BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 48 (1970), pp. 759-768

41. *Development of the Aftershock Area and the Block Structure of the Focal Region of the 1968 Tokachi-Oki Earthquake.*

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(Read November 25, 1969.—Received July 20, 1970.)

1. Introduction

In the accompanying paper[1], it is found that there is a certain regularity in the development of the frequency distribution of aftershocks with respect to the magnitude in the case of the 1968 Tokachi-Oki earthquake. Here, major aftershocks take place first and the smaller aftershocks then follow. In this paper, the relation of this development of the frequency distribution of earthquakes to the development of the aftershock area will be analyzed. As a result of this study it will be found that the development of the area of the aftershocks take place with block structures. The block structures will be presumed for the focal region in the province off the coast of Sanriku.

The province off the coast of Sanriku, along the Japan trench is the area where great earthquakes frequently take place. The role of these block structures in the past earthquake activity is studied too.

Block structure and block movement in the focal region has already been discoverd in the case of the 1923 Kanto earthquake by Imamura and Hasegawa[2] and Yasuda[3].

2. Development of aftershock area

In order to study the development of the aftershock area, the period of the aftershock activity is divided into several intervals. They are taken in accordance with those in the accompaning paper. They are characterized by the major aftershocks. When there is no remarkable aftershock, the period is divided by the proper interval of time. The

1) S. NAGUMO, *Bull. Earthq. Res. Inst.*, **48** (1970), 749-758.

2) A. IMAMURA and K. HASEGAWA, *Bull. Imp. Earthq. Inv. Committee*, Vol. **11**, No. 2 (1928), 64-92.

3) T. YASUDA, *Sinsai Yobo Tyosakai Hokoku* (*Reports of the Imperial Earthquake Investigation Committee*), No. **100**, A, (1925), 261-310.

Table 1. Division of the period of aftershocks of the 1968 Tokachi-Oki earthquake.

Period	M				Interval	N
	Main shock	7.9	May	16,09h49m	0	
A						
	After shock	7.5	May	16,19h39m	0.4 Days	18
B						
	〃	6.7	May	17,08h05m	0.9 〃	47
C						
	〃	6.3	May	23,04h29m	7 〃	114
D						
	〃	7.2	June	12,22h42m	27 〃	178
E						
	〃		July	31,23h59m	76 〃	340

intervals are shown in Table 1. The epicenters of aftershocks are plotted for each period and are shown in Fig. 1. (A)～(E).

First let us see the general feature of the development of the aftershock area. Fig. 1 (A) shows the distribution of the aftershock epicenters for the period from the main shock till the biggest major aftershock (M=7.5) of May 16, 19h39m. As seen in the figure, most aftershocks took place in a wide area, to the west of the main shock. The solid lines in this figure show the boundaries of seismic blocks which will be outlined by the distribution of aftershock epicenters.

Fig. 1 (B) shows, by solid circles, the epicenter distribution for the period from the biggest aftershock M=7.5 of May 16, 19h37m till the 3rd major aftershock (M=6.7) of May 17, 08h05m. The open circles are the epicenters from the former period. In this period, most aftershocks took place around the biggest aftershocks. It will be seen in this figure that aftershock activity has migrated northward in this period. The activity of the seismic block in this period seems to be excited by the shock with M=7.5. Fig. 1 (C) shows, by solid circles, the aftershock epicenters for the period of 24 hours, after the occurrence of 3rd major aftershock with M=6.7. The open circles show the epicenters for the former periods. In this period epicenters are distributed to the south of the main shock. This will show that the aftershock activity of the southern block has been excited by the shock with M=6.7. Fig. 1 (D) show the epicenter distribution of earthquakes in the period of D which is given in the Table 1. The duration of this period is about one month. In is period, aftershocks take place in the all blocks of A, B, and C.

