed in the Japanese Islands. Hypocentral data are taken from Utsu catalogue (Utsu, 1979) for years before 1925 and those in the period 1926—1985 are from the published Seismological Bulletins of the Japan Meteorological Agency, and we made use of SEIS-PC program for personal computers (Ishikawa et al., 1985) in the analyses.

2. Migration and diffusion of seismic activity

In the following we show examples of migration of seismic activity after six large earthquakes which occurred in or near the Japanese Islands. They are the 1923 Kanto earthquake (M7.9), the 1948 Fukui earthquake (M7.1), the 1964 Niigata earthquake (M7.5), the 1965 Shizuoka earthquake (M6.1), the 1975 Kumamotoken-hokutobu earthquake (M6.1) and the 1983 Nihonkai-chubu earthquake (M7.7). Figure 1 represents epicenters of these earthquakes and areas where migration of seismic activity were observed. Among these earthquakes the 1923 Kanto earthquake is a great interplate earthquake which occurred in the subduction zone of the Philippine Sea plate, and the 1964 Niigata earthquake as well as the 1983 Nihonkai-chubu earthquake are considered to be relevant to the activity of the nascent trench along the eastern Japan Sea[1—3], the existence of which plate boundary has been recently proposed by Nakamura[4] and Kobayashi[5]. Further the 1965 Shizuoka earthquake is probably related to the split of the Philippine Sea plate[6]. The 1948 Fukui earthquake and the 1975 Kumamotoken-hokutobu earthquake are shallow intraplate earthquakes to the contrary.

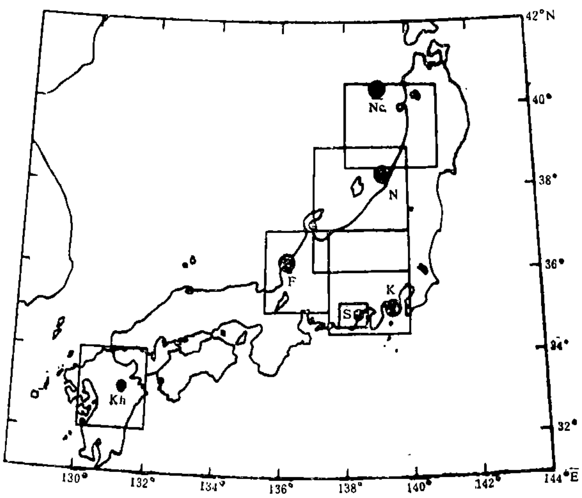

Fig. 1　Epicenters of six large earthquakes and migration and diffusion of seismic activity after these earthquakes

K—the 1923 Kanto earthquake (M7.9); F—the 1948 Fukui earthquake (M7.1); N—the 1964 Niigata earthquake(7.5); S—the 1965 Shizuoka earthquake(M6.1); Kh—the 1975 Kumamotoken-hokutobu earthquake (M6.1); Nc—the 1983 Nihonkai-chubu earthquake (M7.7)

(1) The 1923 Kanto earthquake (M7.9)

After the great Kanto earthquake migration and diffusion of seismic activity were observed in the Kanto, Chubu and Tohoku districts. Figure 2(a) shows epicentral distribution of shallow (depth≤30km) earthquakes with M5 and larger ones in the period from September 1, 1923 (on the day the Kanto earthquake occurred) through 1951. The ordinate in Fig. 2(b) represents epicentral distance of earthquakes in Fig.2(a) from the epicenter of the 1923 Kanto earthquake and the abscissa is time of occurrence of those earthquakes. In Fig.2(b) we can recognize diffusion of seismic activity to surrounding areas from the focal region of the Kanto earthquake, although the pattern is rather vague in space and time. A diffusion tendency of large earthquakes above M6 in the period of ten and several years after the Kanto earthquake is also noted by Mogi[7]. Figure 2(b) shows that the diffusive activity lasted longer periods. The speed of diffusion is estimated at about 4.5km/year. In Fig. 2(a) a zonal distribution of earthquakes is seen in the direction of north-northeast from the Izu Peninsula. Mogi first pointed out a series of moderately large earthquakes along the zone to the Tohoku district[8]. This zone is recognized in recent seismic activity of small earthquakes as well, which fact, we think, is important to consider the mechanism of migration of seismic activity[9]. A tectonic meaning of this zone is discussed in Yoshida[6、8] in relation to the subduction of the Philippine Sea plate and the collision of the Izu Peninsula.

