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Approach to the Earthquake Prediction by Analyzing Foreshocks of Large Korean Historical Earthquakes

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역사지진에서 강진의 전진에 대한 특성 분석을 통한 지진 예지에 대한 고찰

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ABSTRACT Seismicity changes associated with foreshocks of large Korean historical earthquakes of MMI > VIII are investigated for earthquake prediction study. A number of tests showed that b-values of foreshocks associated with these large earthquakes are most stable for precursor period of 13 years before the earthquake and rectangular source area of 1.1° by 1.1° around the epicenter. The b-values of foreshocks for 11 large events of MMI > VIII for the above foreshock area and precursor period turns out to be smaller than the value of 0.36 for the whole historical earthquakes with average 0.27. Epicenters of these foreshocks of small b-values are distributed close to the location of the main large earthquake. These observations indicate a possibility of predicting large earthquakes by closely monitoring the change of b-value for an extended period over decades in the Korean peninsula.

Key words Earthquake prediction, Korean historical earthquakes, foreshocks, b-value

요 약 본 연구에서는 지진 예지 연구를 위하여 한반도에서 발생한 MMI 진도가 VIII 보다 큰 역사 지진들의 전진들에 대하여 지진활동도의 변화를 분석하였다. 한반도에서의 강진에 대하여 13년의 전진기간과 진앙을 중심으로 위도 1.1°, 경도 1.1° 크기의 사각형 모양의 전진범위를 가정했을 경우 가장 안정적인 전진들의 b값을 도출할 수 있었다. 이 전진기간과 전진범위에 의해 결정된 11개의 MMI 진도 VIII 이상의 강진의 전체 전진들에 대한 b값은 전체 역사지진의 b값인 0.36에 비해 확연히 작은 0.27로 결정되었다. 또한 강진 발생을 앞두고 작은 b값을 가지는 지진들이 강진의 진앙 근처에서 집중적으로 발생하였다. 본 연구를 통해 십 수 년 동안의 b값의 변화를 자세히 관찰함으로써 강진의 예지가 가능하다는 것이 확인되었다.

주요어 역사지진, 전진, b값, 지진예지

1. Introduction

The Korean Peninsula has been regarded as a seismically stable region for a long while. However, the concern about the seismic hazard of the peninsula has increased significantly, mainly due to construction of a number of important structures such as nuclear power plants, large dams and high-rise buildings. In the 20th century, no large destructive earthquakes occurred in the peninsula. However, we have records of quite a number of large destructive historical earthquakes occurred in the peninsula since the first century(Lee and Yang, 2005). Since the intraplate seismicity, which is the case for Korean earthquakes, reactivates at the intervals of hundreds to thousands years, the present seismic

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quiescence does not preclude impending destructive earthquakes. In this connection, it is very important to examine the possibility of predicting destructive large earthquakes based on earthquake data, especially historical data, in the peninsula.

It is generally acknowledged that large earthquakes are preceded by some precursors over the world (Shearer, 1999). And the mechanism of some of the precursors is explained by the theory of dilatancy (Bolt, 1978). One of the most important precursors in predicting earthquake is the change of seismicity accompanied by foreshocks and aftershocks , especially foreshocks (Shearer, 1999). Gutenberg and Richter(1954) established a relationship between magnitude and logarithmic frequency of earthquakes. In this relationship, the b-value represents the characteristics of local seismicity. This b-value showed significant change before the 1995 Hyogo-ken Nanbu (Kobe) earthquake (Bogdan and Kiyoshi, 2001). Utsu(1971) and Wyss and Lee(1973) proposed that the b-values of foreshocks and aftershocks are different for large earthquake.

Since we have no large destructive instrumental earthquakes in the Korean peninsula, we used historical earthquakes to examine the change of seismicity accompanying foreshocks and aftershocks for large earthquakes. In this study, only historical earthquakes of MMI > VIII are analysed.

2. Historical Earthquakes in the Korean Peninsula

In this study, a total of 2211 historical earthquake data of Lee and Yang (2005) are used (Fig. 1) Among them, 22 large earthquakes of MMI > VIII are analysed for the change of seismicity before and after the events. These large earthquakes are represented by stars in Figure 1 and tabulated in Table 1 in chronological order.

