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The Time Variation of the Focal Mechanism and the Activity of Earthquake Swarms

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Abstract

The earthquake swarms which have occurred in Japan since 1962 have been investigated. Their origins are found to be situated in the volcanic region, which coincides with the results investigated by Mogi.

The swarms are generally separated into three stages. Each of the three stages corresponds to the foreshocks, main shock and maximum aftershock respectively in the sequence of normal shallow earthquakes of the foreshock type.

The pressure directions of the shocks change with time corresponding to the time variation of the activity of the swarm.

1. Introduction

For the investigation of the mechanism of occurrence of earthquakes, it is important to study the characteristics of various kinds of sequences of earthquakes, such as foreshocks, aftershocks and earthquake swarms ; which will be useful for clarifying the relation between the tectonic forces or the regional characteristics of the crust and the occurrence of shallow earthquakes.

From experimental and observational data, Mogi showed that the types of sequences of shallow earthquakes were closely related to the heterogeneity of the crust, and he divided the seismic zones of Japan into several regions from that point of view.[1] Ichikawa studied the mechanism of the many shallow earthquakes which occurred in and near Japan and showed that the directions of the axis of their maximum pressure had regional characteristics.[2] These are the essential results proving concretely that the occurrence of shallow shocks depends upon the regional state of the crust.

On the other hand, the time variation of the focal mechanism of earthquake swarms was also found out. Ichikawa determined the pressure directions of the major earthquakes of the Matsushiro swarm and showed that they were different in relation to the origin time, location and magnitude.[3] In the Wachi earthquake, Watanabe et al. showed that the directions of the maximum pressure of the aftershocks were found to be scattered over a wide range.[4] The same properties were also found in the case of swarms of smaller magnitude. Based on the time variation of the ratio of the maximum amplitudes of P and S waves, Kishimoto et al. showed that the mechanism of the Hamasaka swarm which occurred on June, 1965 changed with time.[5] The same results were obtained for the swarm which occurred on November 8th, 1968 at Yake-dake Volcano.[6]

The purpose of this paper is to find out the common properties of six earthquake swarms which have taken place in Japan since 1962 with respect to the time variation of their activity and the focal mechanism.

2. Data of the Earthquake Swarms

The locations and beginning times of six earthquake sequences which have occurred in Japan since 1962 showing a pattern of the swarm type are shown in Table 1. Their locations are shown in Fig. 1. In Fig. 1 the dotted area indicates the Neogene Tertiary and Quaternary volcanic region and the numbers of the swarms corrrespond to those in Table 1.

Table 1 Six major earthquake swarms which have occurred in Japan since 1962.

No.	Region	Beginning time	Duration (Approximate value)	Total number (Approximate value)
1	Miyake-jima	Aug. 25, 1962	25 days	1, 100
2	Hamasaka	June 9, 1965	20 days	100
3	Matsushiro	Aug. 3, 1965	30 months	60, 000
4	Wachi	Feb. 14, 1968	15 months	9, 000
5	Ebino	Feb. 21, 1968	10 months	12, 000
6	Yakedake	Nov. 8, 1968	14 hours	40

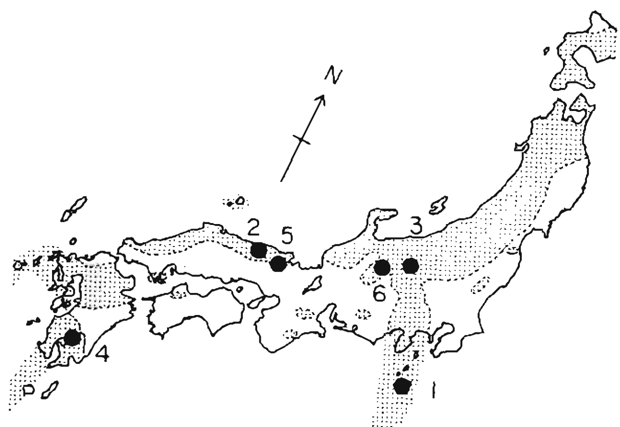

Fig. 1 Dotted area indicates the volcanic region.
Numbers correspond to those in Table 1.

All of the swarms are situated in the volcanic region. Many of them are distributed over a region where Mogi pointed out that the probability of occurrence of swarm type earthquakes was high.[1] The distribution of the origins of the swarms since 1962 also support his results.

a) Miyakejima

A great fissure eruption occurred in the north-eastern part of Miyake-jima on August 24th, 1962 after a dormant period lasting twenty-two years. After the eruption, which had continued for about thirty hours, the earthquake swarm began to take place. Two large shocks occurred on May 5th and 6th, 1962. They may have been the forebodings of the eruption and the occurrence of the swarms. [8]

The data analysed were taken from the Seismological Bulletin of the J. M. A.

b) Hamasaka

The microearthquake swarm occurred at Hamasaka in Hyogo Prefecture on June, 1965. It lasted for almost twenty days and continued with two main shocks of $M=3.6$ and 3.1. About a hundred microearthquakes were recorded by the short period seismographs belonging to the network of the Tottori Microearthquake Observatory.

