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Is there Foreshock Larger than Main Shock ?

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Abstract

In earthquake sequences of foreshock-main shock-aftershock type, sometimes foreshocks themselves make main shock-aftershock type; the largest foreshock which occurs at first is accompanied by smaller earthquakes. In this case, time interval between the largest foreshock and next foreshock observed is considerably longer than that between main shock and the first aftershock observed. While aftershocks tend to occur immediately after main shock, foreshocks have some time delay in their occurrence. This characteristics is supposed to be intrinsic in fracture phenomena. When a conspicuous earthquake is accompanied by smaller events occurring in sporadic intervals, we should suspect that these earthquakes may be foreshocks related to a large earthquake.

We have called naturally the largest event in a sequence as main shock. However, if final rupture in the source region is supposed to be main shock, there may be foreshocks larger than main shock. Extremely small number of aftershocks of 1971 off Erimo Cape earthquake of M 7.0 may be explained if the M 7.0 event were a foreshock and a large aftershock of M 5.6, which was accompanied by many secondary aftershocks, were main shock corresponding to the final rupture.

1. Introduction

Shallow earthquakes tend to occur in a cluster within some limited space and time. Mogi (1963) classified earthquake sequences into three types according to patterns of temporal variation in their activity: main shock-aftershock sequence, foreshock-main shock-aftershock sequence, and earthquake swarm. These three types are schematically represented in Fig. 1, quoted from Utsu (1977).

Sometimes two main shocks accompanied by aftershock sequences occur in succession. When the earlier one has magnitude smaller than the latter, the earlier one and its aftershocks have been called a foreshock sequence (type B-2), and in the reverse case the latter one usually called a large aftershock accompanied by a series of secondary aftershocks (type A-2).

Mogi (1967) mentioned that the time distribution of foreshocks is classified

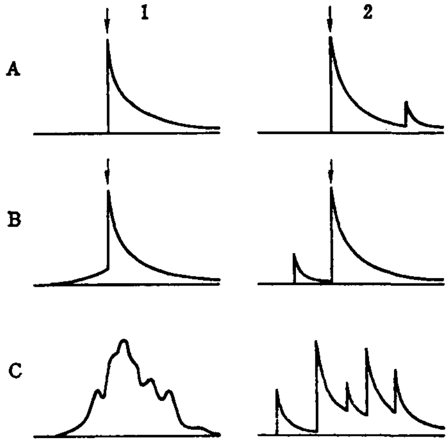

Fig. 1. Patterns of earthquake sequence. A : main shock-aftershock sequence, B : foreshock-main shock-aftershock sequence, C : earthquake swarm. Arrow represents main shock.

into two types, C (continuous type-gradually increase in activity toward the main shock) and D (discontinuous type-sudden increase in activity followed by a decrease before the main shock), which roughly correspond to type B-1 and B-2, respectively. In observation, however, C-type has been much rare compared with D-type (Suzuki, 1979).

2. Temporal distribution of foreshocks and aftershocks

In this paper, type A-2 and B-2 in Fig. 1 are exclusively treated. Earthquakes investigated are listed in Table 1.

In some case of D-type foreshock sequences, the largest foreshock occurs at first and then smaller events follow, as if it is a main shock-aftershock sequence. If there is some difference between such a pseudo main shock-aftershock sequence and the true one, it is useful to identify some earthquakes as foreshocks.

Fig. 2 is the magnitude-time plot of foreshocks, main shock, and aftershocks of 1981 Eniwa earthquake. It is pointed out in this time series that foreshocks tend to occur with some time delay from the largest foreshock, while aftershocks occur immediately after the main shock. Foreshock-main shock-aftershock sequences from both 1982 Urakawa-oki earthquake and 1981 Petegari-dake earthquake have the same characteristics. Fig. 3 shows occurrence times of foreshocks measured from the origin time of the largest fore-

Table 1. List of earthquakes investigated

No.	Date	Time	Event name	N-Lat.	E-Long.	Depth	Mag.
1	1971 Aug. 02	1625	off Erimo Cape	41°14′	143°42′	60 km	7.0
2	1981 Oct. 03	1042	Petegari-daka	42°33.7′	142°45.5′	16	2.7 #
3	1981 Oct. 18	1757	Eniwa	42°49′	141°15′	00	4.0
4	1982 Mar. 21	1132	Urakawa-oki	42°07′	142°36′	40	7.1
5	1985 Sep. 23	1645	Hidaka mountain	42°00.6′	143°19.5′	58	4.7
6	1995 Jan. 17	0546	Kobe	34°35.7′	135°02.2′	16	7.2