If we assume a linear relationship between magnitude and maximum intensity, a similar linear relationship between intensity and logarithmic frequency will hold. The b-value between intensity and logarithmic frequency for all historical earthquakes are calculated as 0.36 (Fig. 2a) and that for earthquakes excluding events > MMI VIII as 0.30 (Fig. 2b). We analyzed only the foreshocks of 11 large earthquakes in Table 2 since the other earthquakes in Table 1 have too few foreshocks to obtain statistically significant b-value

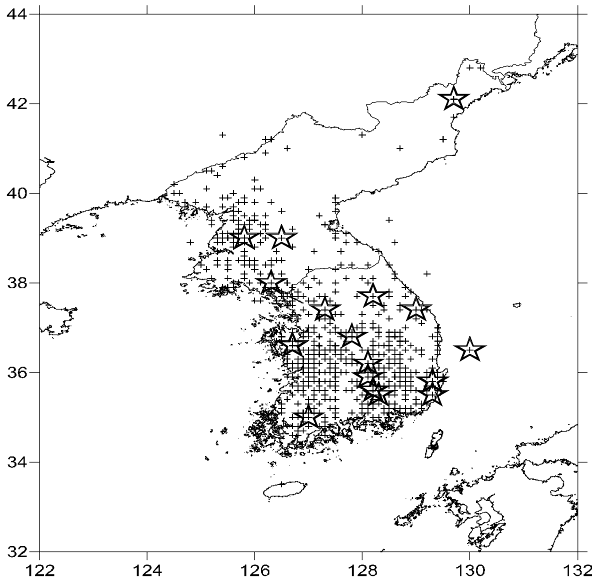


Fig. 1 The distribution of historical earthquakes. The earthquakes are represented as '+', and large earthquakes used in this study are represented as pentagrams.

Table 1 The list of historical large earthquakes.

No.	YEAR	LAT.	LON.	MMI
1	89	37.4	127.3	Ⅷ-Ⅸ
2	100	35.8	129.3	Ⅷ-Ⅸ
3	304	35.8	129.3	Ⅷ-Ⅸ
4	502	39.0	125.8	Ⅷ-Ⅸ
5	510	35.8	129.3	Ⅷ-Ⅸ
6	779	35.8	129.3	Ⅷ-Ⅸ
7	1036	37.7	128.2	Ⅷ-Ⅸ
8	1427	36.2	128.1	Ⅷ-Ⅸ
9	1430	35.5	128.3	Ⅷ-Ⅸ
10	1437	36.8	127.8	Ⅷ-Ⅸ
11	1455	35.0	127.0	Ⅷ-Ⅸ
12	1518	38.0	126.3	Ⅷ-Ⅸ
13	1546	39.0	126.5	Ⅷ-Ⅸ
14	1553	35.9	128.1	Ⅷ-Ⅸ
15	1594	36.6	126.7	Ⅷ-Ⅸ
16	1643	35.5	129.3	Ⅷ-Ⅸ
17	1681	37.4	129.0	Ⅷ-Ⅸ
18	1681	36.5	130.0	Ⅷ-Ⅸ
19	1692	35.6	128.2	Ⅷ-Ⅸ
20	1694	35.6	128.2	Ⅷ-Ⅸ
21	1757	36.6	126.7	Ⅷ-Ⅸ
22	1810	42.1	129.7	Ⅷ-Ⅸ

or have partially overlapping foreshocks with adjacent earthquakes.

3. Area and Period of Foreshocks

Before large earthquakes, some precursory phenomena telling upcoming of large earthquake occur in source regions. Small earthquakes increase and moderate earthquakes decrease in frequency before the occurrence of large earthquakes. Various researchers established relationships between precursor period and magnitude (Tsubokawa, 1973; Scholtz et. al., 1973; Whitcomb et.al., 1973; Rikitake, 1975)We searched for appropriate ranges for foreshock areas and precursor periods for earthquakes in Table 2 by examining historical earthquakes. We also analyzed the distributions of b-values of foreshocks for these events by various combinations of foreshock areas and precursor periods. The foreshock area is defined as a rectangle of some extent with center as epicenter of the large earthquake. The precursor period is defined as some years before the year of occurrence.