The data were given from the records obtained by the networks of the Tottori, Takatsuki and Wakayama Microearthquake Observatories and from the Seismological Bulletin of the J. M. A.

The details of the results of the activity and the mechanism of this earthquake swarm have been reported by Kishimoto et al[9].

c) Matsushiro

The Matsushiro earthquake swarm has been investigated in detail by many seismologists. In this paper the results on the mechanism which were presented by Ichikawa[10] have been adopted so as to make a comparison with the results of other swarms.

d) Ebino

This swarm began on February 21th, 1968 and continued actively for about one year. The data of the time variation of the number of the shocks have been obtained from the preliminary report of the J. M. A., and for drawing up the push-pull pattern of the first P motions of each shock data have been obtained from the records of the short period seismographs of the Aso and Sakura-jima Volcano and Kochi Earthquake Observatories and from the Seismological Bulletin of the J. M. A.

Minakami et al. showed that one of the nodal lines of several major shocks was in the direction of about N 10° W. [11] This result coincides with that obtained from the summed up distribution of the first P motions of the microearthquakes observed by the temporary stations. [12]

e) Wachi

For about six months before the main shock of $M=5.6$ on August 18th, 1968, many foreshocks had occurred continuously and immediately after the main event, the occurrence of the microearthquakes increased abruptly. For the present discussions, we referred to the results on the activity and the mechanism of this sequence which were studied and reported by Watanabe et al. [13]

f) Yakedake

On November 8th, 1968 about 40 shocks were recorded by the short period seismograph of the Kamitakara Crustal Movement Observatory for 14 hours. The epicenters of the major shocks of the swarm were determined from the P~S times observed at several stations to be at a distance of about three kilometers to the southeast from the Yake-dake Volcano. The epicentral distance at Kamitakara is about twenty five kilometers. The activity and the time variation of the mechanism of this swarm have already been reported.[4]

3. Activity

It is necessary to investigate the time variation of the quantity of radiated energy and the number of shocks in order to discuss the nature of the seismic activity of the earthquake swarms. But in the present study, only the time variations of the number of shocks are compared with each other in order to find out the corelations among them. These data are a very simple quantity and so nearly the same reliability is kept in all cases.

The time variation of the number of shocks which occurred within a certain period of time are shown in Fig. 2 for each earthquake swarm. The scales of the number and time are arbitrary for each case. They are in the order of their total number.

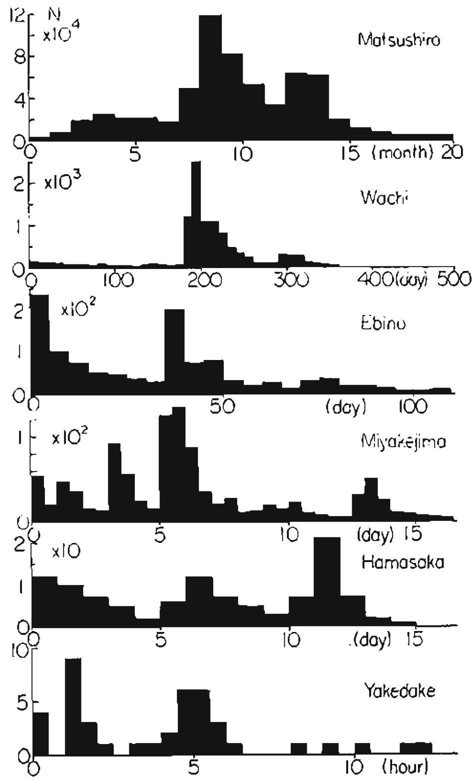

Fig. 2 Time variation of the number of shocks.

Of six swarms the Matsushiso swarm has the largest scale from the viewpoint of its total number and the duration of its activity. Three peaks of activity are seen in the Matsushiro swarm. Corresponding with these peaks this swarm is separated into three stages. The same phenomenon can clearly be found in the Wachi and the Ebino swarms and moreover it can be seen in three other swarms as well. There are three peaks of activity in all the swarms.

In the large shallow earthquakes there are many cases showing the typical pattern of activity which has three stages in the order, foreshocks, main shock and aftershocks. And at the third stage, in which many aftershocks take place, the maximum aftershock occurrs at a certain period of time after the main shock. As is analogized from these facts, it can similarly considered that in the case of the earthquake swarms the seismic energy is released in a process of time being separated into the three stages likely in the case of the other type of shallow earthquake occurrence in the order of foreshocks, main shock and maximum aftershock.

It seems to be that according to the regional characteristics of the crust, for example the heterogeneity, the largest part of the seismic energy of each stage is either released by a single predominant principal shock (foreshock type), or by many shocks with comparatively equal magnitudes (swarm type), Of cause, there exist many cases with patterns that can not be distinguished as belonging to any type particular. For instance, the Wachi earthpuakes should be classified as belonging to the foreshock type.

