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RECURRENCE PERIODS AND MIGRATION CHARACTERISTICS OF GREAT EARTHQUAKES IN NORTH CHINA

WANG Hualin
(*Seismological Bureau of Shandong Province, Jinan* 250021)
ZHANG Jie
(*Earthquake Research Institute of Lanzhou, CSB, Lanzhou* 730000)
LI Haiquan
(*Seismological Bureau of Anqiu City, Anqiu* 262100)
YAN Nailing
(*Seismological Bureau of Shandong Province, Jinan* 250021)

Abstract

Taking paleoearthquakes, historic and recent earthquakes as time domains, and North China, Shanxi seismic zone, Hebei plain seismic zone and Tancheng-Lujiang seismic zone as units, authors analyze and study the recurrence intervals and migration characters of great earthquakes in North China. On this basis, a dynamic problem of seismic activity, block frame motion, earthquake migration and seismicity trend in North China are discussed.

Key words **North China**, **Earthquake recurrence period**, **Earthquake migration**, **Seismicity trend**, Block frame motion

1 Introduction

Study of recurrence interval and migration characteristics of great earthquakes is of great importance in earthquake monitoring and prediction, seismic risk analysis and seismic zoning.

Many studies on recurrence cycle and migration characteristics of great earthquakes in North China[1-10] were made and several meaningful results were obtained. But among these studies some were restricted in investigation of paleoearthquakes on a specific seismogenic fault, others put emphasis on historic and recent earthquakes. These studies are only local and incomplete in temporal and spatial domains of earthquake activity. Paleoseismological study can extend the history of seismicity in a region; records of recent earthquakes provide information of focal dislocation force; and data of historic earthquakes represent a link between recent earthquakes and paleoearthquakes and hence a complete seismic data set is formed. Based on this consideration, the paleoearthquakes, historic and recent earthquakes are taken as time domains and the North China block confined by the Tancheng-Lujiang, Hebei plain and Shanxi seismic zones is taken as spatial domains and these seismic zones are taken as the units for the study. Then the recurrence interval and migration characteristics of great earthquakes in North China are studied in order to have more systematic and complete understanding of great earthquake activity in North China.

2 Recurrence Cycle of Great Earthquakes

In North China, $M \geqslant 7$ earthquakes provide criteria for identifying geological evidence and characteristics of paleoearthquakes which were recorded in historical literature. Thus, $M \geqslant 7$ earthquakes are studied in the paper. The distribution of exposed paleoearthquakes, $M_S \geqslant 7$ historic earthquakes and recent earthquakes in North China are shown in Fig. 1. Totally 27 geeat earthquakes have been recorded in the North China since 70 B. C. (in Table 1), including 15 historic and 6 recent earthquakes. Of them 7 earthquakes occurred in Tancheng-Lujiang seismic zone, 6 in Hebei plain seismic zone, and 8 in Shanxi seismic zone. In addition, many paleoseismic events were found on the Tancheng, Yidu, Huaxian, northern Huailai-Zhulu basin border, Yuhuangmiao-Xiyangfang, Hongtong, northern Wutai piedmont, Heze, Sanhe-Pinggu, Tangshan and Haicheng seismic faults (Fig. 1). The paleoseismic events and their recurrence cycles are given in Table 2.

A comprehensive analysis of data in Fig. 1, Table 1 and Table 2, and results of previous researches enables us to find the recurrence cycle characters of great earthquakes in North China as follows.

Table 1 Historic and recent $M_S \geqslant 7$ earthquakes in North China

No.	Occurrence time	Epicentral location			Magnitude	Seismogenic fault		Recurrence
		°N	°E	Place name	(M)	Strike	Nature	interval (a)
1	1976-07-28	39.7	118.5	Luanxian, Hebei	7.1	NE	Dextral, normal	
2	1976-07-28	39.4	118.0	Tangshan, Hebei	7.8	NE	Dextral, normal	0
3	1975-02-04	40.7	122.7	Haicheng, Liaoning	7.3	NW	Sinistral, normal	1
4	1969-07-18	38.2	119.4	Bohai Sea	7.4	NNE	Dextral	6
5	1966-03-22	37.5	115.1	Ningjin, Hebei	7.2	NE	Dextral, normal	3
6	1937-08-01	35.4	115.1	Heze, Shandong	7.0	NE	Dextral, normal	29
7	1888-06-13	38.5	119.0	Bohai Sea	7%	NE	Dextral, normal	59
8	1830-06-12	36.4	114.3	Cixian, Hebei	7%	NE	Dextral, normal	58
9	1695-05-18	36.0	111.5	Linfen, Shanxi	8.0	NE	Dextral, normal	135
10	1683-11-22	38.7	112.7	Yuanping, Shanxi	7.0	NE	Dextral, normal	12
11	1679-09-02	40.0	117.0	Sanhe-Pinggu, Hebei	8.0	NE	Dextral, normal	4
12	1668-07-25	34.8	118.5	Tancheng, Shandong	8%	NNE	Dextral, normal	11
13	1626-06-28	39.4	114.2	Lingqiu, Shanxi	7.0	NEE	Normal	42
14	1597-10-06	38.5	120.0	Bohai Sea	7.0	NE		29
15	1556-01-23	34.5	109.7	Huaxian, Shaanxi	8.0	NE	Normal	41
16	1548-09-12	38.0	121.0	Bohai strait	7.0	NW		8
17	1501-01-19	34.8	110.1	Chaoyi, Shaanxi	7.0	NE		47
18	1303-09-17	36.3	111.7	Hongtong, Shanxi	8.0	NNE	Normal	198
19	1038-01-09	38.4	112.9	Dingxiang, Shanxi	7½	NE		265
20	512-05-21	38.9	112.8	Yuanping-Daixian, Shanxi	7%	NNE	Normal	526
21	B.C. 70-06-01	36.3	119.0	Zhucheng-Changle, Shandong	7.0	NW	Sinistral, normal	582