We analyzed the behavior of b-values as we change the extent of foreshock areas from 0.2 ° in latitude by 0.2 ° in latitude to 1.8 ° by 1.8 ° at 0.4 ° intervals, and precursor periods from 6 to 18 years at 3-year intervals. (Fig. 3a) Figure 3a shows that the b-values are stable for the extent ranging from 1° to 1.4° and precursor period from 12 to 15 years. If we look into the b-value behavior in these range in more detail with smaller intervals of 0.1°and 1 year, b-value turns out to be most stable for foreshock area of 1.1 ° by 1.1 ° and precursor period of 13 years. (Fig. 3b). This result generally coincides with those obtained from the relations between magnitude and precursor periods by previous studies. We used these values in the subsequent analysis of historical earthquakes in this study.

4. b-Values of Foreshocks

When a large earthquake occurs, precursors precede in many cases. One of the precursors is the temporary change of seismicity. The b-value calculated from only foreshocks of large earthquake shows lowered value compared with that of normal seismicity (Hsu, 1976). Using large Korean historical earthquakes in Table 2, we studied the change of b-value associated with these events and examined the potential of predicting large earthquakes in the peninsula.

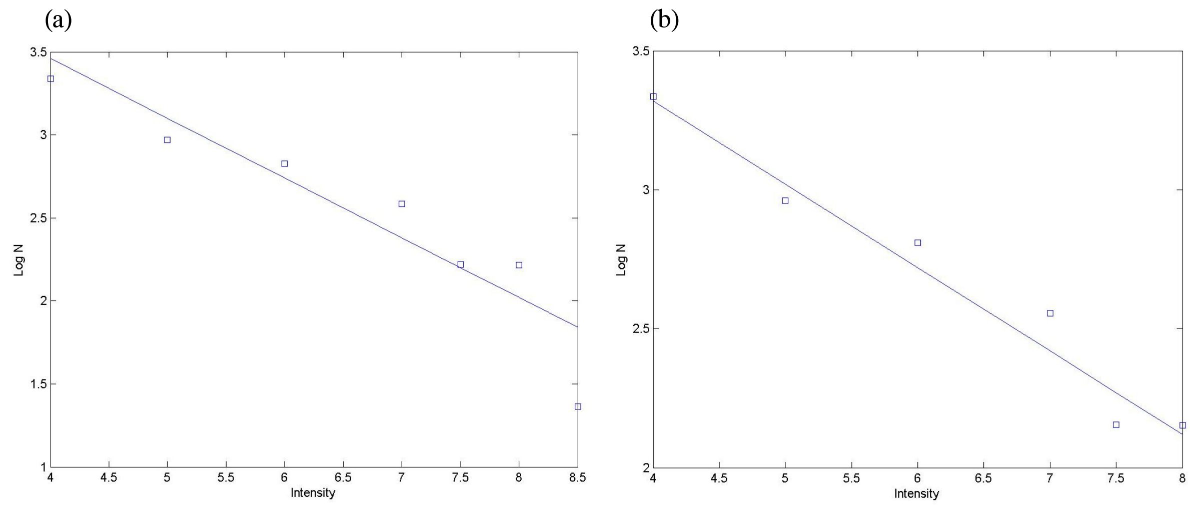


Fig. 2 Linear regression of the distribution of intensity versus logarithmic frequency for the whole historical earthquakes, Log N = 4.90 - 0.36 I0 (a), and for the historical earthquakes of MMI ≦ VIII, Log N = 4.52 - 0.30 I0 (b).

Table 2 The b-values of foreshocks of each large earthquakes.

year of large earthquake	779	1427	1455	1518	1546	1553	1594	1643	1681	1692	1757
b-value of foreshocks	0.19	0.25	0.2	0.3	0.2	0.32	0.22	0.42	0.3	0.24	0.25