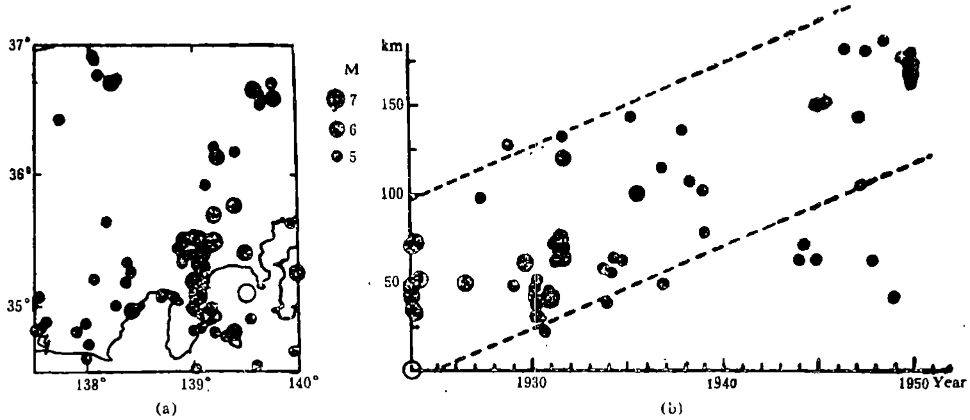

Fig. 2 Epicentral distribution of shallow (depth≤30km) earthquakes with M5 and larger ones in the period from September 1, 1923 through 1951

(2) The 1948 Fukui earthquake (M7.1)

Figure 3(a) shows epicentral distribution of shallow (depth ≤30km) earthquakes with M5 and larger ones during the period 1948 through 1984. In Fig. 3(b) epicentral distance of these earthquakes from the epicenter of the 1948 Fukui earthquake is plotted against time of their occurrence. From these Figures diffusive tendency of seismic activity after the Fukui earthquake is clear. The speed of diffusion is estimated at about 4km/year. Another notable feature of Fig.3 is that the 1961 Kitamino earthquake (M7.0), the 1969 Gifuken-chubu earthquake (M6.6) and the 1984 Naganoken-seibu earthquake (M6.8) occurred succesively along a belt like zone to the east-southeast direction from the focal region of the 1948 Fukui earthquake (M7.1). The fact that the line of these large earthquakes and the distribution of Quarternary volcanoes coincide indicates that the seismic belt corresponds to the weak zone in the crust[10]. It is suggested from seismic activity of small earthquakes and distribution of volcanoes that the weak zone does not extend further to the east but continues to the north from the focal region of the 1984 Naganoken-seibu earthquake.

(3) The 1964 Niigata earthquake (M7.5)

In June 1964 the Niigata earthquake occurred and in August in the next year the Matsushiro swarm activity commenced in a region where seismic..y had been rather quiet for a long time. The zone which connects the two focal regions corresponds to the Shinanogawa seismic belt proposed by Omori[11] many years ago and has been known as an active fold area at the present time[12]. The 1828 Sanjo earthquake

