LONG-RANGE SEISMOLOGICAL PRECURSORS OF STRONG EARTHQUAKES. VI. NORTH CHINA PLATFORM ZONE

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The Tangshan earthquake in 1976 (M = 7.9) was preceded by precursors of the bursts of aftershocks (B) and sigma (Σ) types with an a priori selection of their parameters. In particular, these precursors were generated by the Haicheng earthquake in 1975 (M = 7.4) together with its aftershocks.

Certain long-range seismological precursors of earthquakes in Northeastern China are examined in this work. This region (Fig. 1) includes an example of an exceptionally successful prediction of an earthquake in 1975 with M = 7.4 in Haicheng, and here also occurred an earthquake in 1976 with M = 7.9 in Tangshan. The experience of predicting earthquakes in this region is presented in detail in [1,2]. The question of whether the three earlier described long-range precursors - "bursts of aftershocks" (B) [3,4], "swarms" (S) [5], and "sigma" (Σ) [6]) - are applicable in the indicated region is investigated in this work. Their definition is given in the Appendix.

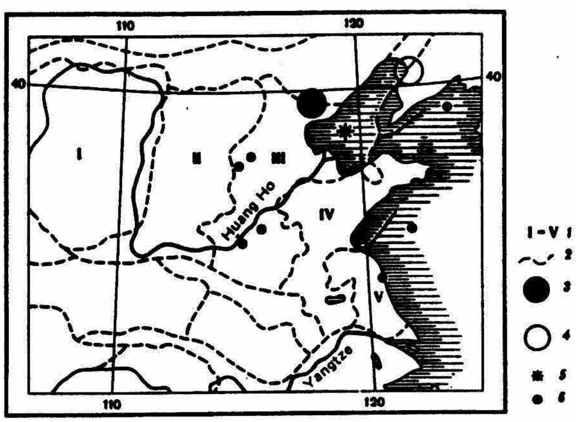

Fig. 1. Structures and strong earthquakes of the North China platform zone. 1) Numbers of structures, according to [7]: I) Ordos Desert, II) Shanxi massif, III) North China depression, IV) Shandong uplift, V) East China basins; 2) boundaries of structures; 3-6) epicenters, according to [9]: 3) M = 7.9, 1976, Tangshan, 4) M = 7.4, 1975, Haicheng, 5) 7.0 ≤ M ≤ 7.3, 6) 6.5 ≤ M ≤ 6.9; 7) boundary of investigated region.

The boundaries of the region were selected on the basis of seismicity and tectonics. According to [7,8], it occupies the eastern (expanded) part of the North China activated platform. The western part of the region is composed of the Ordos Desert separated by a system of grabens in Shanxi from the elevated step in Shanxi. To the east is located the North China depression, including the elevated Shandong massif. These structures are separated by faults of a northeastern direction: the Shanxi system of grabens, a fault between the Shanxi platform and plain, and a fault bordering the Yellow Sea and western Korea Bay on the west. Strong earthquakes are confined here to the North China depression. Possible ambiguity in drawing the boundaries of the depression does not affect the results, since it is surrounded by weakly seismic regions (see Fig. 1).

The unique catalogs of earthquakes of past centuries in the territory of China [8,9], unfortunately, cannot be used in our work, since they are insufficiently representative for detecting bursts of aftershocks, which is seen from Table 1. We therefore use catalog [10], which is sufficiently complete, with the possible exception of 1960.