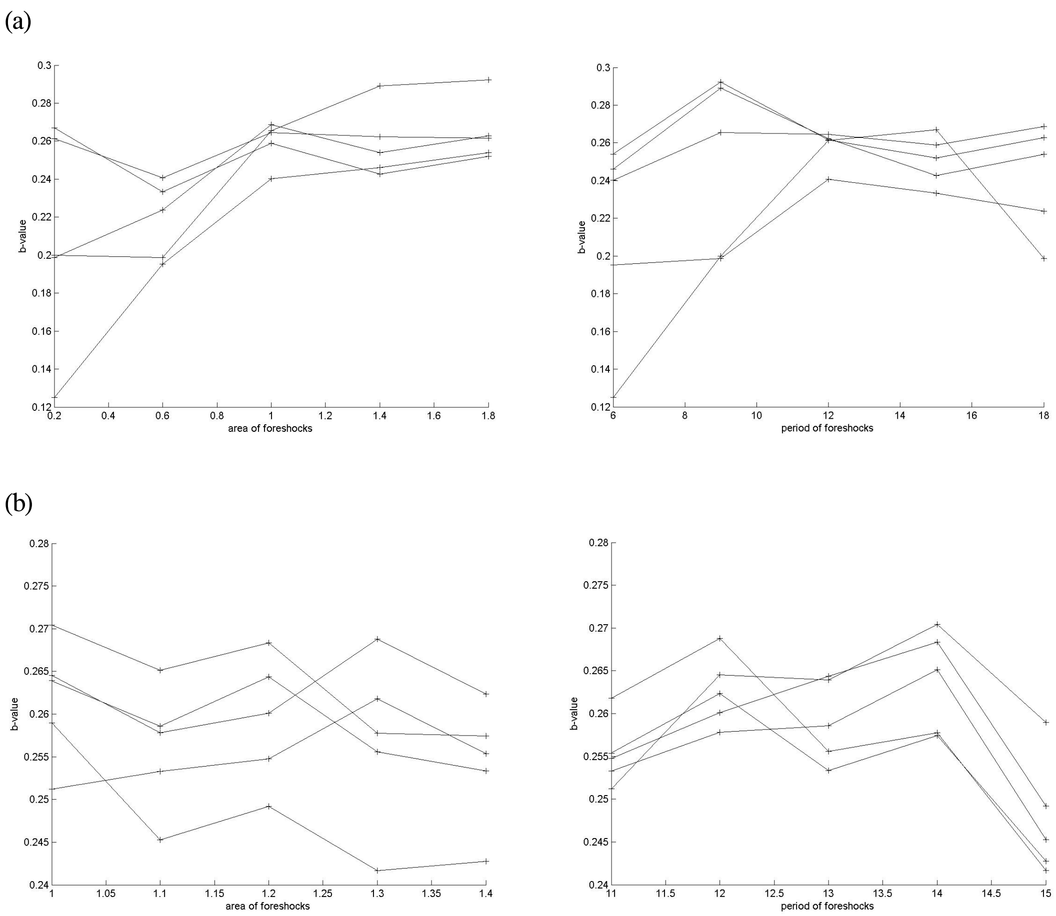


Fig. 3 The distribution of b-values with various ranges of area and period of foreshocks. The lines connect b-values with same period in the left and with same area in the right.

For each large earthquakes in Table 2, all historical earthquakes occurred in the areal extent of 1.1° by 1.1°around the epicenter during 13 years before the large earthquake are considered as foreshocks of the event. The b-values of foreshocks defiend above are calculated (Table 2). In Table 2, it can be seen the b-values of foreshocks of large earthquakes range from 0.19 to 0.42. Except for the event in 1643, all of them are smaller than 0.36, the b-value for whole Korean historical earthquakes. Furthermore, b-values of 7 events among 11 are smaller than 0.30 for whole earthquakes of MMI ≦ VIII. For the whole foreshocks of 11 earthquakes in Table 2, b-value turns out to be 0.27 (Fig. 4). From these results, we can conclude that the foreshocks of large historical earthquakes in the Korean peninsula have smaller b-values compared to that of whole historical earthquakes. This observation seems to be applicable to predicting large de-

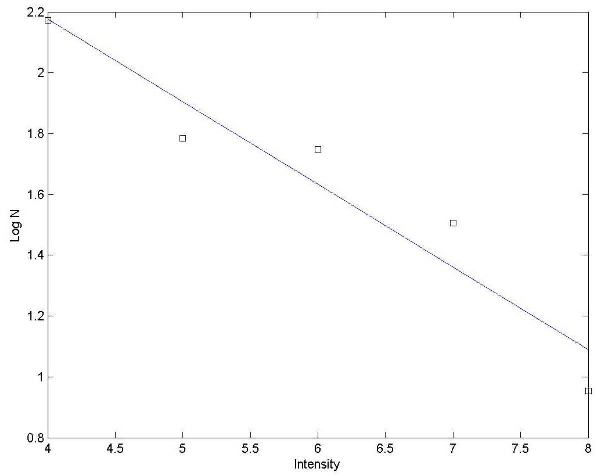


Fig. 4 Linear regression of the distribution of intensity and logarithmic frequency of the whole foreshocks of 11 large earthquakes, Log N = 3.26 - 0.27 I_0.

