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26. The M=3.9 Earthquake Sequence of May 1978 in Eastern Shimane, Japan

—Seismic Process and Possibility on its Prediction—

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Abstract

A sequence of earthquake activity occurred during May 26-29, 1978, in eastern Shimane, western part of the Honshu Island, Japan. The sequence was divided into four stages in activity; (1) foreshocks, (2) the M=3.9 main shock and its aftermaths, (3) precursory activity before the M=3.7 earthquake, and (4) the M=3.7 largest aftershock and its aftermaths. The aftershock activity of the M=3.7 event was much more active than that of the M=3.9 event, both in number and in spatial distribution.

The activity preceding the M=3.7 event was characterized by (1) a small b value, 0.4, (2) an increase in number of minor earthquakes, (3) successive increase in magnitude, and (4) the southeastward spreading of the active area, leaving a small region with no seismicity. If these had been recognized before the M=3.7 event, we might have been able to predict the possibility of its occurrence. Although they were only two, the foreshocks of the M=3.9 event might also have suggested a subsequent major event because of (1) their occurrence in a previously inactive area, and (2) the successive increase in magnitude with a small difference (M=1.0 and 1.3).

We may also admit a possible correlation between the present M=3.9 and 3.7 sequence and the M=6.1 earthquake which occurred nearby about one week later. In the hypocentral region of the M=6.1 event, the differential strain with respect to the P and T axes (namely twice as much as the shear strain on the fault plane) would have been enhanced by about 2×10^{-9} by the preceding M=3.9 and 3.7 events.

1. Introduction

A strong earthquake (M=6.1) took place inland at a shallow depth on June 4 (Japanese Standard Time=GMT+9 hours), 1978, in the central part of Shimane Prefecture, western Honshu Island, Japan. Preceding this event, a sequence of smaller earthquakes occurred on May 26-29 about 10 km northeast of the M=6.1 earthquake (Fig. 1). This sequence may further be divided into two distinct episodes of activity with (1)

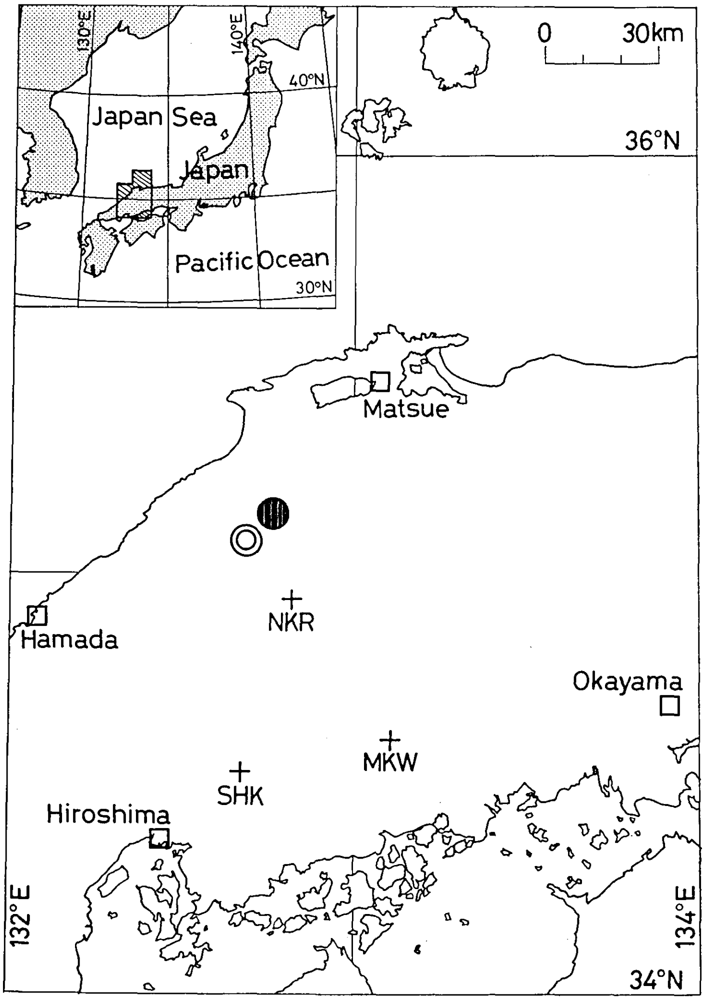

Fig. 1. Locations of the M=3.9 and 3.7 sequence (solid circle) and the M=6.1 earthquake (open circle) which occurred in May and June, 1978, respectively. Crosses and squares show the seismograph stations of the Shiraki Microearthquake Observatory and the Japan Meteorological Agency, respectively.

