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Bulletin of the Earthquake
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1. *Activity Mode of the 1980 Earthquake Swarm Off the East Coast of the Izu Peninsula.*

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Earthquake Research Institute.

(Received February 28, 1981)

Abstract

An earthquake swarm activity which occurred in an area off the east coast of the Izu Peninsula during the period from June 24 to July 28, 1980 was studied on the basis of the waveform analysis. This swarm contained many bursts of activity usually lasting for about one hour. The earthquakes which occurred within a certain time interval, e.g. about 15 minutes, exhibit similar waveforms, suggesting that they belong to one "earthquake family". The epicenters of earthquakes in a family are located within a spatial dimension of a few hundred meters with the same mechanism. When the activity of the first family is finished, the second family appears in an adjacent area separated by 1.5 km at most. Four families are usually observed for the activity of about one hour, except for the activity triggered by the M6.7 earthquake. The earthquakes in a given family distribute over the magnitude range from 2.0 to 4.9. The corner frequency of the source spectrum in a given family is almost constant within a range of 15 per cent, and its value depends on the size of the largest earthquake in a family. The largest earthquake usually occurs in the later stage of its sequence. Continuous monitoring of the spectrum therefore will give us some information useful for the prediction of the size of largest earthquake in an earthquake family.

Introduction

The study of earthquake swarm is important not only for a better understanding the mechanism of earthquake occurrence, but also for the discrimination of the foreshock activity preceding a large earthquake from the swarm activity. In some cases, special spectral features of earthquakes were found for the swarm activity of certain regions. One of the most striking features of the swarm activity was that the earthquakes generated in a certain time interval have similar waveforms (TSUJIURA, 1979a, 1980a), which differ clearly from those of the

foreshock and normal (background) seismic activities (TSUJIURA, 1979b, 1980a).

Recently, a remarkable swarm activity was generated off the east coast of the Izu Peninsula. This activity continued for about one month. The swarm activity in this area occurred repeatedly after 1978, and the present swarm showed the highest activity (*e. g.*, KARAKAMA *et al.*, 1980). In order to check the results obtained in our previous studies, we first studied the similarity of waveform, using the seismogram recorded at high paper speed, and later we conducted a spectral analysis using the data of narrow band-pass filters operating routinely (TSUJIURA, 1978a). We shall show some spectral features of seismic waves closely relating to its activity mode.

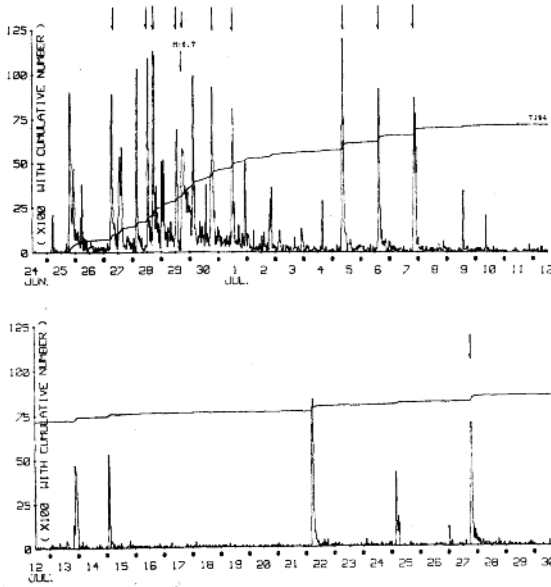

Fig. 1. Frequency distribution of the earthquakes for every 30 minutes obtained at OYM, epicentral distance being about 55 km (after ERI, 1981).

Data

Since June 24 of 1980, many earthquakes occurred in an area off the east coast of the Izu Peninsula. This swarm continued for about one month, repeating intermittent bursts of activity. Figure 1 shows the frequency distribution of the earthquakes for every 30 minutes compiled by the Earthquake Research Institute (ERI, 1981). Figure 2 shows the records of three periods obtained at Dodaira seismic station (DDR), the epicentral distance of about 120 km. It is seen that the earthquakes are concentrated to some brief time intervals (e. g., one hour). Such continual occurrence of the earthquakes may affect the accuracy of the determination of their epicenters. As shown later, the analysis of the waveform by the superposition (overlapping) of the separated seismograms at high paper speed, however, give us more accurate information relating to its activity mode, such as the distribution of epicenters and the migration of epicenters with time (TSUJIURA, 1979a, 1980a).