#: Research Center for Earthquake Prediction, Hokkaido University (RCEP), Others: Japan Meteorological Agency (JMA)

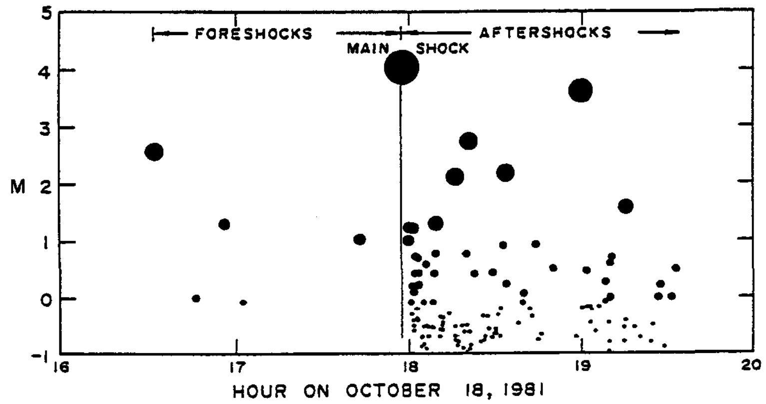

Fig. 2. Magnitude-time plot of 1981 Eniwa earthquake sequence.

shock (solid symbols) and those of aftershocks from main shock (open symbols) in the case of the above three sequences. It is clear that foreshocks start to occur in later stage. Time interval T_A between the first observed aftershock and the main shock and time interval T_F between the first observed foreshock and the largest foreshock are given in Table 2.

In general, the larger triggering shock, the more triggered events. Consequently, time intervals T_A and T_F depend on the magnitude of the triggering shock. However, as magnitudes of main shocks and the largest foreshocks range widely from 2.6 to 7.1 in Fig. 3, the difference between T_A and T_F may not be explained from only the difference of magnitude of the triggering events.

Moreover, T_A and T_F depend on observations inevitably. The seismograms of a large earthquake is often clipped because of the limited dynamic range of observation system. In addition, the coda of a large earthquake masks easily small events. These problems make difficult to ascertain how immedi-

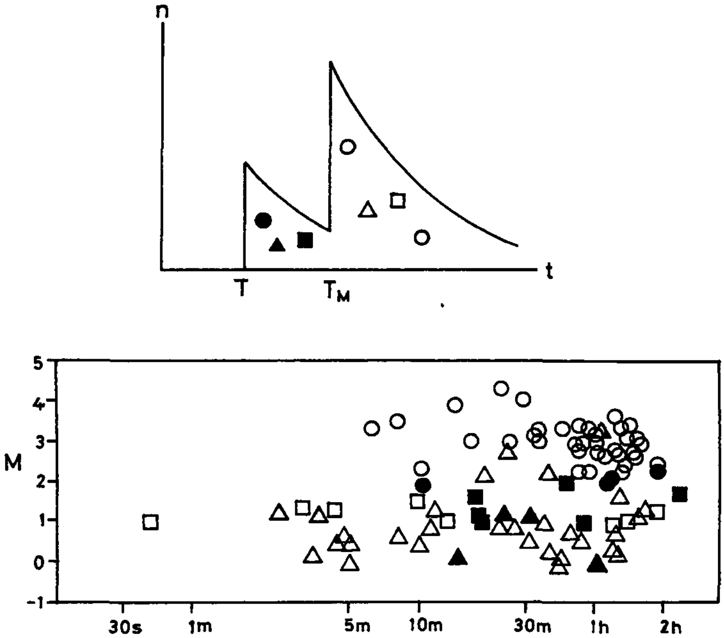

Fig. 3. Schematic representation of foreshock (solid)-main shock-aftershock (open) sequence (upper). Temporal distribution of foreshocks and aftershocks (lower). Time is measured from origin time of the largest foreshock T for foreshocks and that of main shock T_M for aftershocks, respectively. Symbols are the same as in Table 2.