the main shock (M=3.9) on May 26 and (2) the largest aftershock (M=3.7) on the next day, 20.5 hours after the former. Both the M=3.9 and 3.7 events were characterized by foreshock and aftershock activities. Especially the precursory activity of the M=3.7 event was noteworthy from a viewpoint of the earthquake prediction. The present paper reports the characteristics of this M=3.9 and 3.7 sequence and discusses the possibility of prediction, especially of the M=3.7 event. A correlation between the M=3.9 and 3.7 sequence and the M=6.1 event is also discussed.

2. Observations

2-1. Hypocentral Distribution

Hypocenters of 17 earthquakes were determined using data from the tripartite network of the Shiraki Microearthquake Observatory of the Earthquake Research Institute (SHK, MKW and NKR; see Fig. 1). A semi-infinite medium was assumed here with P wave velocity of 6.0 km/sec and Vp/Vs ratio of 1.732. The hypocentral parameters of the M=3.9 and 3.7 events are shown in Table 1 with those by JMA (Japan Meteorological Agency, 1979). The present determination, however, may be biased by about 3-4 km toward the southwest because of a possible systematic error in these regions (NISHIDE, 1979). This bias is probably

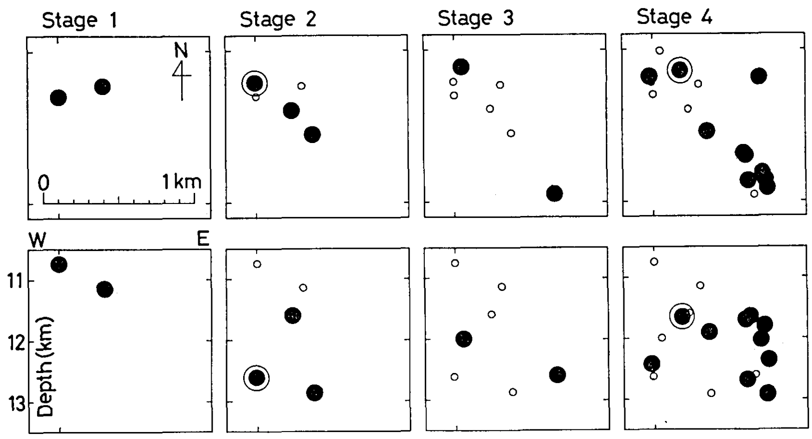

Fig. 2. Plan views (above) and cross sections (below) of hypocentral distributions of the M=3.9 and 3.7 earthquake sequence. (1) Before the M=3.9 main shock at 22:43 on May 26. (2) 22:43 on May 26—12:00 on May 27. (3) 12:00—19:16 on May 27. (4) After the M=3.7 largest aftershock at 19:16 on May 27. Here, the times are represented by JST (=GMT+9 hours). Double circles in stages 2 and 4 are the M=3.9 and 3.7 earthquakes, respectively. Open smaller circles represent superposition of the shocks which occurred previously.

Table 1. Hypocenters of the M=3.9 and 3.7 earthquakes. (A) is obtained using P and S−P times of the SHK's network (SHK, MKW and NKR), assuming the uniform crust with P wave velocity of 6.0 km/sec and Vp/Vs ratio of 1.732. (B) is obtained from P arrival times of the SHK's (SHK, MKW and NKR) and the JMA's (Matsue, Hamada, Hiroshima and Okayama) networks with epicentral distances less than 120 km. P wave velocity is assumed as in Fig. 6. (JMA) is after the Japan Meteorological Agency (1979).