Figure 3 shows the distribution of the seismic stations used in this study together with the epicentral area of the earthquake swarm determined by KARAKAMA *et al.* (1980). All seismic signals are telemetered at the ERI by the radio-waves or the telephone-line. Two different sets

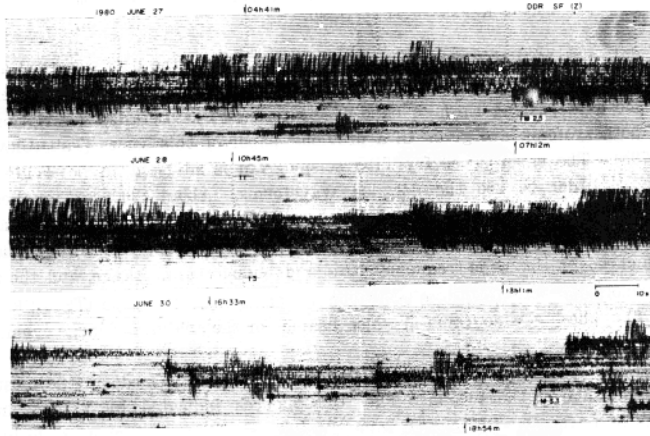

Fig. 2. Seismograms for three periods with concentrated activity obtained at DDR, epicentral distance being about 120 km.

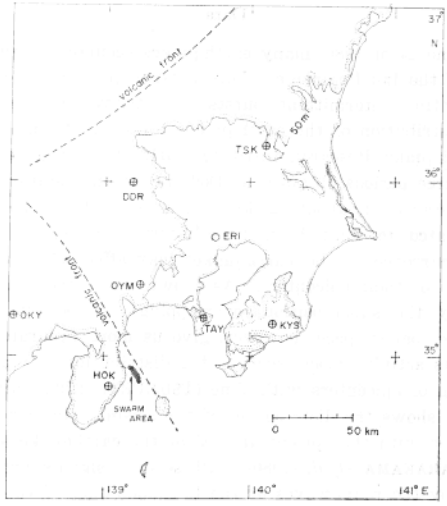

Fig. 3. Distribution of the seismic stations used in this study and the epicentral area of the earthquake swarm taken from the lists of KARAKAMA *et al.* (1980).

of data are available for the present study. One is the data recorded at high paper speed by a trigger mode with memory (TRG), and the other is the data passing through band-pass filters (BPF). Detailed description of both systems are given in a previous paper of this series (TSUJIURA, 1979a). The paper speed for TRG seismogram is adjusted to be 25 mm/sec in order to see the detailed waveforms. About 1200 earthquakes with magnitude ranging from 1.5 to 4.9 are obtained through the swarm sequence. Moreover, the DDR station has various kinds of seismographs which cover the wide-frequency band and wide-dynamic range, and their seismograms are recorded continuously on a magnetic tape (TSUJIURA, 1973). These seismograms are also usable for the analysis of large events ($M>3.2$).

We are especially interested to know the activity mode in the most active stage of the swarm. The 10 sequences indicated by arrows in Figure 1 are finally selected, and the analysis of waveform is made by superimposing the TRG seismograms.

Similarity of waveform

In the course of examining the waveform by the superposition of the TRG seismograms, it was found that the seismograms obtained in a brief time interval (e. g., 15 minutes) exhibit similar waveforms independent of earthquake size. Figure 4 shows an arrangement of seismograms obtained at HOK during the 15 minute interval from 02h 33 m to 02h 48m, June 28. High correlation of the waveforms are clearly seen between the corresponding traces, including *P*, *S* and several isolated

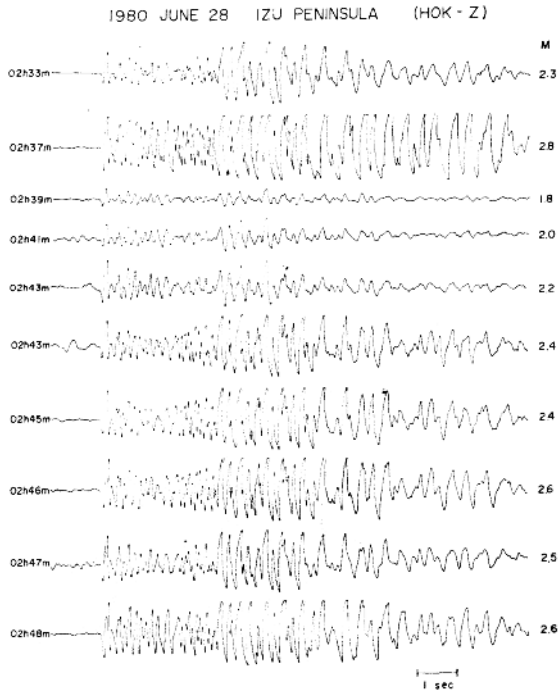

Fig. 4. An arrangement of the seismograms obtained by the vertical component (Z) at HOK during a period of 15 minutes. Magnitudes of these events lie between 1.8 and 2.8. Note the high correlation of the corresponding traces between the seismograms.

waves. Especially, when the seismograms with similar size are compared, their waveforms coincide almost perfectly from P-wave onset till coda waves. The events with similar waveforms, of course, will be expected to have similar S-P times. In fact, we found that the deviation of S-P times of their seismograms falls within a range of 0.06 sec.