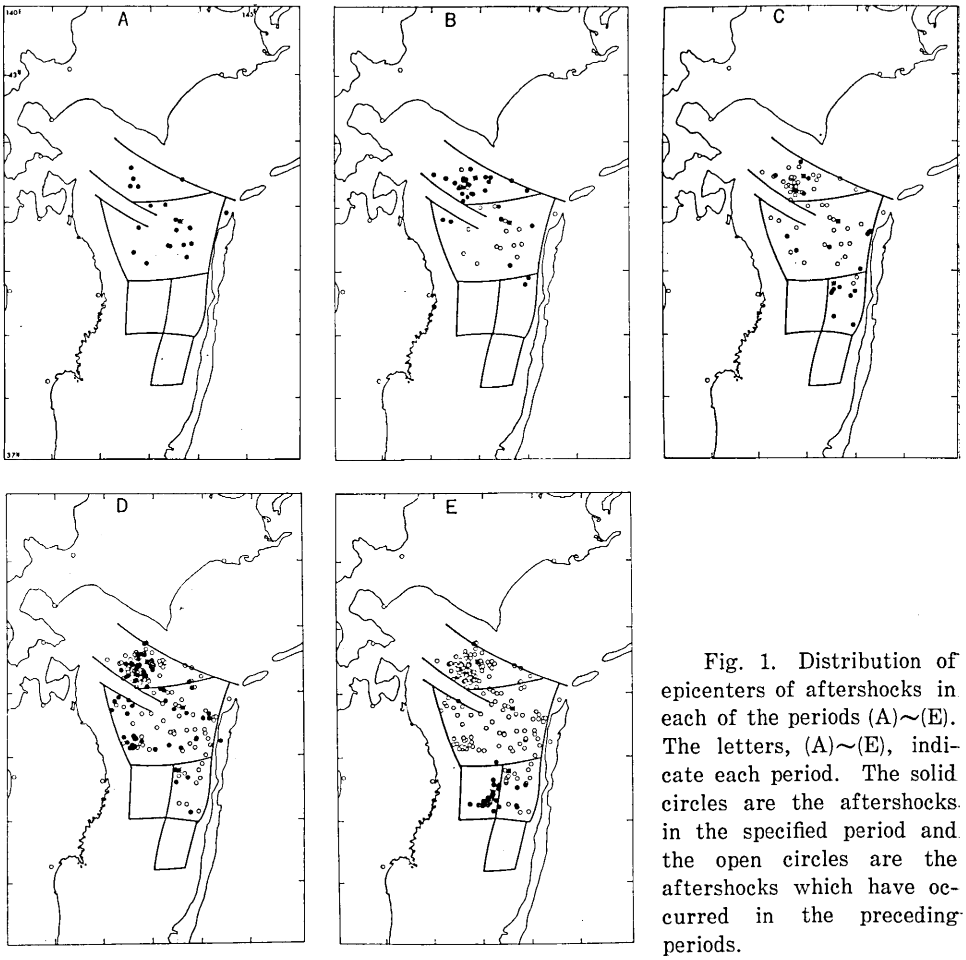

Fig. 1. Distribution of epicenters of aftershocks in each of the periods (A)~(E). The letters, (A)~(E), indicate each period. The solid circles are the aftershocks in the specified period and the open circles are the aftershocks which have occurred in the preceding periods.

Fig. 1. (E) shows, by solid circles, the distribution of aftershock epicenters in the period of about 4 days after the 2nd major aftershock with M=7.2 of June 12,22h42m. The open circles show the epicenters of aftershocks in the former periods.

The aftershocks in this period take place in the south-western part of the aftershock area. It is quite surprising that aftershocks in this period take place only in the newly developed aftershock area and almost none in the former aftershock area.

From these characteristics, it will be evident that the block E is excited by the shock with M=7.2.

Division of Blocks

The successive development of the area of aftershock activity which is shown in the Fig. 1 (A)~(E) will imply the existence of earthquake

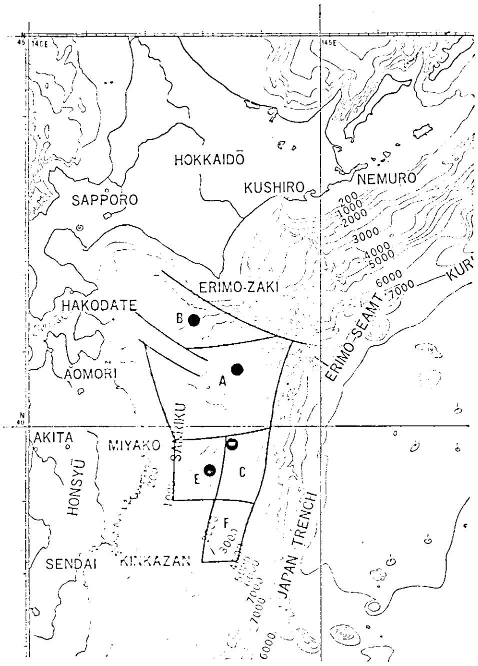

Fig. 2. The foreshock and aftershock blocks of the 1968 Tokachi-Oki earthquake.