	Origin h	m	Time sec	Longitude (E)	Latitude (N)	Depth (km)	Ref.
1978 May 26	22	43	28.5	132°45.4′	35°08.4′	12.6	(A)
(M=3.9)	22	43	27.6±0.1	132°45.2′±0.7 km	35°09.8′±0.6 km	16.6±0.9	(B)
	22	43	27.3±0.1	132°46′±0′	35°07±0′	0	(JMA)
1978 May 27	19	16	00.2	132°45.5′	35°08.5′	11.7	(A)
(M=3.7)	19	15	59.6±0.1	132°45.5′±0.3 km	35°09.2′±0.3 km	16.5±0.4	(B)
	19	15	59.9±0.1	132°47′±1′	35°08′±1′	10	(JMA)

due to an oversimplification of the underground structure. But the present results will be useful in order to understand their relative spatial distribution. In Table 1, the hypocenters, which were located using only the P arrival times of the nearest seven stations (less than 120 km in epicentral distance), are also listed, assuming P wave velocity as shown in Fig. 6.

Fig. 2 shows hypocentral distribution of four successive stages of the present M=3.9 and 3.7 sequence. (1) Two foreshocks occurred about 12 hours (M=1.0) and 15 minutes (M=1.3) before the main shock. Both of these were located near the northeastern corner of the upper margin of the final extent of the focal region. (2) The M=3.9 earthquake occurred in the northwestern corner of the lower margin, about 12.6 km in depth. At this stage, aftershocks were limited to the nothwestern half of the final focal region. (3) Later, two minor events were located before the M=3.7 event. One of them occurred about 19 hours after the M=3.9 event in a place, separated from the previously active area by about 0.5 km southeastwards. (4) The M=3.7 earthquake also occurred in the northwestern corner, about 11.7 km in depth. It was close to the upper margin of the focal region. Many aftershocks occurred both in the northwestern and southeastern parts of the final focal region.

2-2. S-P Times

82 shocks were recorded at NKR, the nearest station about 25 km south of the focal region (Table 2). The S-P times at NKR were limited to a small range, from 3.16 to 3.34 seconds, corresponding to the small

Table 2. Earthquake list of the M=3.9 and 3.7 sequence. Stars represent the shocks of which hypocenters were located in Fig. 2. Question marks represent less reliable readings.