Table 2. Description of foreshocks and aftershocks

No.	Event name	M_0	T_A	M_F	T_F	Symbol	Data
2	Petegari-dake	2.7	40 s	2.6	18 m	quadrangle	RCEP
3	Eniwa	4.0	3 m	2.6	13 m	triangle	RCEP
4	Urakawa-oki	7.1	7 m	4.9	10 m	circle	RCEP
5	Hidaka mountain	4.6	2 m	4.3	10 m		RCEP
6	Kobe	7.2	3 m	3.4	24 m		JMA
1	off Erimo Cape	5.6*	15 m	7.0*	5.6 h		JMA
			15 m		14 m		RCEP

No. and Event name are the same as in Table 1. M_0 : magitude of main shock, T_A : interval between the first aftershock observed and main shock, M_F : magnitude of the largest foreshock, T_F : time interval between the first foreshock observed and the largest foreshock. Symbol in Fig. 3. * See text.

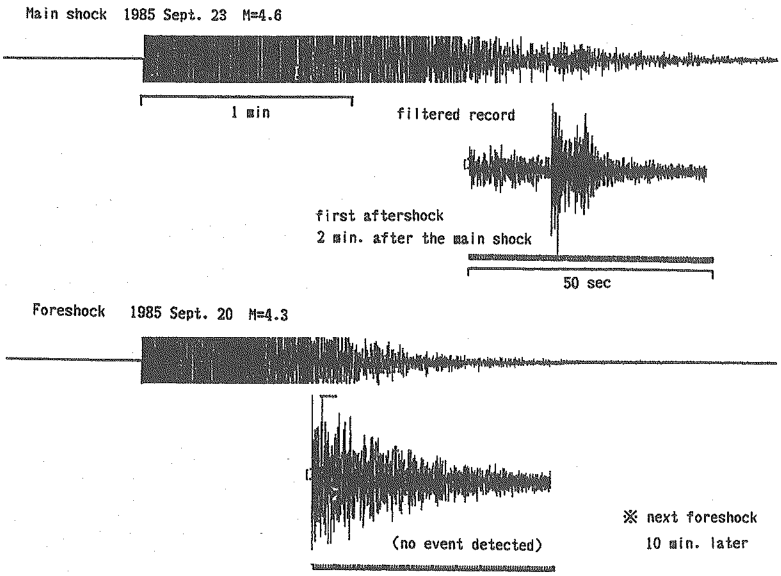

Fig. 4. Seismograms of 1985 Hidaka mountain eatrhquakes recorded at KMU (epicentral distance 38 km).

ately aftershocks start to occur after large main shock. In some case, it become easy to find out events on the filtered seismogram. Fig. 4 shows seismograms of 1985 Hidaka mountain earthquakes recorded at KMU (Urakawa Seismological Observatory, Hokkaido University). While an aftershock is detected within two minutes from the occurrence of the main shock, no event is found within ten minutes from the largest foreshock. As 1982 Urakawa-oki earthquake is large enough to mask small events for several minutes from its origin time, T_A may be shorter than seven minutes. However, other cases in Table 2 have no problem on observations.

Usually, number of foreshocks is much less than that of aftershocks. So, foreshocks may occur sporadically only because of their small number. However, still the above mentioned difference in temporal distribution between foreshocks and aftershocks is probably intrinsic in the fracture phenomena. It is supposed that subsequent slips on a fault plane should turn out a final fracture or main shock. With the situation in which events are to be foreslips, it may be required to keep some time interval between every slips.