The similarity of the waveforms can be expected in the seismograms of the other stations. Figure 5 shows an example of the seismograms of the event pair obtained at five stations distributed around the swarm

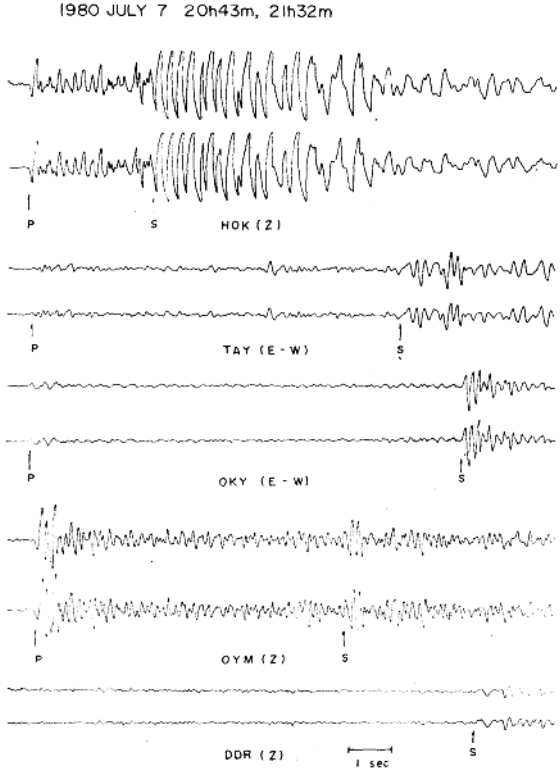

Fig. 5. An example of the seismograms for the event pair with almost exact agreement of the waveform and S-P time at each station.

area. The close similarity of waveforms is clearly found between the event pair at each station, and the S-P time at each station also does not differ no more than by 0.05 sec. According to our previous study, such a behavior suggests that their earthquakes are distributed within a spatial dimension of about 400 meters with almost the same mechanism (TSUJIURA, 1980a). Thus we may conclude that earthquakes occurring during a certain short time interval in the 1980 earthquake swarm have very similar waveforms. The same conclusion was obtained in our previous studies of different earthquake swarms. We call hereafter these earthquakes with similar waveforms a group of similar earthquake or an "earthquake family" (HAMAGUCHI and HASEGAWA, 1975).

Recurrent occurrence of earthquake family

The time interval between two successive earthquake families depends on the degree of seismic activity. When the seismic activity is high, the time interval is short and another family appears soon after the activity of the initial family is finished. Figure 6 shows an example of the seismograms of two families separated at the time of 01h 27m. The similarity of waveforms and the equality of S-P times are recognized clearly for each family, and the dissimilarity of the waveforms between two families is also noticed clearly in the P-wave portion where the polarity of the initial motion systematically changes from compression before 01h 27m to dilatation after that time. Moreover, the S-P time also changes. We found a change of about 0.1 sec by the superposition of the seismograms.

Further measurement of S-P times at four stations gives the difference of the epicenters of two families. The epicenters determined using these values show that the earthquakes of the second family occurred about 1 km northwest of the first family. Figure 7 shows the temporal distribution of earthquakes in the two families shown in the previous figure. The amplitude of each event shows the relative amplitude of S-wave in 3 Hz band taken from the filtered-seismograms at DDR and TSK, and the scale of the ordinate on the right-hand side indicates the magnitude (M) determined by the F-P time method at DDR given by HORI (1973). Solid and dashed lines represent the upward and downward initial motions at HOK, respectively. It is interesting that there is a systematic difference in the polarity of initial motion between the earthquake families as was previously mentioned. The polarity of initial motion at the other stations, however, does not change. Consider-