Date		Origin Time h	m	sec	M	S−P (NKR)
5	26	09	08	13.9	1.0	3.26 *
		22	28	39.4	1.3	3.31 *
		22	43	28.5	3.9	3.30?*
		22	46	27.0	0.8	3.25
		22	48	55.2	0.8	3.30
		22	58	55.9	0.9	3.24
		22	59	08.0	0.1	3.25
		23	12	29.7	1.0	3.26
		23	45	40.4	0.5	3.23
5	27	01	45	55.7	1.0	3.27
		05	26	15.2	0.2	3.27
		07	06	09.4	1.7	3.25 *
		07	51	24.9	1.9	3.23 *
		13	27	09.7	0.0	3.28
		13	47	21.9	0.8	3.18
		14	02	35.7	1.0	3.26
		15	34	33.0	2.5	3.30?*
		15	35		2.2	3.25
		15	39	27.4	0.1	3.24
		15	41	36.7	1.1	3.26
		17	41	35.8	2.0	3.23 *
		18	18	34.8	1.1	3.28
		18	28	50.1	0.2	3.26
		19	16	00.2	3.7	3.32?*
		19	20	48.8	0.9	3.24
		19	22	26.2	0.2	3.34
		19	23	30.2	1.7	3.22?*
		19	26	17.9	0.7	3.26
		19	26	47.0	3.0	3.30?*
		19	29	11.2	0.4	3.20
		19	31	19.2	0.8	3.3
		19	50	41.9	0.8	3.26
		19	52	20.7	2.3	3.25 *
		20	08	03.4	0.7	3.32
		20	08	24.5	0.5	3.34
		20	27	23.6	1.3	3.22
		20	37	20.1	0.7	3.25
		20	45	56.5	0.0	3.21
		20	46	10.6	0.6	3.19
		20	47	06.9	0.0	3.28
		20	47	58.8	0.4	3.19
		20	51	12.2	0.5	3.20
5	27	21	00	16.9	0.5	3.24
		21	07	52.5	0.3	3.24
		21	19	54.1	0.9	3.20
		21	21	23.6	1.6	3.27 *
		21	27	10.2	0.5	3.25
		21	30	48.2	0.8	3.17
		22	20	44.1	1.1	3.21 *
		23	23	28.0	0.1	3.26
5	28	00	24	58.3	0.8	3.22
		00	28	41.9	0.0	3.29
		01	58	54.0	2.1	3.25 *
		02	46	16.3	1.5	3.21 *
		02	53	05.5	2.1	3.25 *
		03	04	35.9	0.2	3.33
		04	29	52.4	0.2	3.18
		05	12	43.2	0.5	3.26
		05	18	18.1	1.2	3.24
		07	55	53.8	0.2	3.20
		08	16	38.5	0.4	3.19
		10	09	49.3	1.5	3.25
		10	36	18.2	0.0	3.29
		10	59	32.8	1.1	3.26
		11	56	42.3	0.3	3.23
		14	39	20.4	1.6	3.28
		14	39	39.2	2.0	3.32 *
		16	03	39.3	0.8	3.23
		19	01	03.2	1.0	3.24
		19	42	28.3	0.6	3.23
		19	45	06.5	0.5	3.23
		20	18	27.7	0.1	3.22
		20	21	31.3	1.0	3.20
		23	32	42.0	1.0	3.21
5	29	00	28	56.4	0.7	3.16
		02	57	45.7	0.7	3.25
		04	09	08.4	0.4	3.26
		08	06	34.7	0.6	3.28
		08	55	23.5	0.5	3.25
		22	21	48.7	0.8	3.23
		22	55	28.5	0.7	3.25
		23	36	22.1	0.6	3.23

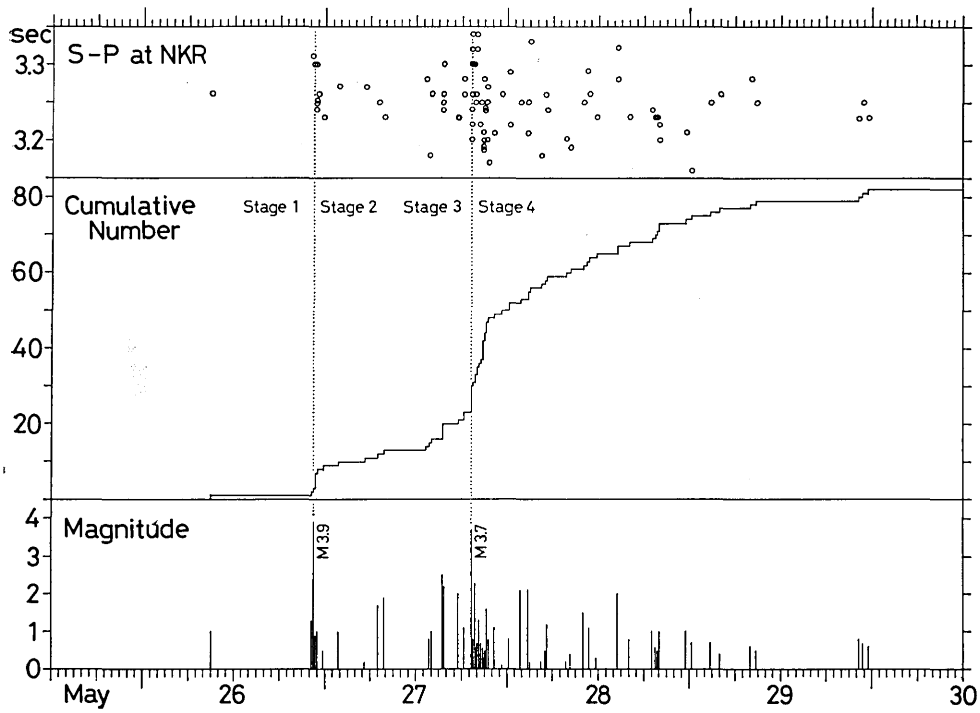

Fig. 3. Temporal change of the activity of the M=3.9 and 3.7 sequence. (a) Distribution of S−P times at NKR which is located about 25 km south of the epicentral region. (b) Cumulative numbers of earthquakes recorded at NKR. (c) Local magnitude of the earthquakes.