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Table 1

Statistics of Strong Earthquakes According to [8,9]

Magnitude	Up to XV cent.	XVI cent.	XVII cent.	XVIII cent.	XIX cent.	XX cent. (to 1976)
6,0–6,5	19	7	10	3	5	18
6,6–7,0	5	3	3	1	4	7
7,1–7,5	2	1	–	–	2	4
> 7,6	1	1	3	1	–	1
> 6,0	27	12	16	5	11	30

Table 2

Parameter	B	S	Σ
$R(M)$, km	50; 100	–	–
$T(M)$, year	2	2	2
H_1, km	0	0	0
H_2	100	100	100
ϵ_1	0,1	0,1	0,5
ϵ_2	1,0	2,0	2,0
ϵ_3	3,4	–	–
S, year	–	1	1–3
C_1	–	3	–
C_2	–	1	–
C_3	–	0,5	–
f	–	–	0,91
d	–	–	4,5
τ, year	3	3	3
e, hr	48	–	–

Table 3

Date	Coordinates		M	b_i	δT, year	δL, km
	φ, deg	λ, deg				
1966.III. 7	37,3	114,9	6,8	6	10,39	370,1
1966.III. 22	37,6	115,2	6,9	6	10,35	327,4
1975.II. 4	40,64	122,58	7,4	9	1,48	406,1
1976.VII. 27	39,57	117,97	7,9			

Here φ, λ are the latitude and longitude of the epicenter, deg.; M, the magnitude; b_i, the number of aftershocks in the first two days; δT, the time from the precursor to a strong earthquake, years; δL, the distance between the precursor and earthquake, km.

This compels us to be especially careful of a posteriori adjustment of the numerical parameters entering into a determination of precursors. We took the same values of all parameters, except two, as when testing the examined presursors in [11] (these values are given in Table 2). We were forced to select two parameters a posteriori: M_0, the minimum magnitude of the earthquakes being predicted, and the threshold $\overline{B}$ for diagnosing bursts of aftershocks. The results of detecting the precursor burst of aftershocks (B) are shown in Fig. 2 and Table 3.

The best results are obtained when M_0 = 7.9 (see Fig. 1): a burst of aftershocks precedes the 1976 earthquake with M = 7.9 during 1.5 years. The probability that large values of b_1 occur independently of strong earthquakes is about 1/3, so that it cannot be ignored. However, our task does not include an estimation of the significance of precursor B - we postulate it on the basis of the experience of preceding works. We could formally increase the estimate of the significance of precursor B to 90% by including the period from 1900 to 1960 in the investigation. During this period the catalog does not contain either strong earthquakes or bursts of aftershocks (they would give false alarms), but we do not have confidence in the completeness of the catalog prior to 1960.

The described results are stable to the selection of all parameters except M_0. Having reduced M_0 to 7.4, we obtain a miss of the target and a false alarm in 1966. There are no a priori grounds to assume M_0 = 7.9, especially as the possibility of earthquakes with M = = 7.9 was not evident in the given region prior to the 1976 earthquake [1].

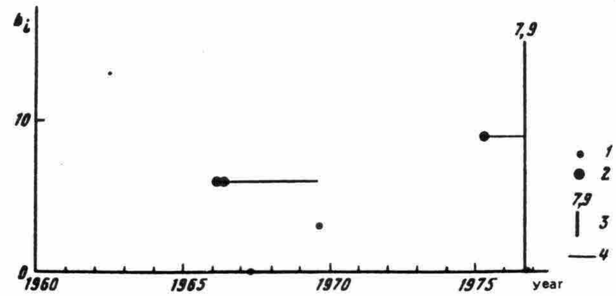

Fig. 2. Bursts of aftershocks B and strong earthquakes of the North China platform zone. 1, 2) Main shocks: 1) $b_i < 6$; 2) $b_i \geq 6$; 3) time and magnitude of strong earthquake; 4) alarm interval.