The more the total number of shocks of swarm increases, the better the pattern of activity approaches the typical one with its three stages as mentioned above. The relation between the total numbers and the duration times of the swarms is represented by a straight line, as shown in Fig. 3.

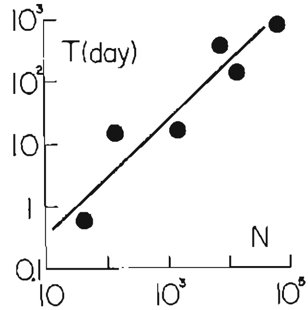

Fig. 3 Relation between the total number and the duration time.

4. Relation between the Activity and the Focal Mechanism

a) Matsushiro

The directions of maximum pressure of the major shocks are shown in the upper half of Fig. 4. φ is measured clockwise from the north to the pressure axis. The lower half shows the accumulative number of shocks recorded by the short period seismograph of Benioff type at the Matsushiro Observatory of the J. M. A.

The results of the study by Ichikawa are that these directions coincide well with that determined for the earthquakes which occurred in this region during the half century or so before this swarm, but in detail they changed relating to the change of its activity. This time variation is closely related to the spreading or the movement of the active area.[5]

b) Wachi

The directions of the axis of maximum pressure are shown in the upper part of Fig. 5. Their distribution changes remarkably at the second stage and concentrates in the same direction as the beginning of this swarm.[6]

There are two peaks in the frequency distribution of the directions of the axes. They correspond to those of the main shocks of February 14th and August 18th, respectively. This may indicate that the change in the distribution of the pressure axes is related to the location of their origins.

c) Ebino

The relation between the activity and the mechanism are shown in Fig. 6. The upper half indicates the time variation of the push-pull distribution of the first P motions observed at several stations. The closed circles and the open circles indicate the compressional and dilatational motions, respectively. At Kumamoto, Aso and Shimonoseki the direction of the first P motion changes in a manner related to the occurrence of the large shocks. This can also be concluded from the nodal lines of the major shocks, as shown in Fig. 10. But the data are not sufficient to be discussed statistically.

It is interesting that one of the nodal lines of the large shocks is in the direction of about N 45°W, as shown in Fig. 10. In this region the trend of the

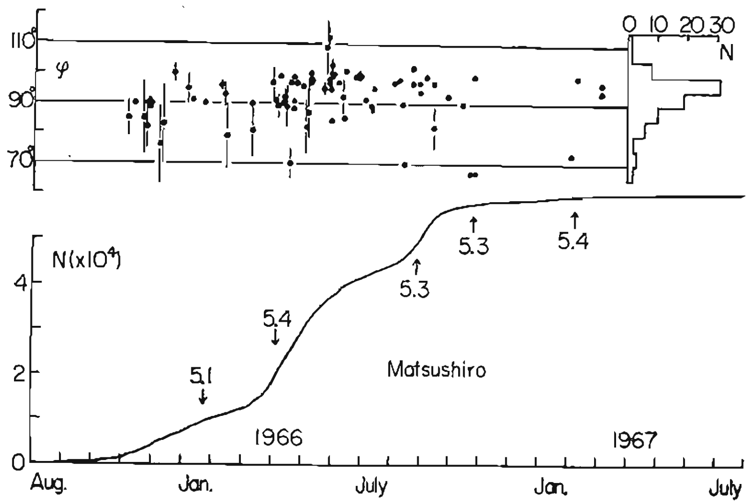

Fig. 4 Direction of the pressure (after Ichikawa) and activity.

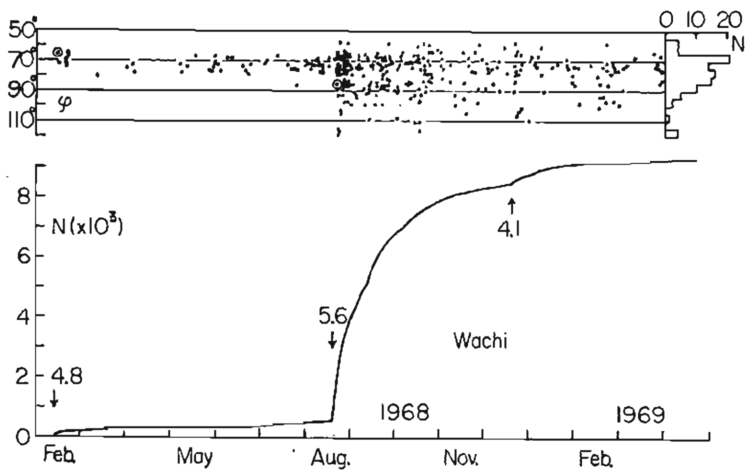

Fig. 5 Direction of the pressure (after Watanabe et al.).

summits of the cones in the Kirishima volcanic belt runs in the same direction of from N 45° W to S 45° E.