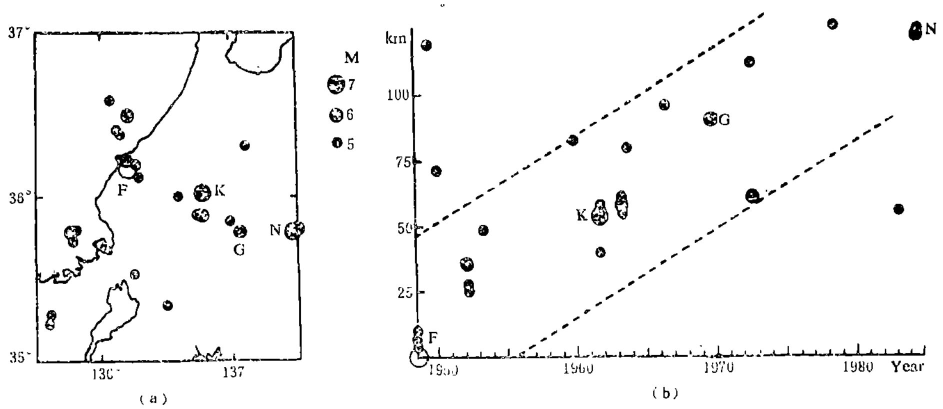

Fig. 3　Epicentral distribution of shallow (depth≤30km) earthquakes with M5 and larger ones during the period 1948 through 1984
F—the 1948 Fukui earthquake (M7.1); K—the 1961 Kitamino earthquake (M7.0); G—the 1969 Gifuken-chubu earthquake (M6.6); N—the 1984 Naganoken-seibu earthquake (M6.8). The open circle represents the epicenter of the Fukui earthquake.

(M6.9) and the 1847 Zenkoji earthquake(M7.4) occurred along this zone. If we take into consideration these facts it is natural to expect that occurrences of the Niigata earthquake and the Matsushiro earthquake swarm were correlated each other.

Figure 4(a), (b), (c) shows seismic activity in the periods of 5 years before the Niigata earthquake, just after the Niigata earthquake, and the next 5 years respectively. It is obvious from these Figures that seismicity in the zone connecting the two focal regions was high in the period just after the Niigata earthquake. In order to see change of seismic activity for a longer period epicentral distribution and space-time distribution of earthquakes over 36 years from 1950 through 1985 are shown in Fig.5(a) and Fig. 5(b)[13]. From Fig. 5 it is clear that seismic activity in the zone became high in the period when the Niigata earthquake and the Matsushiro swarm occurred, the fact strongly supports the idea that the occurrences of the two earthquakes were related.

(4) The 1965 Shizuoka earthquake (M6.1)

Figure 6(a) shows seismic activity in the region to the west of Suruga Bay during the period 1965 through 1973, and Figure 6(b) shows epicentral distances of those earthquakes in the rectangular region in Fig.6(a) from the epicenter of the 1965 Shizuoka earthquake and time of their occurrence. From these Figures we can recognize tendency of diffusion of seismic activity to the west, although it is not so obvious.

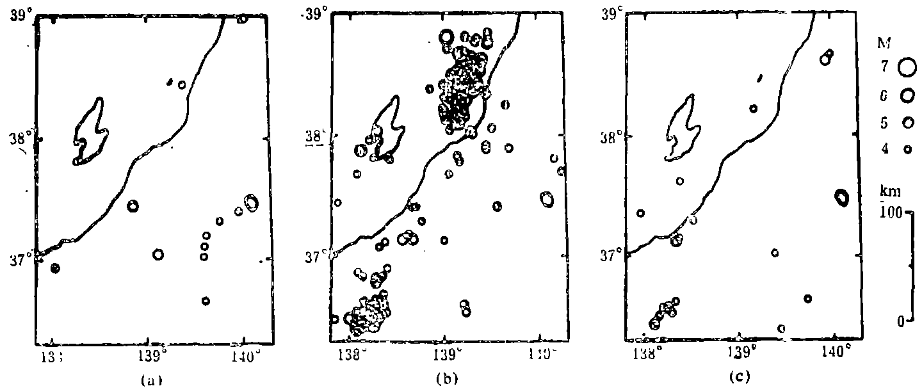

Fig. 4 Epicentral distribution of shallow (depth⩽30km) earthquakes with M4 and larger ones
(a)over five years before the Niigata earthquake (June 16, 1959 June 15, 1964)
(b)over five years just after the Niigata earthquake (June 16, 1964-June 15, 1969)
(c)over next five years (June 16, 1969-June 15, 1974)