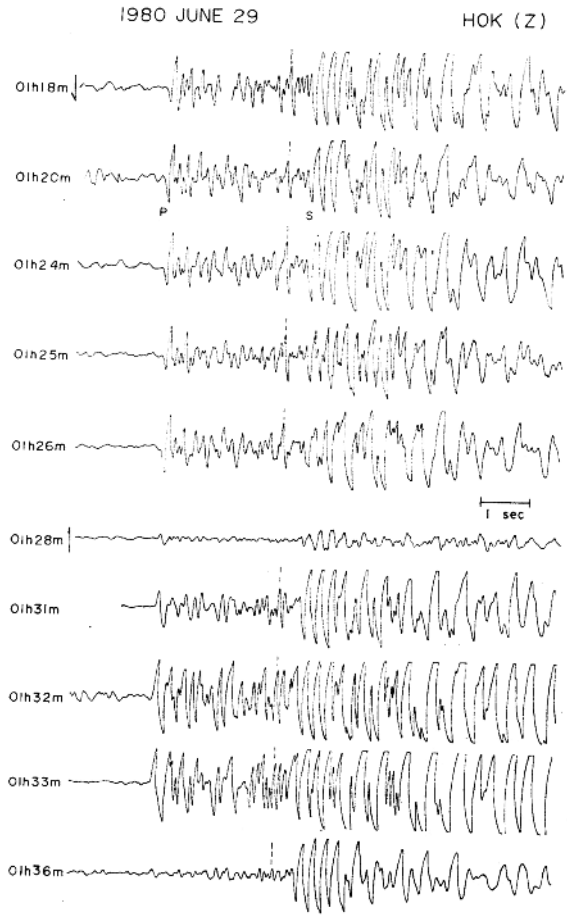

Fig. 6. An example of the seismograms for two earthquake families separated by 01 h 27 m. Note the difference of the polarity of initial motion of *P*-waves between two families.

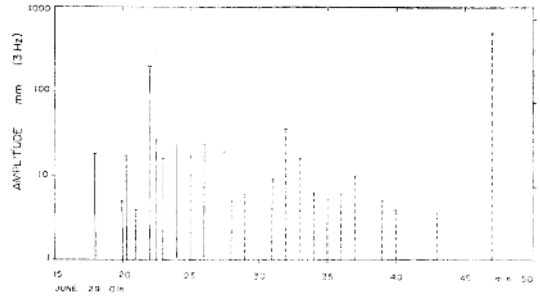

Fig. 7. Distribution of the earthquakes belonging to two earthquake families. Solid and dashed lines show the upward and downward initial motions at HOK, respectively. The amplitude and magnitude (M) are determined on the basis of the filtered-seismograms at DDR and TSK.

ing the station arrangement of our network, it is expected that the difference of the source mechanism between two families is not large. There may be only a slight change in the dip and strike of the nodal planes, and the station HOK probably lies near the nodal planes.

Figure 8 shows an example of the distribution of earthquake families during a 70-minute period of concentrated activity. Numerals at the top show the group number of earthquake family. We find that during a

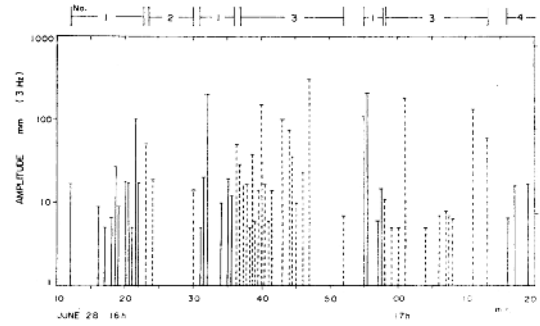

Fig. 8. Distribution of earthquake families obtained for a swarm sequence of 70-minutes with concentrated activity. Numerals indicated in the upper abscissa is the group number of the earthquake family. Explanation of the other symbols is the same as those of Fig. 7.

certain active period several earthquake families of different source mechanism appear alternately. For example, the earthquake family represented by solid lines (No. 1) appears at first, and its activity continues for about 10 minutes. After the activity of the first family stopped, the second family represented by dashed lines starts. When the No. 2 family finished, the No. 1 family again appears, and similar activities repeat until its sequence is finished. The S–P times for events in each family do not differ by more than about 0.06 sec, and the S–P times for events in the different families may differ by about 0.2 sec. Such evidence suggests that the earthquakes in the active period do not occur randomly in space. They occur only within several limited small areas.