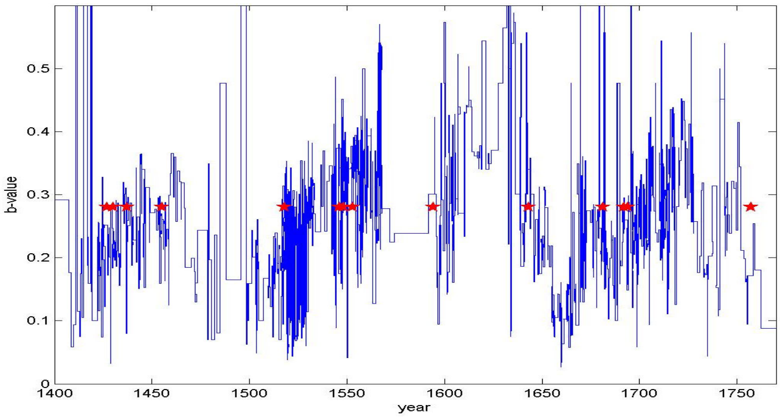


Fig. 5 The variation of b-values(blue line) calculated from earthquakes in preceding 13 years and in 1.1° by 1.1° square about the each historical earthquakes with the distribution of large earthquakes(red asterisks).

structive earthquakes in the Korean Peninsula.

We designed a simple algorithm to predict an upcoming large earthquake from above observations. This algorithm is based on that a drop of b-value may tell the coming of a large earthquake. For each historical earthquake of MMI ≦ VIII, the b-value of earthquakes occurred within the square 0.1 ° by 0.1 ° with its center as epicenter of large earthquake during the past 13 years are investigated. The mean and median of calculated b-values are 0.30 and 0.28, respectively. In Figure 5, the calculated b-values are illustrated with the distribution of large earthquakes represented as asterisks from 1400 to 1770. Outside that period, there are too few b-values to consider for statistically significant change. In Figure 5, it can be seen that b-values around the large earthquakes are smaller than 0.28, the median of b-values.

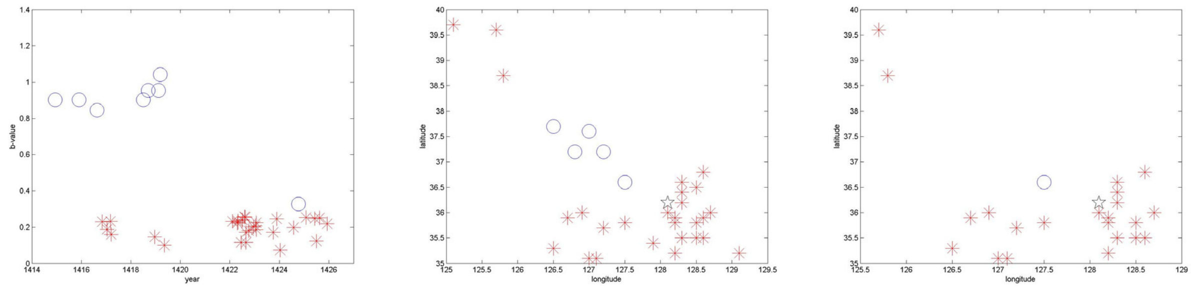
The variation of b-values during 13 years before each large earthquakes in Table 1 is studied. For some large earthquakes, the variation of b-values shows significant behaviors. In Figure 6a, the b-values during the past 13 years before the large earthquake in 1427 are plotted in the left. The b-values > 0.28, the median of the whole b-values, are plotted as blue circles, and the others are plotted as red asterisks. In the middle of Figure 6a, locations of earthquakes of the left of Figure 6a are plotted with circles or asterisks representing respective b-values in the same way as in the left . And in the right of Figure 6a, the locations of earthquakes during 5 years before the large earthquake in 1427 are plotted in the same way. In the middle and right of Figure 6a, the location of large earthquake in 1427 is plotted as pentagram. In the same way, Figure 6b and 6c are plotted about the large earthquakes in 1553 and 1692, respectively.