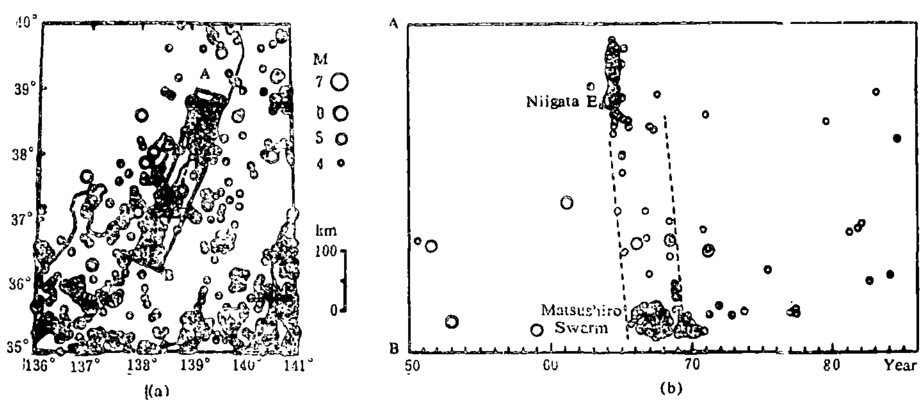

Fig. 5(a) Epicentral distribution of shallow (depth⩽30km) earthquakes with M4 and larger ones during the period 1950 through 1985
(b) Space-time distribution of earthquakes in the rectangular region of Fig.5(a)

The line in Fig. 6 (b) corresponds to the speed of 4km/year.

Mogi proposed an existence of active tectonic line connecting the southern tip of the Izu Peninsula and Shizuoka city in the region of the rectangular zone in Fig. 6 (a)[14], following which Yoshida et al. pointed out a possibility that the tectonic line further continues to the west, investigating characteristics of epicentral distribution,correlation of earthquake occurrence, gravity Bouguer anomaly, crustal deformation and regional geology[15—17]. Hypocentral distribution of earthquakes in this region suggests that the active tectonic line is related to the fissure in the Philippine Sea plate[6].

(5) The 1975 Kumamotoken-hokutobu earthquake (M6.1)

Figure 7(a) shows epicentral distribution of shallow (depth ⩽30km)

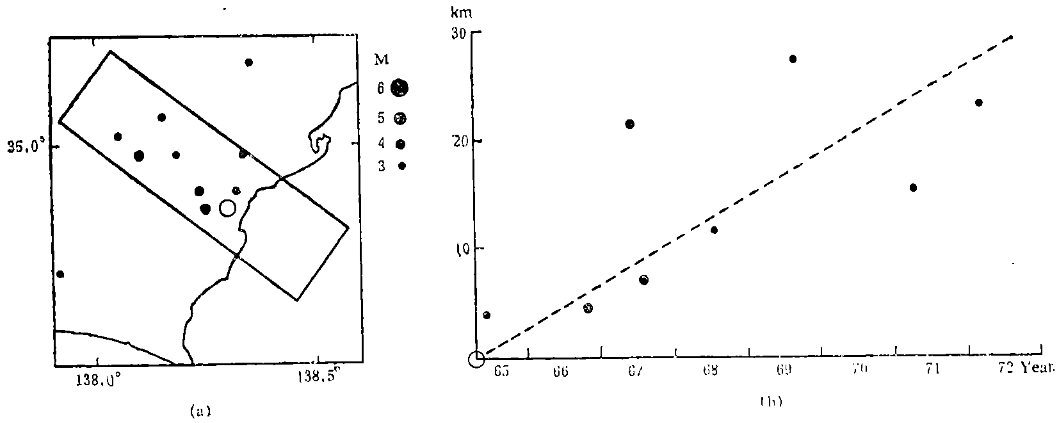

Fig. 6　Epicentral distribution of shallow (depth≤30km) earthquakes with M3 and larger ones during the period 1965 through 1973 (the open circle represents the epicenter of the Shizuoka earthquake)

earthquakes with M4 and larger ones which occurred in the central and northern part of the Kyushu island during the period 1975 through 1984, and Figure 7(b) shows epicentral distance of earthquakes in the rectangular region in Fig. 7 (a) from the epicenter of the Kumamoto-ken-hokutobu earthquake and time of their occurrence. The tendency of migration of seismic activity to the west in the central part of the Kyushu island is clear, and the velocity of migration is estimated at about 8km/year.