Figures 9 and 10 show the activity mode of earthquakes in other sequences. Alternate occurrence of four families is apparent. Two large earthquakes with $M \geqq 4.5$ occurred in each sequence. Such events are usually followed by aftershocks. In the present case, however, the activity preceding the M4.5 earthquake is higher than the activity following the event. This is probably one of the most important features of the activity of similar earthquakes. This feature can qualitatively be explained as follows. The earthquakes belonging to a family occur on the same fault plane as repeated slipping, and the largest event with M4.5

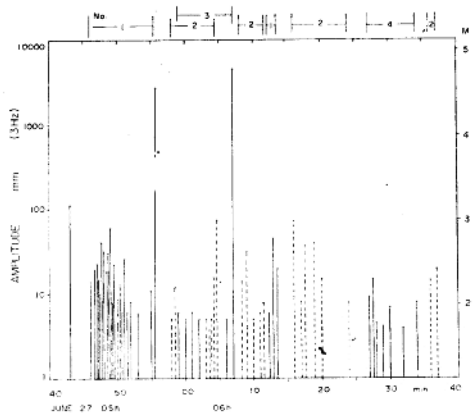

Fig. 9. Distribution of the earthquake families including large events with $M \geqq 4.5$. Note that the activity preceding the large earthquake is more dominant than the activity following the event. Explanation of the other symbols is the same as those of Fig. 7.

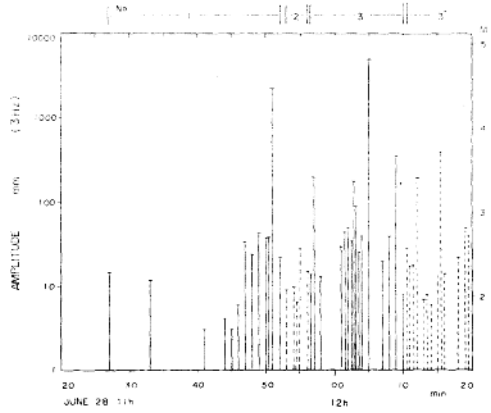

Fig. 10. Distribution of earthquake families including the large events with $M \geqq 4.5$.

occurs as the earthquake with the maximum slip or complete rupture corresponding to the "highest stress drop earthquake" (AKI *et al.*, 1977). Consequently, only a weak activity will be followed on the same fault plane. On the other hand, this maximum stress release produces the stress concentration elsewhere, and promotes the occurrence of another family.

Figure 11 shows the distribution of earthquake families in a sequence belonging to the later stage of the 1980 swarm. There is no systematic variation of the polarity of initial motion. The activity still consists of four families with their own waveform features.

We studied the activity mode for ten sequences, each of which lasts about one hour. Table 1 shows the proportion of earthquakes occurring in families together with the number of families recognized. We found that about 80 per cent of the earthquakes belong to the earthquake families.

Besides the earthquake groups described above, the activity associated with a specially large earthquake with $M=6.7$ occurring on June 29 must be noted. The activity mode of the sequence including the $M6.7$ earthquake is quite different from the other sequences. For example, the $M6.7$ shock appeared suddenly without any preceding small earthquake and was followed by many small earthquakes. This suggests the activity

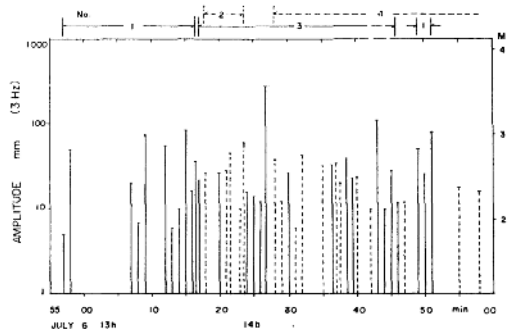

Fig. 11. Distribution of earthquake families obtained for the activity belonging to the later stage of the swarm sequence.

Table 1. Ratio of the number of earthquakes belonging to earthquake families to the total number of earthquakes. N; total number of earthquakes concerned, n; number of earthquakes in the family, F; number of earthquake families, M_{max}; magnitude of the largest earthquake included in each family.

Date	Time				N	n	n/N	F	M_{max}
	h	m	h	m			%		
June 27	05	43	— 06	37	77	65	84	4	4.9
June 28	11	25	— 12	20	80	66	83	4	4.9
June 28	16	12	— 17	19	87	70	80	4	3.8
June 29	12	07	— 13	12	44	35	80	4	3.2
June 30	17	20	— 18	15	56	41	73	5	3.6
July 1	10	45	— 11	40	50	40	80	5	3.4
July 5	07	45	— 09	02	51	38	75	6	3.3
July 6	13	58	— 14	58	77	61	79	4	4.1
July 7	19	43	— 20	57	42	34	81	4	4.5
July 27	17	49	— 18	50	53	35	66	4	4.6

of the main shock-aftershock type. The activity mode for 41 earthquakes which occurred during three hours after the M6.7 earthquake is studied by the same procedure. All of these events appear with an individual waveform character except for two event pairs with similar waveforms, and no earthquake family was observed.

Detailed study of the activity mode including the migration of epicenters with time is very useful for better understanding of the mechanism of the earthquake swarm. We studied here the distribution of S-P