d) Miyake-jima

This swarm was situated separately off Honshu to the south, and only one of the nodal lines could be determined. However, it can be assumed that one of the nodal lines of these shocks is perpendicular to the other, considering that their origins are very shallow and that the larger shocks which occurred in the

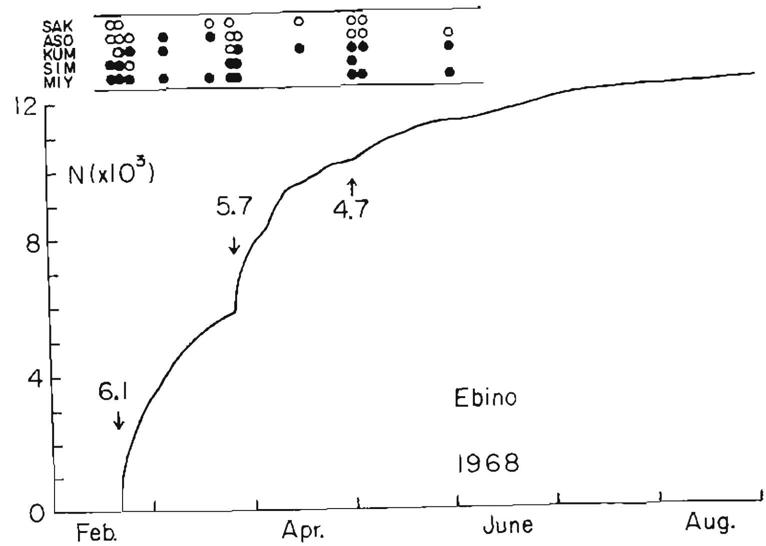

Fig. 6 Push-pull distribution of the first P motions and activity.

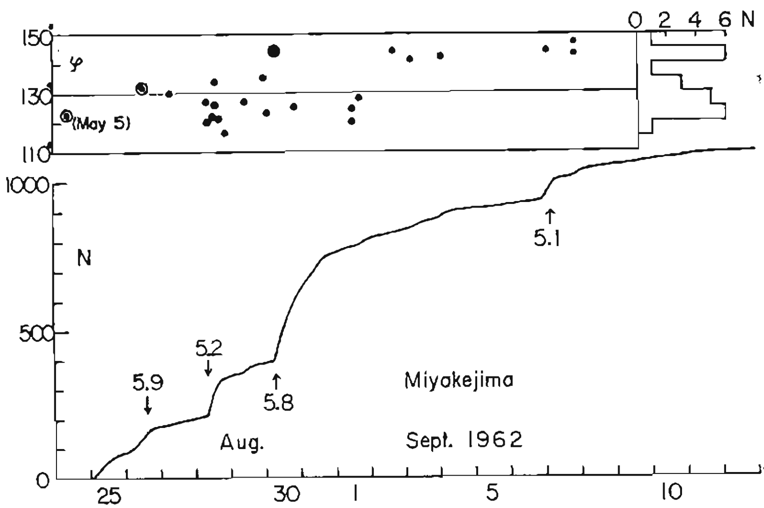

Fig. 7 Direction of the pressure and activity.

same region showed such distributions. Four examples of the push-pull patterns used to determine the direction of the maximum pressure axis are shown in Fig. 11.

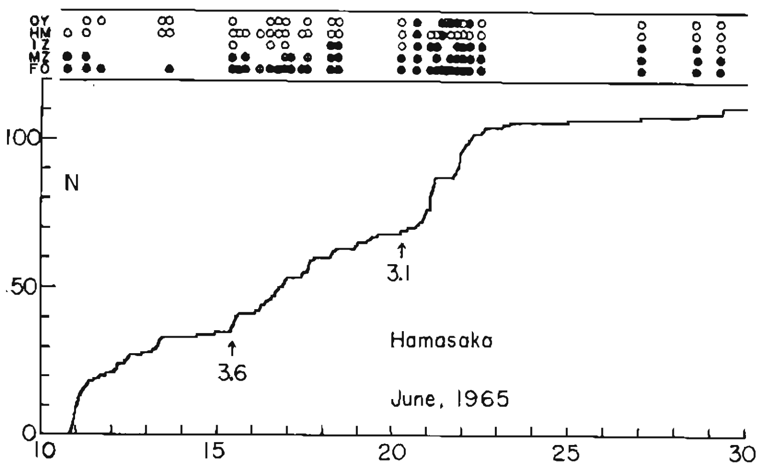

Fig. 8 Push-pull distribution and activity.