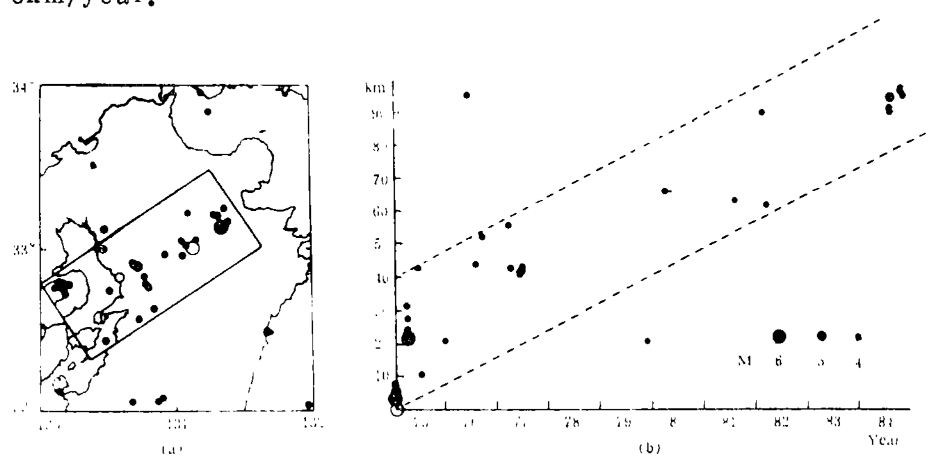

Fig. 7　Epicentral distribution of shallow (depth≤30km) earthquakes with M4 and larger ones during the period 1974 through 1984 (the open circle represents the epicenter of the Kumamotoken-hokutobu earthquake)

In the rectangular zone in Fig. 7 (a) the Beppu-Shimabara graben exists[18], and intraplate shallow seismicity in the Kyushu island is high in the graben. Moreover, conspicuous crustal expansion in the north

-south direction is observed in the zone as well[19,20]. The graben is considered extension of the spreading Okinawa trough[21].

(6) The 1983 Nihonkai-chubu earthquake(M7.7)

Figure 8(a) shows epicentral distribution of earthquakes with depths equal or less than 40km over two years following the 1983 Nihonkai-chubu earthquake, and Figure 8(b) shows epicentral distance of earthquakes in Fig.8(a) from the epicenter of the Nihonkai-chubu earthquake and time of their occurrence. We can see a diffusive tendency of seismic activity to the southeast direction in the Tohoku district from the aftershock area of the Nihonkai-chubu earthquake in Figures 8(a) and 8(b). The speed of diffusive activity is about 100km/year.

It should be noted that most earthquakes are distributed in the belt-like zone of northwest-southeast direction in Fig. 8(a). This zone corresponds to the Oga-Oshika tectonic zone proposed by Yoshida et al[10]. An existence of active tectonic line in the direction connecting the Oga Peninsula and the Oshika Peninsula was first proposed by Mogi[22], following which tectonic meaning of the zone was discussed in detail from various points of view by Mogi, Tada and Yoshida et al. [23,24,10]. Anyhow seismic activity in this case also diffused along tectonic zone or weak belt in the crust similarly to previous examples.