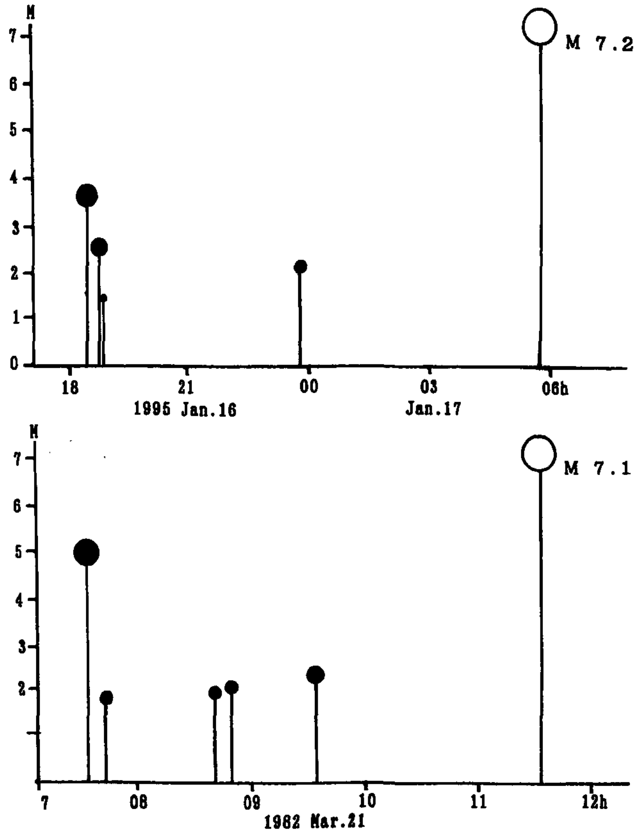

Fig. 5. Foreshock sequences of 1995 Kobe earthquake (upper) and 1982 Urakawa-oki earthquake (lower). Time scale is normalized with time interval between the first foreshock and main shock.

3. Experiential foreshock identification

When a conspicuous earthquake is followed by smaller events occurring in sporadic intervals, we should suspect that the events may be foreshocks related to a large earthquake. A consistent routine observation is of practical use for discrimination of time intervals between events occurring in succession. An expert on duty may experientially notice unusual time intervals. In addition, it is pointed out that foreshocks in B-2 type have similar waveforms each other (Motoya and Abe, 1985).

To our regret, we did not succeed in predicting 1995 Kobe earthquake which caused catastrophic disasters, more than 6400 casualties and 170,000 buildings destroyed in Hanshin and Awaji areas. Actually, this shock was preceded by a foreshock sequence of the same characteristics discussed in this section. As shown in Fig. 5, 1995 Kobe earthquake resembles 1982 Urakawa-oki earthquake in magnitude and occurrence mode of foreshocks as well. Moreover, waveforms of foreshocks of the Kobe event were similar each other (DPRI, 1995), as those of the Urakawa-oki earthquake were.

4. Foreshock larger than main shock

Usually main shock is the largest in one earthquake sequence. However, if main shock is defined as final rupture in the source region, there may be foreshocks larger than main shock. Consider analogy to rock specimen fracture experiment. In most case, after small slips occur, specimen loses strength by a large slip. In some case, while large slips occur, specimen still holds strength and it breaks finally by a rather small slip. The latter case may correspond to the case in which foreshock is larger than main shock.

Three shallow earthquakes equal or larger than M 7.0 occurred around Erimo Cape from 1965 to 1998. Fig. 6 shows epicenter distribution of earthquakes within one day from the occurrence of the three main shocks, respective-

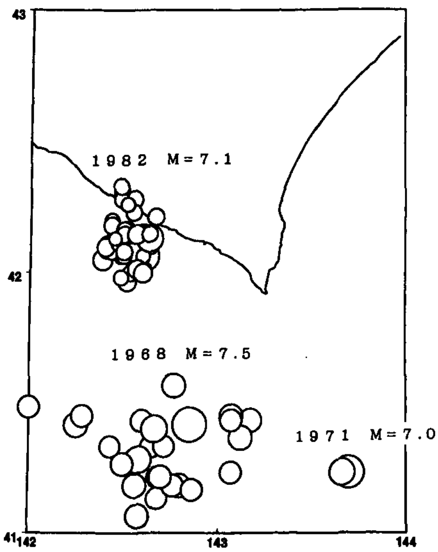

Fig. 6. Epicenter distribution of earthquakes within one day from origin times of three main shocks, respectively. Data from JMA.