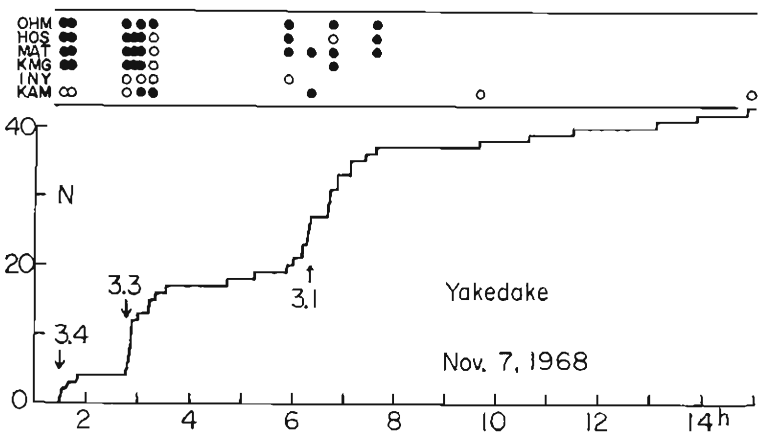

Fig. 9 Push-pull distribution and activity.

The directions of the pressure axes of the major shocks are shown in Fig. 7. After a large shock of M=5.8 on August 30th, it can be seen that the pressure directions changed. In the frequency distribution of the directions there are two peaks. One of them corresponds with the major shock of M=5.8 on August 30th. The other corresponds closely to that of the shock on May 5th which has been analysed by Honda et al.[7] These characteristics obtained are similar to the results obtained for the Wachi swarm.

Also in the case of this swarm, it is possible to consider that the focal region was enlarged at the same time when the swarm became very active on August

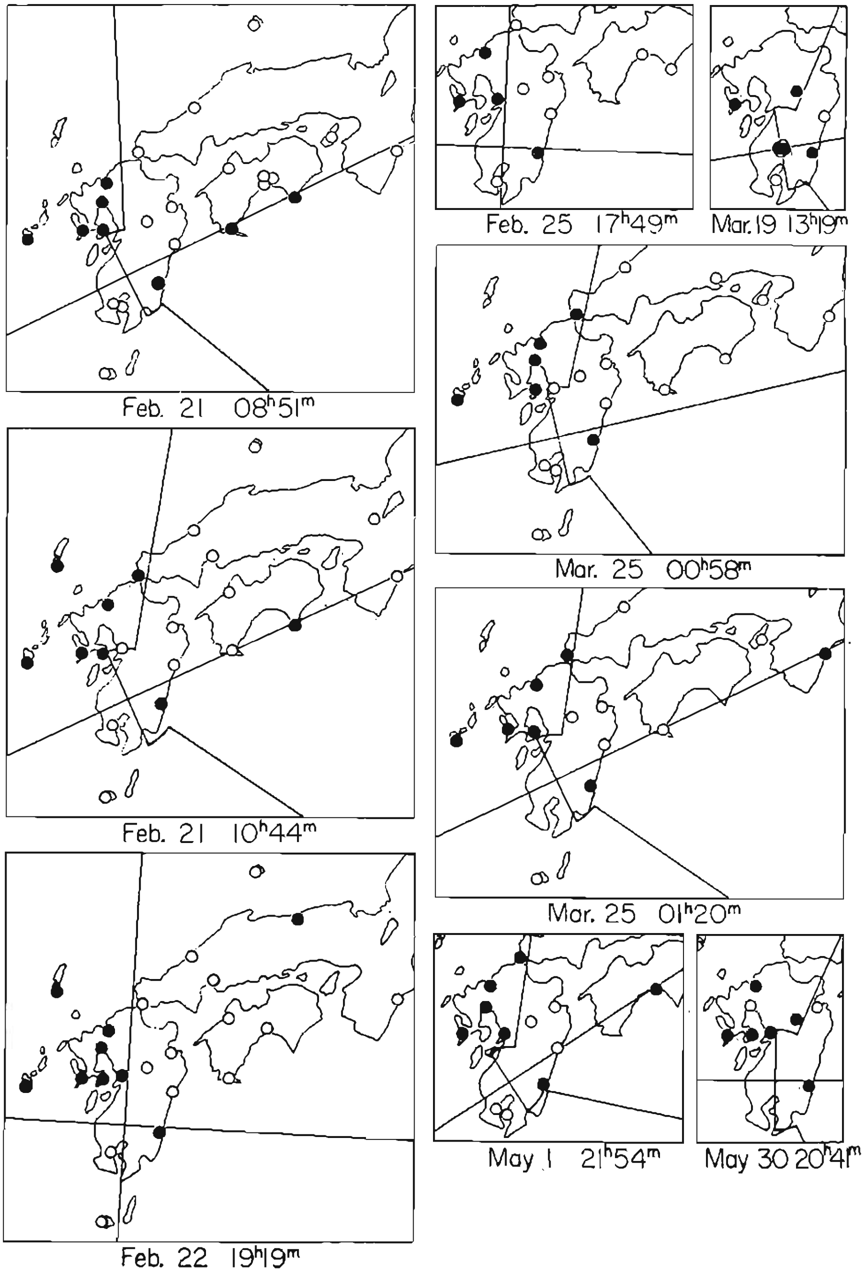

Fig. 10 Nodal lines of the major shocks of the Ebino Swarm.