blocks in the focal region. The successive enlargement of the area of aftershocks seems to correspond to the successive excitement of composing blocks. The extent and boundary of each block seem to be best represented by the major aftershock and the following small aftershocks. The solid lines in the Fig. 1 (A)$\sim$(E) are the boundaries of such blocks which are postulated from the major aftershocks and the following small aftershocks. From these considerations the earthquake blocks which compose the aftershock area of the 1968 Tokachi-Oki earthquake will be the blocks of A, B, C, and E as shown in Fig. 2.

By using the concept of such earthquake blocks, the development of aftershock activity of the 1968 Tokachi-Oki earthquake will be described as follows. First, the central block A was activated by the main shock with $M=7.9$. About 10 hours after the main shock, the northern block B is excited by the biggest major aftershock with $M=7.2$. Then, about 23 hours after the main shock, the southern block C was excited by the major aftershock with $M=6.7$. By these three shocks the major aftershock area seems to be formed. After that, even though there seems to be several small groups of epicenters, indicating the existence of smaller size of blocks, the aftershock activity continued to take place in all blocks A, B and C. However about one month later, there occurred a new development of the aftershock area. The 2nd major aftershock with $M=7.2$ took place and block E became active.

General characteristics

It will be evident that the enlargement of the area of aftershock activity is controlled by the structural unit of earthquake block, and the activity of each block is excited by the principal shock or the major aftershocks. The area of aftershock activity is formed at the early stage of the great earthquake activity. In this 1968 Tokachi-Oki earthquake, the three blocks A, B, and C started to be active in the early stage of the aftershock activity. The aftershock activity continued to take place in these blocks for more than a month. However, there seems to be a tendency that when the activity of one block increased, the activities in the other blocks calmed down.

3. Relation between the magnitude∼frequency distribution and the development of the aftershock area

It will be seen that there are definite relations between the development of the aftershock area and the characteristics of the development of the magnitude∼frequency distribution which is shown in the accompanying paper[4]. Some of them are as follow.

(1) The activity of a block is excited by a major aftershock; the corresponding characteristics in the magnitude∼frequency relation is that the large M occurres first and smaller aftershocks follow.

(2) The major aftershocks occurre in the same population of the main shock in the magnitude∼frequency distribution. This characteristics corresponds to such development of the aftershock area that the aftershock areas are excited by the main shock and the major aftershocks at the early stage of the earthquake activity.

(3) That the smaller aftershocks satisfy Gutenberg-Richter's statistical formula for the magnitude∼frequency relation means that these smaller aftershocks are the earthquakes which occur in each earthquake block and represent the activity of that block.

(4) The occurrence of aftershocks of moderate size in the later stage of the aftershock activity will mean the readjustment of state of stress in the composing blocks in the whole area of the aftershocks.

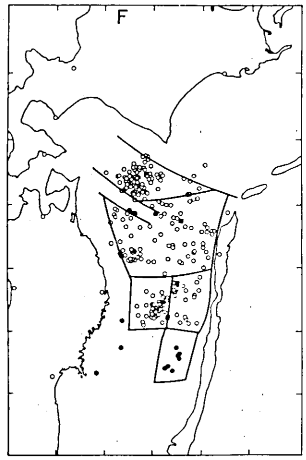

Fig. 3. Distribution of epicenters of foreshock (solid circles) of the 1969 Tokachi-Oki earthquake. The open circles are the aftershocks.

4. Blocks of foreshocks

There were high seismic activities during a few months before the main shock. Even though there are many arguments about the definition of the foreshocks, it will be definite that the high seismic activity will be related to the occurrence of the main shock.

The epicenters of foreshocks which occurred in April and May are plotted by solid circle sin the Fig. 3. The open circles represent the after-

4) S. NAGUMO, *loc. cit.*, 1).

shocks. The distribution of foreshocks shows the presence of different earthquake blocks adjacent to the southern part of the aftershock area and along the boundary between the blocks A and B. It is a remarkable feature that aftershocks did not take place in the southern foreshock block which was active about a month earlier in April.