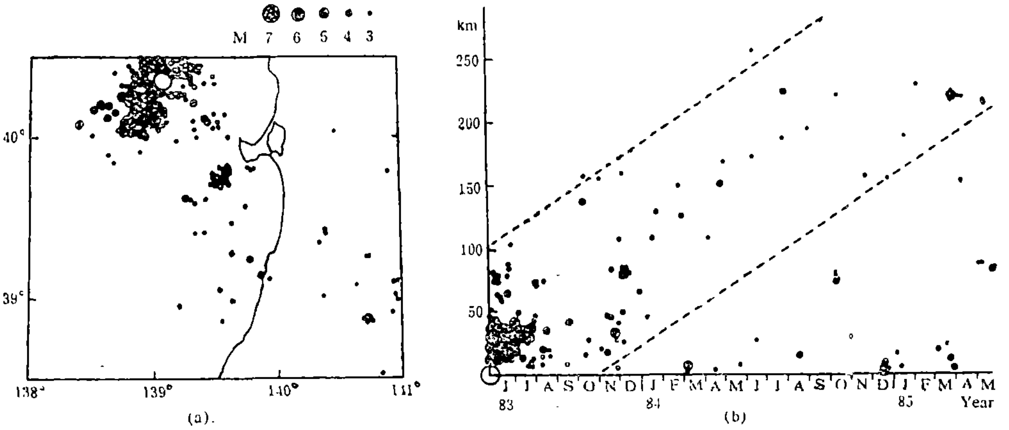

Fig. 8 Epicentral distribution of earthquakes with depths equal or less than 40 km over two years following the 1983 Nihonkai-chubu earthquake (the open circle represents the epicenter of the Nihonkai-chubu earthquake)

3. Discussion

There have been already pretty many studies on the mechanism of migration and diffusion of seismic activity. They can be classified to two kinds, in one of them an existence of some substantial wave behind the phenomena is considered and in the other only successive concentration of stress field is allowed for. A slow decay wave, proposed by Bott and Daen[25], which results from coupling of brittle crust with ductile layer beneath it, and a kinematic creep wave of edge dislocation in transform plate boundary zone suggested by Savage[26], and a crack solution of constant velocity in a thin viscous fault gouge between elastic rocks obtained by Ida[27], belong to the first kind. A description of crustal strain field by reaction-diffusion system[28] may be also included in it. On the other hand in the second kind rather simple and naive ideas are proposed such that high stress field is produced in front of fracture zone or fracture of one asperity increases stress on other asperities. It seems to depend on each case as to which model is most suited for the migrational phenomenon of seismic activity. In the examples we investigate migration velocity is about several km/year except for the case of seismic activity after the Nihonkai-chubu earthquake, however there also exist such phenomena that migration velocity reaches 100km/day in activities of small earthquakes [13]. Possibly it is not correct to intend to explain all migrational phenomena of seismic activity by only one model, but it is necessary to consider several types.

It should be noted that migration of seismic activity occurred along geological active tectonic zone in all six examples we investigated. Characteristics of intraplate seismic activity becomes clear when compared with that in the plate boundary zone. In subduction zones extention of seismic activity to surrounding areas is usually observed after occurrence of great earthquakes in addition to enlargement of the aftershock area. For example, Mizoue et al.[29] pointed out that seismically active region gradually moved landward after the 1982 Ibaraki-ken-oki earthquake (M7.0). On the other hand in the case of the 1981 Miyagiken-oki earthquake (M7.0) seismic activity extended toward the Japan trench[30]. It is needless to say that there are many studies reporting that influence of occurrence of large earthquake is transmitted to neighbouring large earthquake genetic field along the mechanically coupled plate boundary including pioneer works of Fedotov[31] and Mogi[32]. All of these phenomena can be considered as manifestation of diffusion of seismic activity along mechanically coupled plane between oceanic and land plates. Analogizing to this feature, It is possible to consider that seismic belts along which seismic activity migrates or diffuses in land area are mechanicaly coupled zone between crustal blocks. One of the differences between occurrence of large earthquakes in subduction zone and that in intraplate seismic belt is that there remain gaps between focal regions of large earthquakes in intraplate seismic belt contrary to plate boundary zone where seismic belt is covered by focal regions of great earthquakes[6, 9]. It is an important problem whether these gaps could be focal regions of large earthquakes in the future or not. In order to solve this problem it is necessary to investigate ordinary seismic activity of small earthquakes minutely and to clarify characteristics of crustal structure where large earthquake do not occur as well as where large earthquakes do occur in each seismic belt.