30th, and therefore a local difference of mechanism was brought into being. To ascertain this the relation between the direction of the principal axes, φ and the longitude or latitude of the epicenter is shown in Fig. 12. It can be seen from

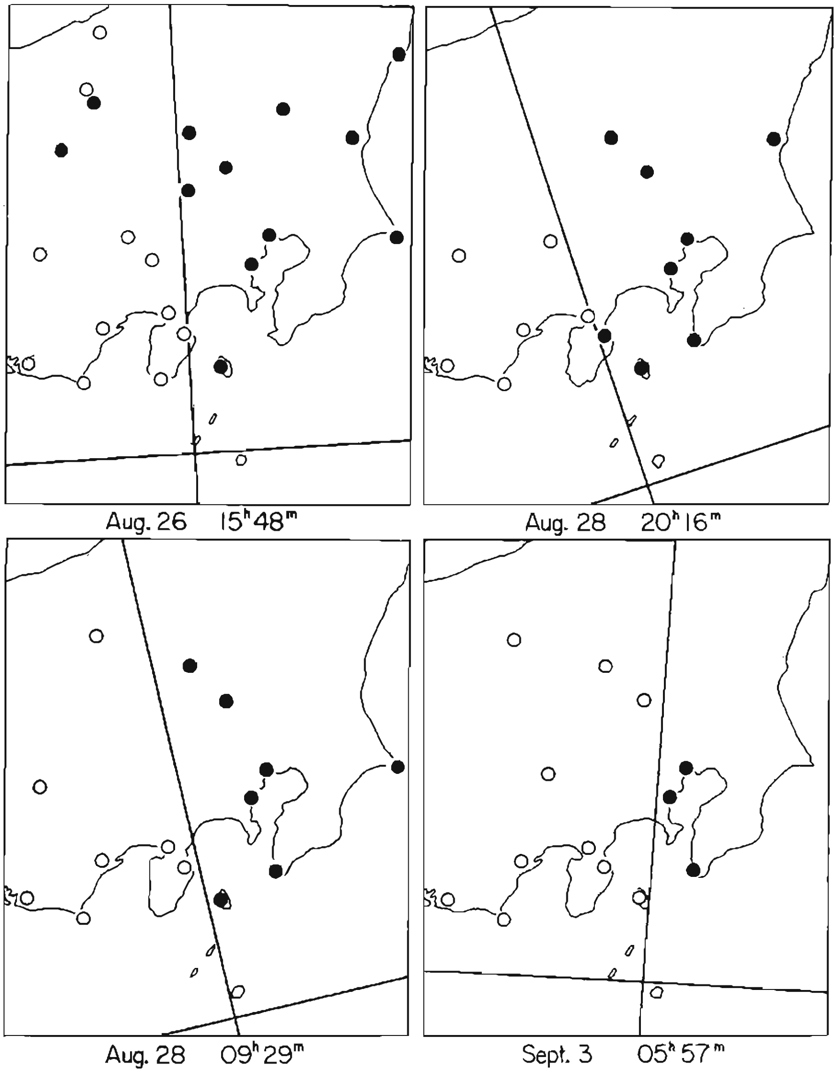

Fig. 11 Examples of the Push-pull distributions of the Miyake-jima Swarm.

Fig. 12 that there is a dependence of φ upon the location.

e) Hamasaka

Kishimoto et al. studied the time variation of the mechanism using the P and S amplitudes. In the present study the push-pull pattern of the first P motions are used to study the same problem. The distribution of the first P motions observed by the network of the Tottori Microearthquake Observatory of each shock is shown in Fig. 8.

The push-pull distribution changes depending upon the time variation of the

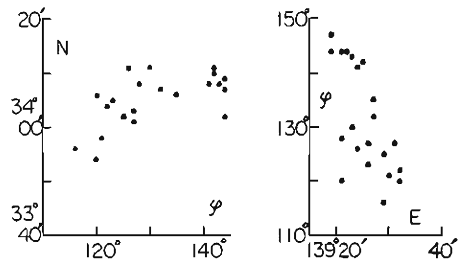

Fig. 12 Relation between the direction of the pressure and the location of the origin of the Miyake-jima Swarm.