The presence of an independent block along the boundaries of the aftershock block A and B is not so clear because of the small number of earthquakes. This block may correspond to the aftershock area of the large earthquake in 1945. There was no tendency in the case of the 1968 Tokachi-Oki earthquake for the foreshocks to occur near the region of the main shock, as remarked by Mogi[5] in the case of 1963 Urup earthquake (M=8.3) and the 1960 Chile earthquake (M=8.4). Instead it is seen that the foreshock occured in the blocks adjacent to the blocks of future aftershocks and along the boundaries of the aftershock block.

5. Aftershock blocks of past large earthquakes

If one admits the existense of earthquake blocks for the aftershocks and foreshocks of the 1968 Tokachi-Oki earthquake, one should examine whether such blocks are the inherent structure in the focal region off the coast of Sanriku along the Japan trench or whether they form an accidental appearance in the earthquake activity of the 1968 Tokachi-Oki earthquake. In other words, the question will be raised whether these blocks appeared always at the same places in the past large earthquake activities or whether the division of the blocks changes each time. As is well known, the province off the coast of Sanriku along the Japan trench is the place where great earthquakes take place from time to time. Among many past large earthquakes, the areas of aftershock activity have been registered in the earthquakes of 1933, 1945, 1952 and 1960.[6]

In Fig. 4A∼4D are shown the relation between the aftershock area of the past earthquakes and the blocks which were recognized in the 1968 Tokachi-Oki earthquake.

As is seen in Fig. 4-D and C, the earthquake activities in 1960 and 1952 correspond to the activity of the C-block of the 1968 Tokachi-Oki earthquake. It will be very interesting to note that the same block became active repeatedly in 1952, 1960 and 1968. The block of the activity of the earthquake in 1945 seems to lie in the region along the boundary between the block A and B. However, the activity of this

5) K. MOGI, *Bull. Earthq. Res. Inst.*, **47** (1969), 429-451.

6) *The Seismo. Bull. Japan Meteorological Agency, Supplementary Volume*, No. **1** (1958), No. **2** (1966).