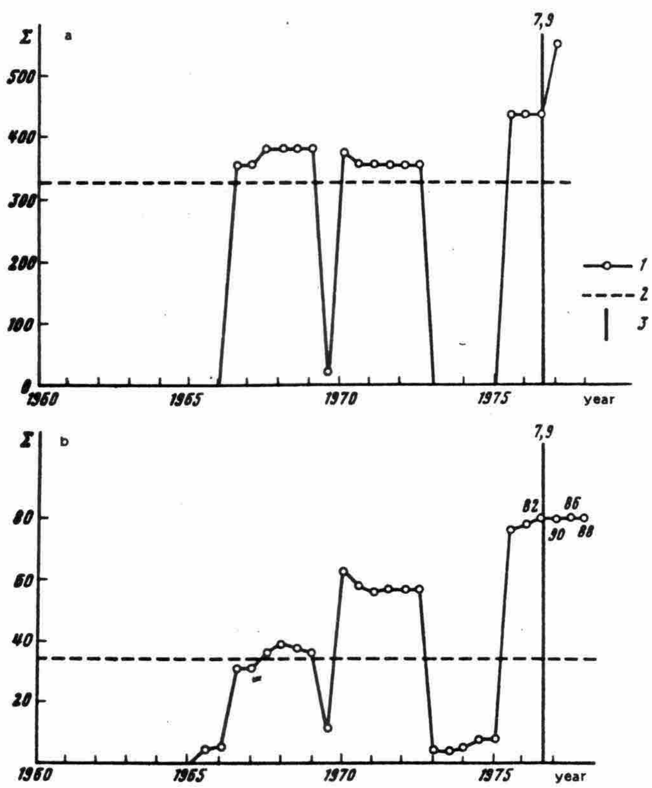

Fig. 3. Diagnosis of precursor sigma (Σ). a) $\beta = 0.91$; b) $\beta = 0.6$; 1) $\Sigma(t)$; 2) a priori $\bar{\Sigma}(t) = 0.5\ G(\bar{M}_0)$; 3) time and magnitude of strong earthquake.

The precursor Σ gives similar results (Fig. 3), in this case the threshold for detecting the precursor $\bar{\Sigma} = 0.5 \cdot B(\bar{M}_0) = 330$ is a priori. We investigated the stability of this precursor relative to parameter β in the definition of function Σ (see Appendix). This was due to the need to check the stability of the precursor relative to the magnitude scale. The results for $\beta = 0.6$ are shown in Fig. 4. They did not change.

When calculating precursor Σ we used the value of magnitude M_S. It is necessary to stipulate that variations in the magnitudes can shift the maximum of Σ in 1975 below the a priori threshold, although qualitatively the graph of Σ does not change.

In statistical tests we should consider the maximum of Σ in 1966 as a false alarm. It is interesting to note that in [6] the peaks of Σ were observed for 8-15 years before earthquakes with magnitude 7.6-8.0. However, in [4] the peaks of Σ were distinguished 3-4 years ahead of time. It is not precluded that the maximum of Σ in certain cases occurs twice: as a very long-range and then as a long-range-precursor. A similar circumstance was noted in [12]. But this assumption has to be checked in a sufficient number of other regions.

The precursor S gives exactly the same results as precursor B, since both detected swarms in the given case are formed by aftershocks.

We examined the possibility of detecting the same precursors from the catalog of earthquakes in China [8,9]. For precursor Σ the results are completely analogous, but these catalogs do not contain aftershocks of the 1975 earthquake in Haicheng, which is why it is impossible to detect precursors B and S.

The relative location of precursors and the epicenter of the earthquake making ready arouses increased interest; many precursors are often at a considerable distance from the earthquake getting ready. Precursors of earthquakes with a magnitude M were observed at a distance up to $10^{0.43M}$ km. This circumstance was noted both for the precursors examined above and also for many other precursors.

APPENDIX. DEFINITION OF PRECURSORS B, S, Σ

We denote: t, the time of the earthquake; φ, λ and h, respectively, the latitude, longitude, and depth of the focus; M, magnitude. We will denote by the subscript j the serial number of the earthquake in the catalog in the order of increasing time ($t_j < t_{j+1}$).

We will examine precursors of earthquakes with $M \geq M_0$; such earthquakes are called strong.