extent of the focal region. No other activities were known to have occurred during this period with the same S-P times as the present sequence at NKR.

The temporal spreading of the focal region, previously described, is also seen in the distribution of S-P times (Fig. 3a). The events just after the M=3.9 earthquake were limited to 3.23-3.30 seconds in S-P times, suggesting that they occurred in the northwestern half of the final focal region (namely, the farther half from NKR). The event, which occurred about 15 hours after the M=3.9 event, was the first one with a S-P time of 3.18 seconds which was apparently shorter than the preceding events. Once the M=3.7 earthquake occurred, however, the S-P times extended to a somewhat broader range, from 3.16-3.34 seconds.

2-3. Cumulative Number

The cumulative number of the shocks is represented in Fig. 3b. The aftershock activity just after the M=3.9 event decreased rapidly within a few tens of minutes. But the activity began to increase again about 15 hours after the M=3.9 event. This increase was followed by the M=3.7 event with the marked growth of the cumulative curve thereafter. The activity ended around May 29.

The number of the observed shocks just after the M=3.9 and 3.7 events were 5 and 11 within one hour, and 10 and 34 within 10 hours, respectively. Accordingly, the M=3.7 largest aftershock was much more active than the M=3.9 main shock, not only in the extension of the focal region but also in the number of the subsequent shocks.

2-4. Magnitudes

The magnitudes of the M=3.9, 3.7, and 6.1 earthquakes were determined by JMA (1979). Those of the smaller events were determined by

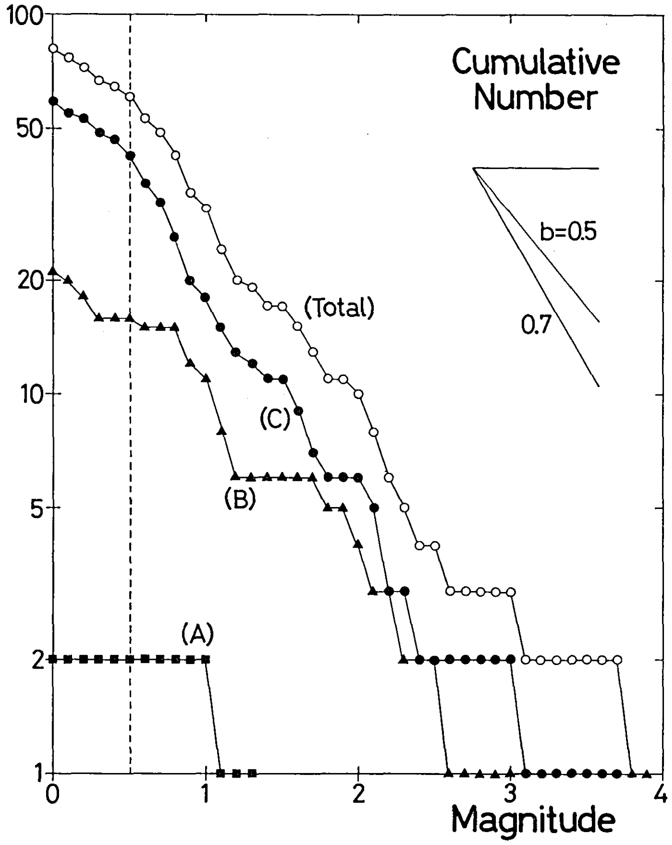

Fig. 4. Relations between magnitudes and cumulative numbers of earthquakes in respective stages in Fig. 2. (A) Stage 1 (foreshocks). (B) Stages 2 and 3 (M=3.9 and aftershocks). (C) Stage 4 (M=3.7 and aftershocks).

using the maximum trace amplitudes of the seismograms at SHK and NKR. The cumulative number of events (N) greater than a given magnitude (M) is plotted in Fig. 4. The slope of the curve decreases for events with magnitude less than 0.5, suggesting that the detection threshold for events within this area was about 0.5. The observed minimum magnitude was 0.0.