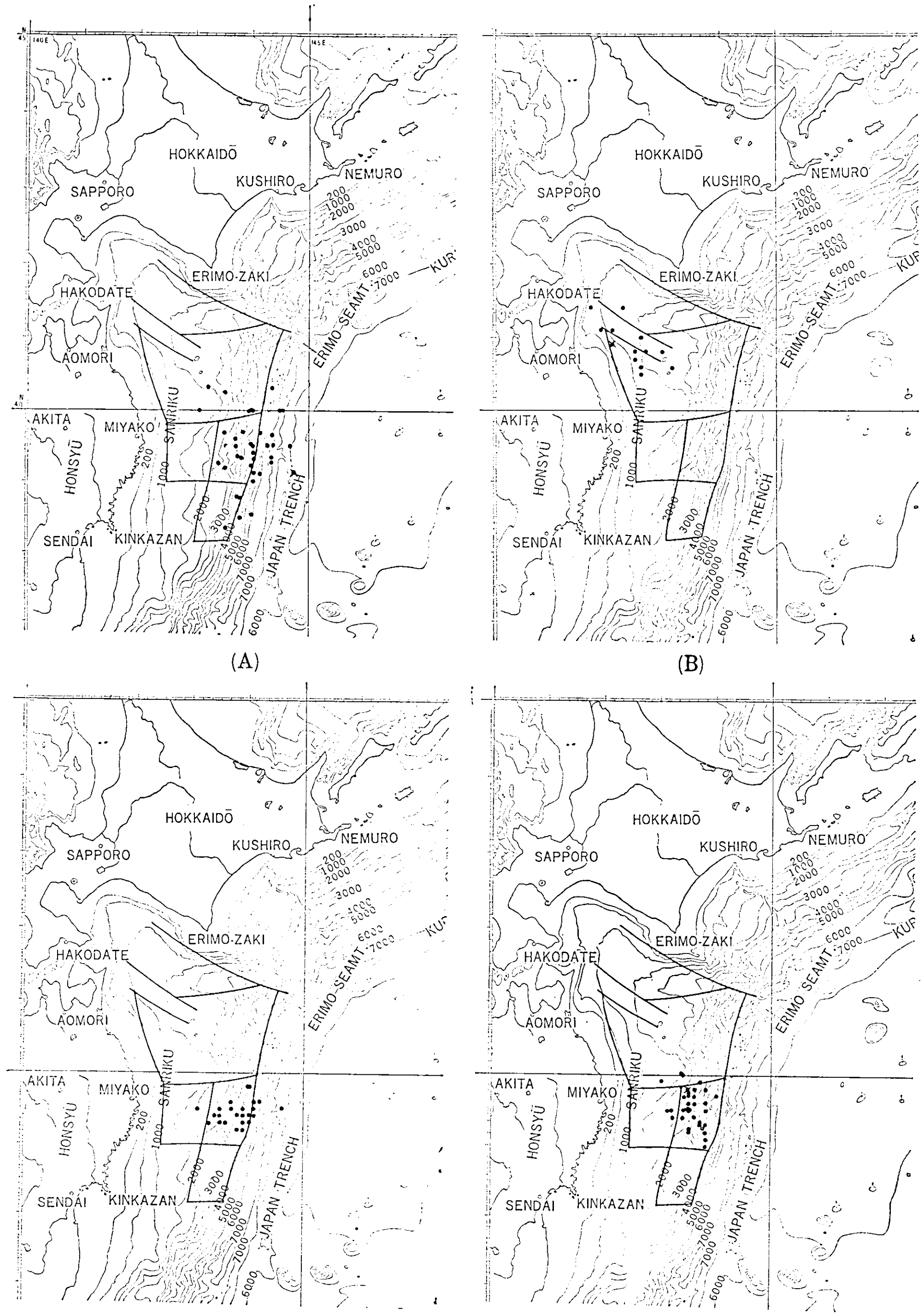

Fig. 4. (A)~(E) The relation of earthquake blocks of the 1968 Tokachi-Oki earthquake to the aftershock area of the past large earthquakes. A) 1933, B) 1945, C) 1952, D) 1960.

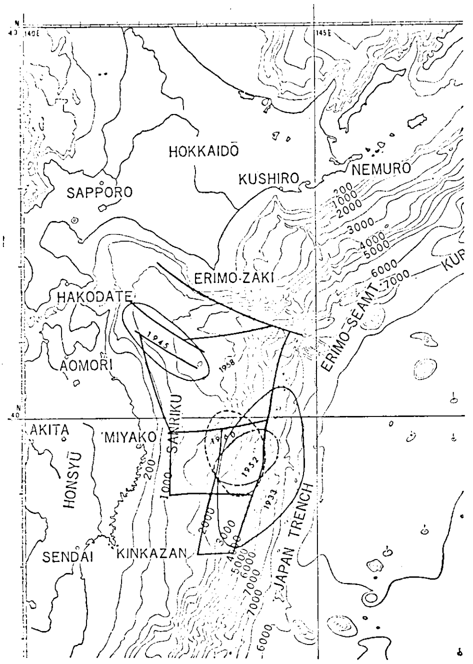

Fig. 4 (E)

block is not so clear in that of the 1968 Tokachi-Oki earthquake. A slight indication of the block may correspond to the smaller number of aftershocks.

The aftershock area of the great 1933 Sanriku-Oki earthquake ($M=8.4$) is shown in Fig. 4-A. The aftershock area of this earthquake covers the blocks B and C and the vast region extending along the deepest portion of the the Japan trench. This shows that there is another earthquake block in the oceanic region of the Japan trench at the outside of the aftershock area of the 1968 Tokachi-Oki earthquake.

The existence of such earthquake block in the oceanic region is very interesting. The earthquake block in this region, which is shown in Fig. 4-E by the solid line is the block of the oceanic lithosphere.

As was discovered by Ludwig, *et al.*,[7] the oceanic crust extends to the west crossing the deepest part of the Japan trench. The boundary of the geophysical ocean and continent is a sharp fault and exists at the steep slope where the water depth ranges from about 3.5 km to 4.0 km. From this result, it will be evident that the 1933 great Sanriku-Oki earthquake corresponds to an activity in the oceanic lithosphere. It is very important that the oceanic lithosphere has the capability of generating first class earthquake activity.

The northward extention of the earthquake blocks of the 1968 Tokachi-Oki earthquake is connected with the earthquake blocks of the 1952 Tokachi-Oki earthquake. The southward extention is connected with the earthquake blocks off Miyagi prefecture and Fukushima prefecture.