As stated first it is seldom that large earthquakes occur isolated, but in most cases they occur successively along boundary of tectonic blocks in active periods. One of plausible explanations for the feature is that stress field in block boundary increases due to relative movement of blocks and concentration of stress field occurs on asperities in active tectonic zone, then they break one after another. According to the idea focal regions of large earthquakes correspond to the areas of concentrated stress field and it is anticipated that various anomalous precursory phenomena appear around the regions. If so, there is a possibility that we can estimate locations of future large earthquakes and read a process of stress concentration on the regions by investigating ordinary seismic activity and preshock activity carefully. This is a future problem.

References

[1] Satake, K. and Abe, K., A fault model for the Niigata, Japan, earthquake of June 16, 1964, J. Phys. Earth, 31, 217—223, 1983.

[2] Fujiwara, K. and Seno, T., Redetermination of the aftershock distribution of the 1964 Niigata earthquake, J. Seismol. Soc. Japan (Ser. 2), 38, 259—261, 1985.

[3] Sato, T. et al., Aftershock distribution of the 1983 Nihonkai-chubu (Japan Sea) earthquake determined from relocated hypocenters, J. Phys. Earth, 34, 203—223, 1986.

[4] Nakamura, K., Possible nascent trench along the eastern Eurasian and North American plates, Bull. Earthquake Res. Inst., Tokyo Univ., 58, 711—722, 1983.

[5] Kobayashi, Y., Commencement of "subduction" of plate, Earth Monthly, 5, 510—514, 1983.

[6] Yoshida, A., Characteristics of seismic activity in and around the Izu Peninsula and their tectonic implications, in preparation, 1989b.

[7] Mogi, K., Seismic activity, Earthquake prediction in and around the Tokyo metropolitan area, Bull. Reg. Comm. Coord. Comm. Earthquake Predict., 2, 20—21, 1980.

[8] Mogi, K., Some features of recent seismic activity in and near Japan, 2. Activity before and after great earthquakes, Bull. Earthquake Res. Inst., Tokyo Univ., 47, 395—417, 1969.

[9] Yoshida, A., Seismic activity in the Japanese Islands, in preparation, 1989c.