The b values of the present earthquake sequence were 0.44 and 0.72 for the periods before and after the M=3.7 event, respectively. For the whole period, it was 0.62. Here the b value was determined by the following formula by UTSU (1965); $b=S\log_{10}e/(\sum M_i-SM_s)$. M_s is the minimum magnitude and is taken as 0.5 in this case. S is the number of the events equal to and larger than M_s, and $\sum M_i$ is a sum of the magnitudes.

Fig. 3c shows the temporal change of the magnitude. The aftershocks just after the M=3.9 event were quite small in magnitudes. The maximum magnitude was only 0.9. Hereafter, however, the magnitudes increased in succession (M=1.0, 1.7, 1.9, and 2.5) with the growth of the cumulative curve of the number, until the M=3.7 event occurred. After the M=3.7 event, the magnitudes, generally speaking, decreased gradually.

2-5. Focal Mechanism

Fig. 5 shows the focal mechanisms of the M=3.9 and 3.7 earthquakes. Both of the plausible solutions represent a strike-slip faulting with the

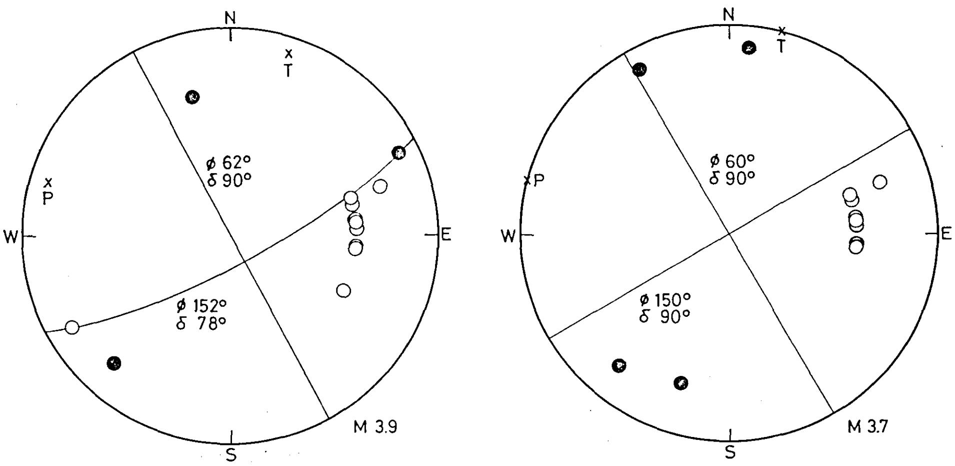

Fig. 5. P wave first motions and possible focal mechanisms of the M=3.9 (left) and 3.7 (right) earthquakes. Open and solid circles represent dilatation and compression, respectively. Plot is an equal-area projection on the lower hemisphere of the focal sphere. P wave velocity is assumed as in Fig. 6.

P axis trending nearly horizontally in a N75°W direction. They agree with those of the adjacent major earthquakes (YAMASHINA and NAKAMURA, 1978). The hypocentral distribution (Fig. 2) suggests that the NW-SE nodal plane was the fault plane which caused the present activity with left-lateral offsets. Fig. 6 is the assumed structure of the P wave velocity which was used to project the P wave initial motions onto the focal sphere in Fig. 5.

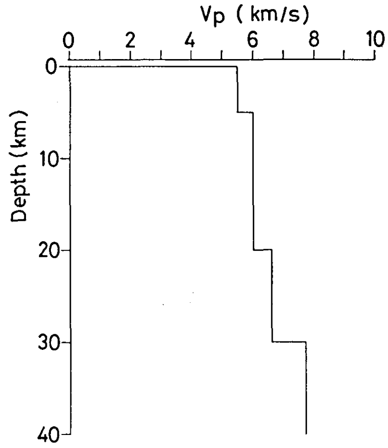

Fig. 6. Assumed P wave velocity structure.