6. Discussions about the earthquake block

The block structure of the focal region of the great earthquakes

7) W. J. LUDWIG *et al.*, *Jour. Geophys. Res.*, **71** (1966), 2121–2137.

was already discovered by Imamura and Hasegawa[8], and Yasuda[9] in the study of the aftershocks of the 1923 Great Kwanto Earthquake. There, a very similar development of the aftershocks was clearily observed and definitely stated in their papers. It will be very interesting to study the cases of other great earthquakes from this point of view. The concept of the geodetic block was developed by M. Miyabe[10] for the crustal deformation in the focal region of the great Kwanto Earthquake. The earthquake blocks stated in this paper form a base for the aftershock activity. By the recent observation of aftershocks with many temporary stations, it has been discovered that the boundaries of the aftershocks or earthquake swarms are very sharp.[11] The shape of the aftershock area is no longer an ellipsoid but it shows a sharp linear structure in many cases. Many investigators have suggested block structures for the focal region of the great earthquakes.[12]

The earthquake blocks will certainly have close relations to the submarine structure,[13] geological structure and tectonic faults. The investigation of these relations is another field of further study.

7. Summary and Conclusions

Studying the development of the aftershock area in the case of the 1968 Tokachi-Oki earthquake, several interesting features have been found for the block structure of the focal region and for their roles in the development of aftershock activity.

The main results are as follows.

1) The focal region is composed of several blocks, as shown in Fig. 3.

2) The development of the aftershock area proceeds with the successive excitation of these blocks.

3) The activity of each block is excited by the main shock or each new large aftershock.

4) The above characteristics is represented by such characteristics of the magnitude∼frequency relation that the earthquakes of large magnitude precede and aftershocks of smaller magnitude follow.

5) The approximate extent of the region of the aftershock activi-

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8) A. Imamura and K. Hasegawa, *loc. cit.*, 2).

9) T. Yasuda, *loc. cit.*, 3).

10) N. Miyabe, *Zisin*, **11** (1939), 105-115.

11) J. N. Jordan and J. F. Lander, *Science*, **148** (1965), 1323-1325.
I. Kayano, *Bull. Earthq. Res. Inst.*, **46** (1968), 223-269.

12) J. N. Jordan, *loc. cit.*, 11).
K. Mogi, *loc. cit.*, 5).

13) Y. Iwabuchi, *La Mer.* (*Bull. Soc. Franco-Japonaise océanographie*), **7** (1469), 197-205.

ties were determined in the first two days. About a month after the main shock, a large aftershock took place and the aftershock area was newly extended to the southern region.

6) The above feature will be seen in such magnitude~frequency relation that major aftershocks take place in the same population as the main shock.

7) There was such a feature that when activity of one block became violent the activity in other regions decreased.

8) The so-called 1968 Tokachi-Oki earthquake is one of the large earthquakes which took place repeatedly in the region of the Sanriku-Oki earthquake province.

9) The aftershock areas of the earthquakes of 1933, 1945, 1952 and 1960 are closely related to the blocks which appeared in the 1968 Tokachi-Oki earthquake.

10) The earthquake block structure of the 1968 Tokachi-Oki earthquake seems to be inherent to the focal region off the coast of Sanriku along the Japan trench.

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41. 1968年十勝沖地震における余震域の発達とそのブロック構造

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1968年十勝沖地震における余震域の発達を調べてみると，震源域のブロック構造およびその余震活動の発達における役割について二三の面白い特徴が見出された．

主な結果は次の通りである．

(1) 震源域は第 2 図に示されるように数個のブロックから構成されている．

(2) 余震域の発達はこれらのブロックの活動が次々に誘起されることによって進行する．

(3) 夫々のブロックの活動は夫々主震或は新しい大きい余震によって誘発される．

(4) 以上の特徴はマグニチュード別度数分布の発達において大きなマグニチュードの地震が先行し，それに続いて小さな余震が起るという特徴に対応している．

(5) 余震活動の大凡の拡がりは最初の二日間に決定された．しかし，主震から約 1 ケ月後に大きな余震が起り，その余震域は新しく南の領域に拡大された．

(6) 以上の特徴は主な余震が主震に規定される同じ母集団を形成するように発生するというマグニチュード別度数分布の発達に対応する．

(7) 1 つのブロックの活動が盛んになるとその他の領域の活動が少なくなるという特徴がみられた．

(8) 1968年十勝沖地震は三陸沖の地震発生域に繰返し発生する大地震の 1 つである．

(9) 1933, 1945, 1952, 1960 年の地震の余震域は 1968 年十勝沖地震に表われたブロック構造と密接に関連している．

(10) 1968年十勝沖地震のブロック構造は日本海溝に沿う三陸沖の地震発生域に固有のもののようである．