〔10〕Yoshida, A. et al., Seismotectonics in Tohoku, northeast Japan and the Oga-Ojika tectonic zone, J. Seismol. Soc. Japan, (Ser. 2), 42, 1989 (in the press).
〔11〕Omori, F., Recent strong earthquakes in the Shinanogawa valley (central Japan), Bull. Earthquake Invest. Comm., 1, 138—141, 1907.
〔12〕Huzita, K., Role of the Median Tectonic Line in the Quaternary tectonics of Japanese Islands, Memoirs Geol. Soc. Japan, No.18, 129—153, 1980.
〔13〕Yoshida, A., Migration of seismic activity along intraplate seismic belts in the Japanese Islands, Tectonophysics, 145, 87—99, 1988.
〔14〕Mogi, K., An interpretation of the recent tectonic activity in the Izu-Tokai district, Bull. Earthquake Res. Inst., Tokyo Univ., 52, 315—331, 1977.
〔15〕Yoshida, A., Seismicity on the west side of Suruga trough, J. Seismol. Soc. Japan(Ser. 2), 36, 111—113, 1983.
〔16〕Yoshida, A. and Taniwatashi, N., Regional correlation of earthquake occurrence in the west side of Suruga trough, J. Seismol. Soc. Japan, Ser. 2, 37, 269—279, 1984.
〔17〕Yoshida, A. et al., On the possibility of the existence of an active tectonic line in the west side of Suruga trough, J. Seismol. Soc. Japan, Ser. 2, 37, 453—464, 1984.
〔18〕Matsumoto, Y., Some problems on volcanic activities and depression structures in Kyushu, Japan, Memoirs Geol. Soc. Japan, No.16, 127—139, 1979.
〔19〕Tada, T., Spreading of the Okinawa trough and its relation to the crustal deformation in Kyushu, J. Seismol. Soc. Japan (Ser. 2), 37, 407—415, 1984.
〔20〕Tada, T., Spreading of the Okinawa trough and its relation to the crustal deformation in Kyushu (2), J. Seismol. Soc. Japan (Ser. 2), 38, 1—12, 1985.
〔21〕Kimura, M., Formation of Okinawa trough grabens, Memoirs Geol. Soc.Japan, No.22, 141-157, 1983.
〔22〕Mogi, K., Tectonic singularities of the epicentral region of the 1983 Japan Sea earthquake, J. Seismol. Soc. Japan (Ser. 2), 38, 262—265, 1985a.
〔23〕Mogi, K., The 1983 Japan Sea earthquake (M7.7) and seismotectonics in northeastern Japan, Bull. Earthquake Res. Inst., Tokyo Univ., 60, 401—428, 1985b.
〔24〕Tada, T., Horizontal crustal strain in the northeastern Japan arc and its relation to the tectonics, J. Seismol. Soc. Japan (Ser. 2), 39, 257—265, 1986.
〔25〕Bott, M. H. P. and Dean, D. S., Stress diffusion from plate boundaries, Nature, 243, 339—341, 1973.
〔26〕Savage, J. C., A theory of creep waves propagating along a transform fault, J. Geophys. Res., 76, 1971.
〔27〕Ida, Y., Slow-moving deformation pulses along tectonic faults, Phys. Earth Planet.Inter., 9, 328—337, 1974.
〔28〕Ouchi, T., A model of earthquake genetic field by reaction-diffusion system, in Suri Zisin Gaku (Mathematical Seismology) III, Ed. SAITO, M., Cooperative Res. Rep., 8, Inst. Statist. Math., Tokyo, 61—77, 1988.
〔29〕Mizoue, M. et al., Westward movement of the seismic activity associated with the earthquake of July 23, 1982 off Ibaraki prefecture, northeastern Honshu, Japan, Bull.Earthquake Res. Inst., Tokyo Univ., 58, 25—63, 1983.
〔30〕Tohoku Univ. Faculty of Science, Microearthquake activity in and around the Tohoku district (May-October, 1981), Rep. Coord. Comm. Earthquake Predict., 27, 21—28, 1982.
〔31〕Fedotov, S. A., Regularities of the distribution of strong earthquakes in Kamchatka, the Kuril Islands, and northeast Japan, Tr. Inst. Fiz, Zemli, Akad. Nauk SSSR, 36, 66—93, 1965.
〔32〕Mogi, K., Migration of seismic activity, Bull. Earthquake Res. Inst., Tokyo Univ., 46, 53—74, 1968.

日本内陆地震活动的迁移与扩散*

吉田明夫
（日本气象厅气象研究所）
细野耕司
（日本气象厅地震观测所）

摘　　要

本文研究了日本内陆及其外围海域发生大地震后的地震活动迁移现象。在所研究的6个震例中，一个共同的特点是，地震活动的迁移总是沿着地壳内的活动地质构造带发生。有时可以根据地震活动的迁移来进一步确定活动构造带的存在。把板块边缘地区的地震活动类比为沿着力学偶合平面迁移和扩散，我们可以认为，岛上的活动构造带对应着地壳块体的力学相互作用边界。地震迁移的形式可能不只一种。在我们所研究的震例中发现了以下特征：地震迁移速度约为几km/年；大地震震源区之间存在着地震空区；在每一条地震带上有一定的地震活动周期。地震迁移的一种可能机制是：由于地壳块体的相对运动，在其边界上的凹凸不平区造成了构造应力集中，这些凹凸不平区相继地发生破裂，形成了地震迁移。

*本文作者委托冯德益投稿及代写中文摘要。吉田明夫先生曾于1988年10月访问过兰州地震研究所和天津市地震局。