3. Discussions

3-1. Possible Prediction of the M=3.9 and 3.7 Earthquakes

It took many days to process the seismic data associated with the present M=3.9 and 3.7 earthquakes. This was due to the present inefficient system of seismic data analysis used at the Shiraki Microearthquake Observatory. The authors, however, would like to discuss the data and their possible significance in the effort of earthquake prediction.

The process of the activity is represented by schematic vertical sections in Fig. 7. Although the M=3.9 event was preceded by two foreshocks, it would have been difficult to predict, because these foreshocks were quite small and would not have been taken seriously. If one must say something at this point of time, however, the facts that two events occurred in previously inactive areas and that the larger event (M=1.3) followed the smaller one (M=1.0) with small difference in magnitudes may have suggested the possibility of an occurrence of a still larger

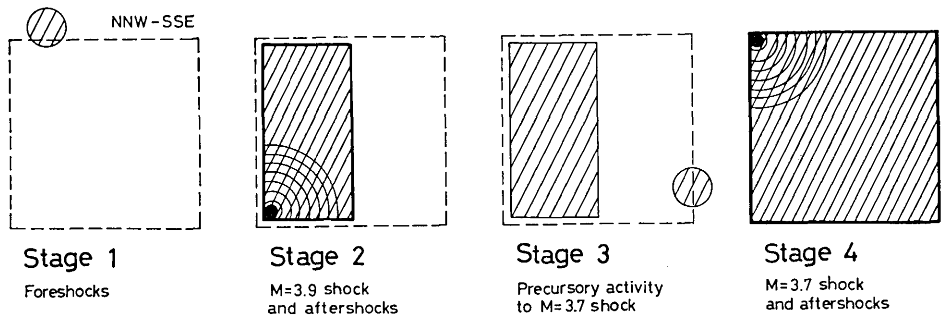

Fig. 7. Schematic cross sections parallel to the fault strike (NNW-SSE), representing the seismic process of the M=3.9 and 3.7 sequence.

event (M>1.3) in the near future (YAMASHINA, 1980).

Contrasting to the activity before the M=3.9 event, the M=3.7 event was preceded by remarkable precursors. Consequently, it might have been predicted to some extent, if we were able to continually monitor and rapidly analyze the data. The *b* value of the aftershock activity of the M=3.9 event was only about 0.4. Since foreshock activities are characterized in some cases by small *b* values (e.g., SUYEHIRO and SEKIYA, 1972; PAPAZACHOS, 1975), this observation might have been sufficient to call attention to an impending larger event. Increase in the number of minor eartquakes, successive increase in magnitude, southeastward spreading of the activity leaving a possible inactive and area might also have corroborated the possibility of a forthcoming earthquake. At that time, a predicted shock would be most likely to occur in the inactive area which lay between the focal region of the M=3.9 event and the small activity which occurred southeastwards about 0.5 km (Fig. 7). The horizontal extension of this inactive area was nearly equal to the focal region of the M=3.9 event, suggesting that an earthquake with magnitude of 3.9 or so might occur again. Nothing could be said when the predicted event might occur.

The actual event was 3.7 in magnitude. Its focal region included both the expected area and the focal region of the preceding M=3.9 event. Incidentally, the *b* value after the M=3.7 event was about 0.7, which was probably not an abnormal one. Although YAMASHINA (1980) proposed that a small difference in magnitudes between the largest and the second largest events might suggest a possibility of a still larger event, the lively aftershock activity declined within a few days.