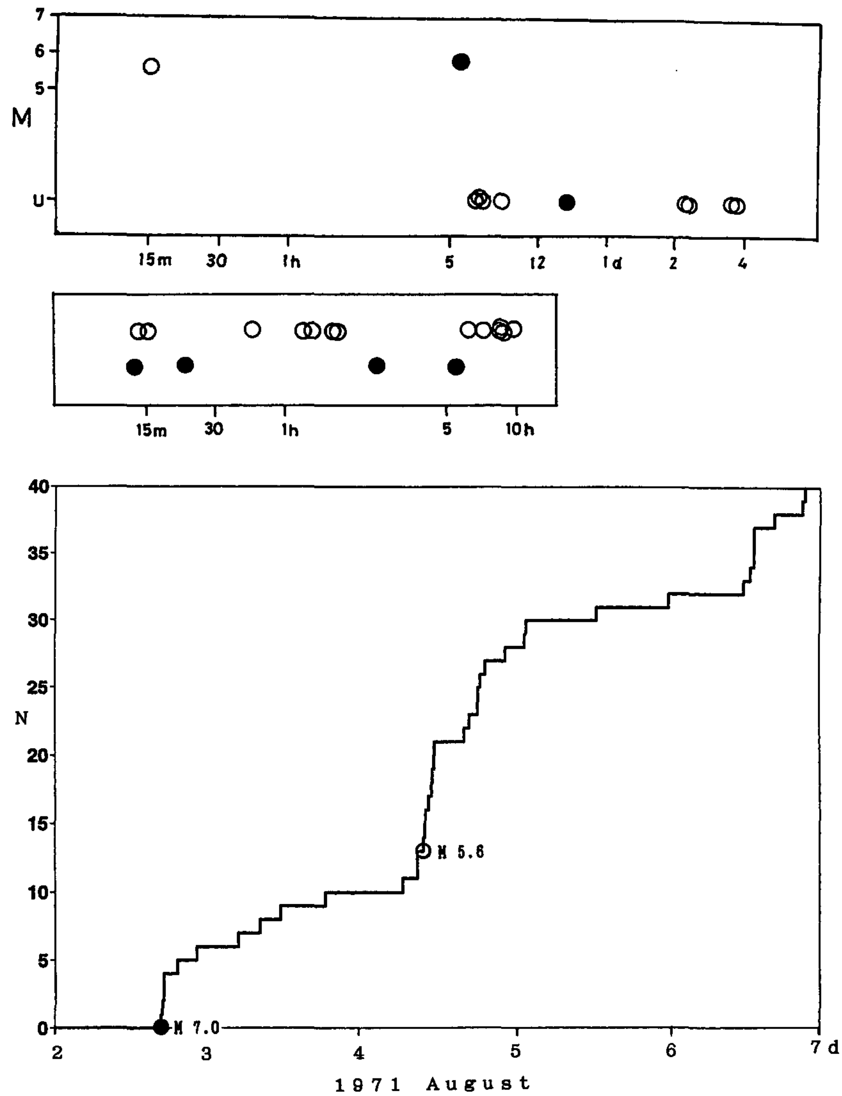

Fig. 7. Temporal distribution of events in 1971 off Erimo Cape earthquake sequence. Data of JMA (upper, u : magnitude undetermined) and KMU (middle, magnitude undetermined) are used, respectively. Explanation is same as in Fig. 3. Here events of M 7.0 and M 5.6 are supposed to be foreshock and main shock, respectively. Curve of cumulative number of events detected at KMU (lower).

ly. Extremely small number of aftershocks of 1971 off Erimo Cape earthquake of M 7.0 puzzles us. We discuss this event under the conception presented here.

A large aftershock of M 5.6 occurred 1.71 days after the main shock and it was accompanied by rather many secondary aftershocks. First, data from JMA are examined. While the first event was observed 5.6 hours after the main shock, an event occurred only 15 minutes after the M 5.6 event. Fig. 7 shows occurrence times of earthquakes measured from the origin time of M 7.0 event (solid symbols) and those from M 5.6 event (open symbols). This figure is made to be like Fig. 3. Next, data from KMU are used. As KMU is located near Erimo Cape and has more sensitive seismometers than JMA stations, more earthquakes are reported. Data from KMU shows the same tendency as JMA, though no seismogram available within ten minutes from the two large events because of short exposure of recording film due to too widely swinging light spot just after the events. The observed temporal distribution of events has similar characteristics as that mentioned in the previous section and it suggests that M 7.0 event (off Erimo Cape earthquake) is a foreshock and that M 5.6 event is the main shock.

5. Concluding remarks

Sometimes foreshock sequence is a main shock-aftershock type; the largest foreshock which occurs at first is accompanied by smaller earthquakes. The time interval between the largest foreshock and the next foreshock is considerably longer than the time interval between main shock and the first aftershock. While aftershocks occur immediately after the main shock, foreshocks hold some time delay in their occurrence. This characteristics may be useful for identification of foreshocks.

If main shock is supposed to be final fracture in the source region, there may be foreshocks larger than main shock. It is possible to say that off Erimo Cape earthquake of M 7.0 on August 2, 1971 is a foreshock of M 5.6 event which occurred 1.7 days after the M 7.0 event.

Acknowledgment

An idea that there may be foreshocks larger than main shock was suggested in discussion with members of Research Group for Earthquake Swarms. I am grateful to all of them.

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