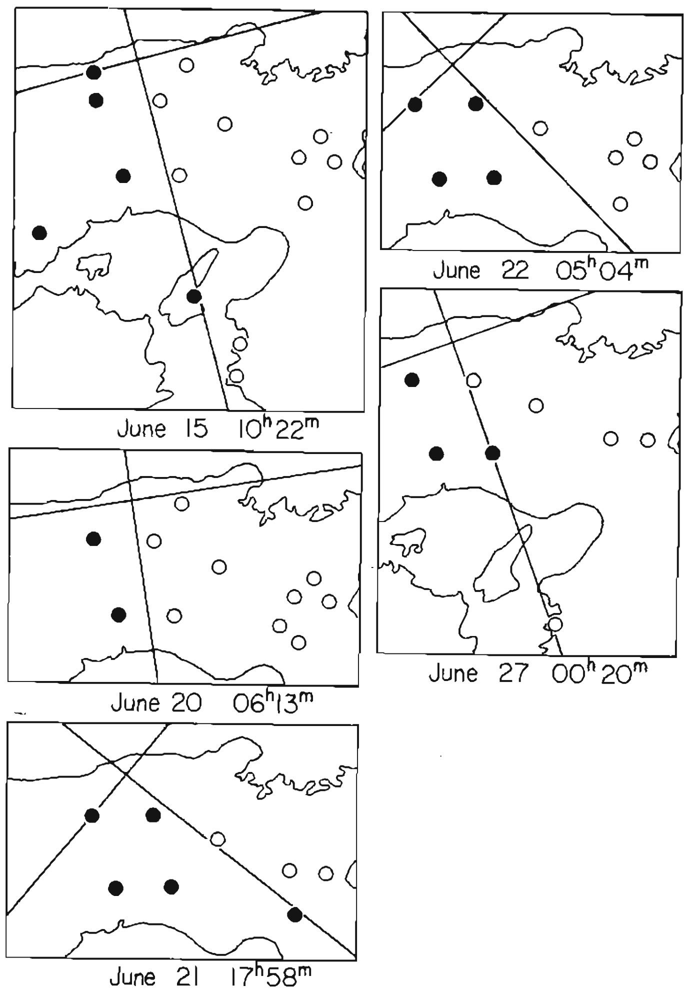

Fig. 13 Nodal lines of the major shocks of the Hamasaka Swarm.

activity. During the most active period after June 20th, the distribution changed remarkably. The foci of the shocks are confined within a small earthquake volume, and so the difference of the distributions of the first P motions indicates the difference of the pressure directions.

The nodal lines determined from the push-pull distributions of several major shocks are shown in Fig. 13. The directions of the nodal lines of the first and last shocks in Fig. 13 coincide with that of the stationary state.[18]

f) Yake-dake

The push-pull distribution obtained from the records of the short period seismographs at the surrounding stations is shown in Fig. 9. As in the case of the

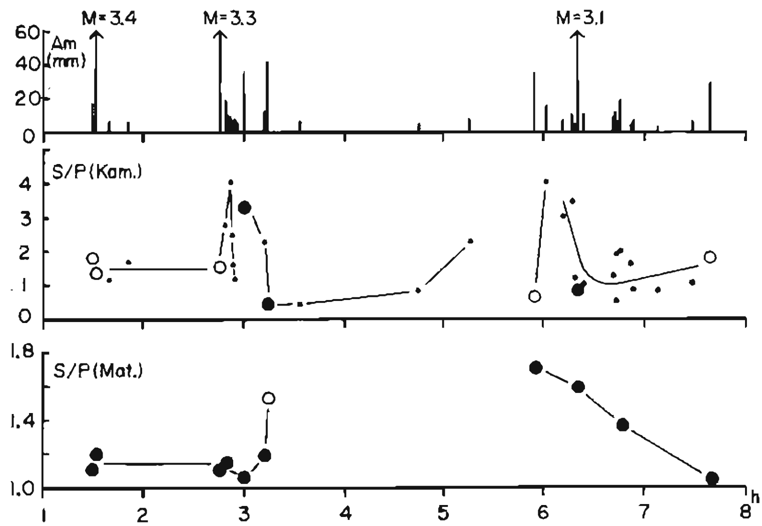

Fig. 14 Time variation of S/P of the shocks of the Yake-dake Swarm observed at Kamitakara and Matsushiro.

Hamasaka swarm, the distribution changes as the activity changes.

In Fig. 14 the time variations of the ratio of the maximum amplitudes of the P and S waves observed by the vertical short period seismograph at Kamitakara and Matsushiro comparing the maximum amplitude of each shock are shown. The push-pull distribution of the first P motions of the major shocks is shown in Fig. 15. The distribution of the stations is not so satisfactory as to determine the nodal lines, but the results shown in Figs. 14 and 15 suggest that the mechanism of the shocks which occurred during the active period of the swarm varied greatly.