In Figure 6a and 6c, most of b-values are smaller than 0.28 and they are plotted as asterisks. And the locations of asterisks are concentrated near the pentagram which is the epicenter of large earthquake. But in Figure 6b, there are more circles than asterisks. And the locations of asterisks are distributed diffusely, not close to the epicenter of large earthquake. In the right of Figure 6b, there are few asterisks. In the middle and the right of Figure 6b, the small b-value shows no correlation with the large earthquake. But in Figure 6a and 6c, a good correlation between small b-value and the large earthquake is recognized. Similar studies for other earthquakes in Table 1 along with those mentioned above lead us to conjecture that b-values, calculated for the time span of 13 years before the large earthquake in the area of 1.1° by 1.1° around the epicenter are smaller than 0.28 with foreshocks concentrated around the location of large earthquake in general. This result indicates that a close monitoring of the variation of b-values in the Korean peninsula may be used to predict an impeding destructive large earthquake. However, further studies are needed in this direction to substantiate this possibility.

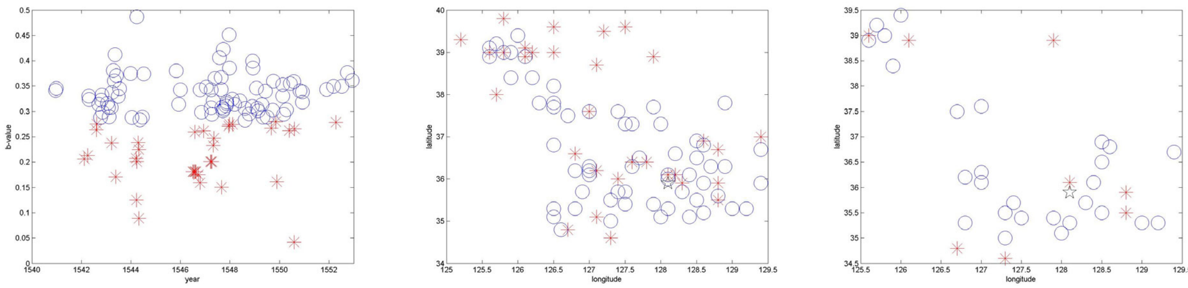
5. Conclusions

By analyzing the variation of seismicity preceding large destructive earthquakes from Korean historical earthquake data, we examined the possibility of predicting large earthquakes based thereon. We studied the b-value changes in the time span of 13 years prior to large earthquakes of MMI

(a)



(b)



(c)

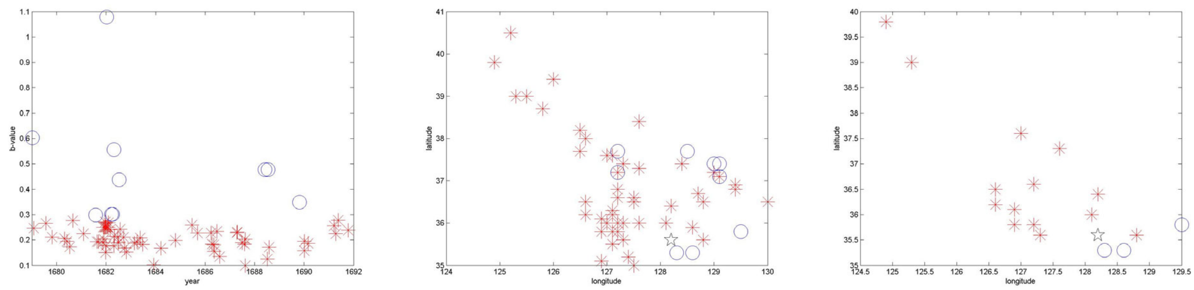


Fig. 6 The distribution of b-values in preceding 13 years(left and middle) and 5 years(right) before the large earthquakes in 1427(a), 1553(b) and 1692(c). Blue circles and red asterisks represent b-values > 0.28 and b-values ≦ 0.28, respectively. And the black pentagrams represent large earthquakes.

> VIII in the area of 1.1° by 1.1°around the epicenter and found that the b-value obtained therefrom is significantly lower than the average value for the whole historical earthquakes in the peninsula. This study seems to indicate a possibility of predicting an impending large earthquake based on close examination of the b-value change for a long time extending to decades. However, further studies are needed in this direction.

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