We will use the following rule for intensifying aftershocks. We will examine two earthquakes with serial numbers i and k, i < k. The second earthquake will be considered an aftershock of the first when the following conditions are fulfilled: the distance between their epicenters is not more than $R(M_i)$,

$$t_k - t_i < T(M_i), \quad |h_k - h_i| < H(M_i), \quad M_k < M_i, \tag{1}$$

where T(M), R(M), H(M) are empirical functions [3].

Applying this definition to the catalog of earthquakes, starting from the first, we will divide the catalog into main shocks and their aftershocks. The first earthquake will always be identified as the main shock. Each subsequent main shock will be identified as after excluding the aftershocks of the preceding main shocks. We will denote the serial number of the main shocks by the subscript i. This definition of aftershocks is rough, but it is sufficient for our purposes.

Earthquakes are examined in the depth interval

$$H_1 < h < H_2. \tag{2}$$

We will now formulate the definition of each precursor.

"**Bursts of aftershocks**" (B) [13]. We will examine the main shocks in the interval of magnitudes

$$\bar{M}_2 \equiv \bar{M}_0 - a_2 < M < \bar{M}_0 - a_1 \equiv \bar{M}_1 \tag{3}$$

and aftershocks in the interval of magnitudes

$$M_i > M > \bar{M}_0 - a_3 \equiv \bar{M}_3 \quad \text{or} \quad M_i > M > M_i - m, \tag{4}$$

where M_i is the magnitude of the i-th main shock; a_1, a_2, a_3, and m are numerical coefficients. In certain cases we will require that the aftershocks satisfy simultaneously the two equalities (4).

We will denote by $b_i(e)$ the number of aftershocks of the i-th main shock during time interval e after this shock, i.e., the interval from t_i to $(t_i + e)$. Precursor B is determined by the condition

$$b_i > \bar{B},\qquad (5)$$

where $\bar{B}$ is a certain threshold.

"Swarm" (S) [5,14]. We will examine earthquakes in magnitude interval (3). The values of parameteters a_1 and a_2 can be different from those which are taken for precursor B.

We denote: N(t), the number of earthquakes in the time interval from (t - s) to t; n(t) is obtained from N(t) by excluding aftershocks of strong ($M \geq M_0$) earthquakes.

Let us examine the map of the epicenters of earthquakes which are included in n(t). From this map we determine a third function: r(t), the maximum number of earthquakes whose epicenters can be enclosed inside a rectangle of size $\Delta\varphi°$ in latitude and $\Delta\lambda°$ in longitude.

Precursor S is determined by the conditions

$$\begin{aligned} &n(t) > \max\{C_1, C_2\ \bar{N}(t)\},\\ &r(t) > C_3 n(t), \end{aligned}\qquad (6)$$

where C_1, C_2, and C_3 are given thresholds; $\bar{N}(t)$ is the mean value of N(t) in the interval from t_0 to t or in the moving interval from (t - ks) to t, depending on the length and uniformity of the catalog.

"Sigma" (Σ) [6]. As before, we will examine earthquakes in magnitude interval (3) and in time interval from (t - s) to t. The values of a_1, a_2 and s can be different than for the preceding precursors.

Let us examine the function $\Sigma(t) = \Sigma G(M_i)$, where G(M), the weight of the earthquake with magnitude M, is taken in the form $G(M) = 10^{f(M-d)}$, where f and d are numerical parameters. Precursor Σ is determined by the condition

$$\Sigma(t) = \bar{\Sigma}.\qquad (7)$$

In [6] $\Sigma(t) = 0.5G(\bar{M}_0)$ was taken.

The values of the parameters presented above are given in Table 2.

An alarm (more exactly, an increase of the probability of a strong earthquake) is sounded for the period τ years after the detection of one of the precursors or a certain combination of them, depending on the experience of retrospective prediction in the given region. An alarm ends after the first strong earthquake. If it does not occur during τ years, the alarm is considered false and is removed.

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