3-2. Relation to the M=6.1 Earthquake

The M=6.1 earthquake occurred in the adjacent area about one week after the M=3.9 and 3.7 sequence. Both focal regions were trending in a NW-SE direction, parallel to each other about 10 km apart. Since there was an apparent distance between the two focal regions, the latter could not be regarded as a foreshock activity in a narrow sense. After YAMASHINA (1980), however, the M=3.9 and 3.7 events might have suggested an occurrence of a still larger event with a probability of about 20%. The M=6.1 earthquake might have been such an event predicted by his method. Incidentally, the present M=3.9 and 3.7 sequence and other microearthquakes during the previous months appeared to form a doughnut-shaped pattern around the epicentral area of the M=6.1 event (YAMASHINA and INOUE, 1979). The M=3.9 and 3.7 sequence would have suggested the existence of a generally high level of tectonic stress in these regions.

Taking the focal mechanisms of both the M=3.9 and 3.7 sequence and the M=6.1 event into consideration, at the hypocenter of the latter, the earthquake-generating stress seems to have been increased by the occurrence of the former. Assuming plausible fault models, the total increase was preliminarily estimated about 2×10^{-9}, in differential strain with respect to the P and T axes (twice as much as the shear strain on the fault plane). The method of the calculation was the same as YAMASHINA (1978, 1979). It is, of course, doubtful that such a small fluctuation in strain (and stress) played an essential role to the occurrence of the M=6.1 event, but could have been one of the secondary factors which triggered it.

The *b* value of the M=3.9 and 3.7 sequence totalled about 0.6. That of the aftershocks of the M=3.7 event was about 0.7. They both might be slightly less than that of the M=6.1 sequence, which was about 1.0 for the magnitude range M=1.2-2.5 (Shiraki Microearthquake Observatory, 1978). Against this, however, a smaller value of *b*, 0.6, was reported for the M=6.1 sequence by the Tottori Microearthquake Observatory (1978). Further study of the general *b* value of these regions is needed to use *b* value of respective sequence as a possible warning to subsequent earthquakes.

4. Conclusions

In the small earthquake sequence of May 1978 in eastern Shimane, both the main shock (M=3.9) and the largest aftershock (M=3.7) were preceded by precursory microearthquakes. Especially, the activity preceding the M=3.7 event might have suggested the possible occurrence of an earthquake somewhat equal to the main shock. The small difference in magnitudes between the M=3.9 and 3.7 events might have also suggested the M=6.1 earthquake which occurred nearby about one week later. A possible increase in differential strain (2×10^{-9}) caused by the M=3.9 and 3.7 events might have also played a certain role resulting in the M=6.1 earthquake.

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26. 1978年5月，島根県東部の小地震 (M=3.9) —活動経過と予測可能性—

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1978年5月26～29に，島根県東部で M=3.9 の地震が発生した．活動は，(1) 前震，(2) M=3.9 とそれに伴う余震，(3) M=3.7 に先だつ前兆的活動，(4) M=3.7 とそれに伴う余震の4つの段階に区分できる．M=3.9 と 3.7 の余震活動を比較すると，後者の方が数，余震域の拡がりともはるかに活発であった．

M=3.9 発生後の活動経過は，本震と同程度の地震が新たに発生するかもしれないことを示唆していたと考えられる．M=3.7 発生以前に，そうしたデータを検討できれば，ある程度の予測が可能だったかもしれない．その根拠は，(1) b 値が約 0.4 とかなり小さかったこと，(2) いったんおさまっていた M=3.9 以後の余震活動がふたたび活発化していたこと，(3) 同時に，しだいにマグニチュードのより大きな地震が起こるようになってきたこと，(4) 活動域が南東方へ拡がり，本震の破壊域と同程度の末破壊領域が推定されたこと，である． M=3.9 に先だつ前震は2つ観測されただけであるが，(1) それまで活動のなかった場所に起きたこと (2) 後者の方がマグニチュードが大きく，またマグニチュードの差が小さいこと (M=1.0 と 1.3) は注目される．

M=3.9, 3.7 の地震から約1週間後に，近くで M=6.1 の地震が発生している．何らかの関係があったかもしれない．なお，M=3.9, 3.7 の発生により，M=6.1 の震源付近では 2×10^{-9} 程度の(起震応力を増大させる方向の) 差歪みの増加が推定される．