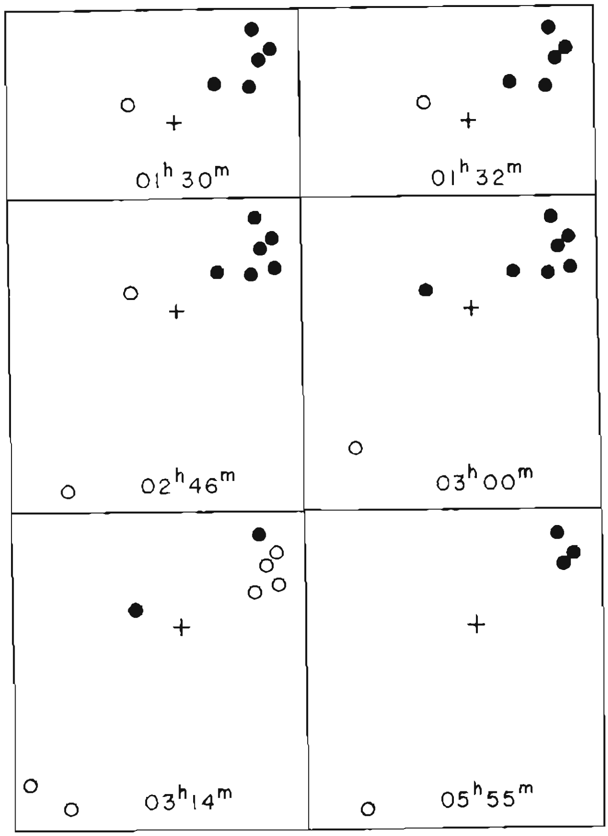

Fig. 15 Push-pull distribution of the major shocks of the Yake-dake Swarm.

5. Concluding Remarks

The earthquake swarms which have occurred in Japan since 1962 are situated corresdonding to the results of Mogi.

Each of these swarms is separated into three stages of activity. The more the total number of shocks of the swarm increases, the more the three stages become similar to the pattern of activity of ordinary shallow earthquakes which occurred in the order of three stages, namely foreshocks, main shock and maximum after-shock.

The swarms disccussed in this paper have duration times of from 14 hours to two years. They are proportional to the total numbers of the shocks in the swarms.

The mean direction of the maximum pressure of the major shocks coincides with that of the stationary state in the same region. But the direction of each shock changes closely related to the time, especially when the swarm is very active.

In some cases the time variation of the mechanism above-mentioned is caused by the systematic variation of the position of the focus. It may suggest that the variation of the mechanism is due to the difference of the local stress field.

It will be a subject for future study to clarify whether the time variation of the mechanism is due to the locality of the stress field in the crust or to the stress change caused by the release of the major part of the energy in the focal region by the occurrence of the main shocks, and it will also be necessary to investigate the mechanism of the foreshocks and the aftershocks from the same point of view.

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References

1) Mogi, K. : Some Discussions on Aftershocks, Foreshocks and Earthquake Swarms —the Fracture of a Semi-infinite Body Caused by an Inner Stress Origin and its Relation to the Earthquake Phenomena (Third Paper), Bull. Earthq. Res. Inst., Vol. 41, 1963, pp. 615-658.
2) Ichikawa, M. : Mechanism of Earthquakes in and near Japan, 1950-1962, Papers in Meteorology and Geophys., Vol. 16, 1966, pp. 201-229.
3) Ichikawa, M. : Statistical Study of the Focal Mechanism of Matsushiro Earthquake Swarm, Zisin II, Vol. 20, 1967, pp. 116-127 (in Japanese).
4) Watanabe, H. and A. Kuroiso : Seismic Activity in the Northern Part of Kinki District and Related Problems (I)—Earthquake Swarm Accompaning the Wachi Earthquake of August 18, 1969, Spec. Contr. Geophys. Inst., Kyoto Univ. No. 9, 1969 (in press).
5) Kishimoto, Y. and M. Hashizume : On the Mechanism of Earthquake Swarm at Hamasaka, Bull. Disast. Prev. Res. Inst., Vol. 16, 1966, pp. 41-55.
6) Oike, K. : On the Mechanism of the Earthquake Swarm at Mt. Yakedake on November 8, 1968, Disast Prev. Res. Inst. Annuals, No. 12, 1970, pp. 133-140 (in Japanese).
7) loc. cit. 1).
8) Matsuda, T. and R. Morimoto : An Eruption of Miyake Island—August, 1962, Kagaku, Vol. 32, 1962, pp. 578-585 (in Japanese).
9) loc. cit. 5).
10) loc. cit. 3).
11) Minakami, T., S. Hiraga, T. Miyazaki and H. Terao : The Ebino Earthquake Swarm and the Seismic Activity in the Kirishima Volcanoes, in 1968-1969, Part 2. Geographical Distribution of Initial Motion and Travel Time Curves along the Kirishima Volcanoes, Bull. Earthq. Res. Inst. Vol. 47, 1969, pp. 745-767.
12) Watanabe, K. : Some Investigations about Ebino Earthquake Swarm, Zisin II, Vol. 23, 1970, (in press).
13) loc. cit. 4).
14) loc. cit. 6).

15) loc. cit. 3).
16) loc. cit. 4).
17) Honda, H., A. Masatsuka and M. Ichikawa : On the Mechanism of Earthquakes and Stresses Producing Them in Japan and Its Vicinity (Third Paper), Geophys. Mag., Vol. 33, 1967, pp. 271-279.
18) Hasizume, M., K. Oike and Y. Kishimoto : Investigation of Microearthquake in Kinki District—Seismicity and Mechanism of Their Occurrence, Bull. Disast. Prev. Res. Inst., Vol. 15, 1966, pp. 35 -47.
19) loc. cit. 6).