Table 2 The exposed paleoseismic events and recurrence cycles of great earthquakes in North China

Name of fault	Date of paleoearthquake	Magnitude (M)	Recurrence cycle of great quake (a)	Note
Hongtong earthquake fault	A. D. 1303	8. 0		From Xu Xiwei et al. [11]
	3 015 a B. P. (2 555-3 475 a B. P.)	8. 0	2 325	
	5 038 a B. P. (4 620-5 455 a B. P.)	8. 0	2 015	
Huaxian earthquake fault	A. D. 1556	8. 0		From Zhang An-liang et al. [13]
	2 750 a B. P. (2 500-3 000 a B. P.)	8. 0	2 323	
	4 250 a B. P. (4 000-4 500 a B. P.)	8. 0	1 500	
	7 288 a B. P.	8. 0	3 038	
Tancheng earthquake fault	A. D. 1668	8%		From Lin Weifan et al. [6]
	3 500 a B. P. (3 000-4 000 a B. P.)	8-8%	3 174	
	7 000 a B. P. (6 500-8 400 a B. P.)	8%	3 500	
	11 000 a B. P. (10 000-12 000 a B. P.)	8%	4 000	
Fault along northern border of Huailai-Zhulu basin (XH segment)	less than 1 600 a B. P.	7-7%		From Ran Yongkang et al. [14] A paleoseismic event at about 3 000 a B. P. (2 000-4 000 a B. P.) was exposed on XX and JH segments besides XH segment.
	about 6 700 a B. P.	7-7%	5 000	
	about 14 500 a B. P.	7-7%	7 800	
Yuhuangmiao-Xiyangfang fault	5 767 a B. P.	7. 8	more than 5 765	From Cheng Shaoping et al. [15]
	10 880 a B. P.	7. 8	5 115	
Tangshan earthquake fault	A. D. 1976	7. 8		From Wang Tingmei et al. [3] Since 2 500 a B. P., no large earthquake have been recorded.
	7 665 a B. P.	7% -8	7 640	
	14 865 a B. P.	7% -8	7 200	
Sanhe-Pinggu earthquake fault	Since 15 500 a B. P., only a M 8 quake occurred in 1679. Empirical formula gives recurrence cycle of M 7% earthquake.	7%	3 800-8 000	From Xiang Hongfa et al. [7]
Haicheng earthquake fault	A. D. 1975	7. 3		Han Dianzhong et al. [8]
	5 872 a B. P.	7-7%	5 850	
Northern Mt. Wutai piedmont fault	Since 7 000 a B. P., two paleoseismic events occurred besides M 7% quake in 512.	7%	3 230	Liu Guangxun et al. [16]

续表 2

Name of fault	Date of paleoearthquake	Magnitude (M)	Recurrence cycle of great quake (a)	Note
Heze earthquake fault	A 0.7 m offset of sediments at 5 800 a B. P. may result from 1937 Heze M7 earthquake. A 2.7 m offset of sediments at 20 400 a B. P. may result from 4 M7 earthquakes.	7	5 130	Wang Hualin et al.[17]
Yidu fault	An offset of sediments at 7 000 a B. P. is a product of the 70 B. C. Zhucheng–Changle earthquake. A 2 m offset at 17 360 a B. P. was calculated to be a product of 3 M7 seismic events.	7–7½	5 800	Wang Hualin et al.[18]
Bohai seismic fault zone	In Bohai seismic zone, 3 m, 6 m and 12 m offsets may result from intermittent stick-slip fractures since the Holocene.	7–7½	3 000–4 000	Hu Zheng et al.[19]

(1) The recurrence cycle of great earthquakes in North China has zonal characteristics. Earthquake recurrence periods in Shanxi, Hebei plain and Tancheng–Lujiang seismic zones are different from each other. The recurrence interval of paleoearthquakes on a single fault in Shanxi seismic zone is 2 000 a, 3 000–4 000 a on a single fault in Tancheng–Lujiang fault sone, and 5 000–7 000 a on a single fault in Hebei plain seismic zone, indicating that in North China, the seismic activity is strongest in Shanxi seismic zone, strong in Tancheng–Lujiang seismic zone and relatively weak in Hebei plain seismic zone.

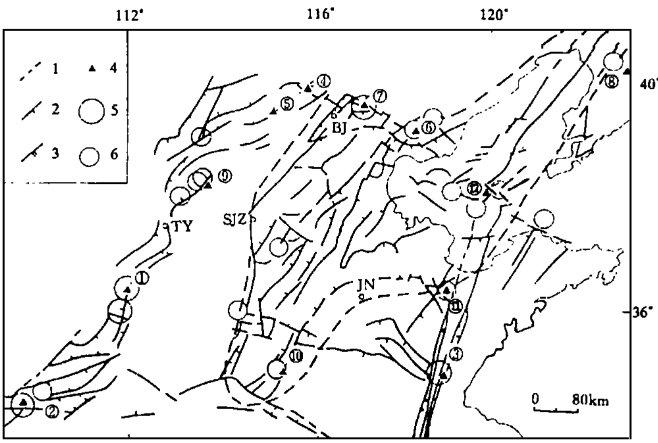

Fig. 1 Distribution of great earthquakes ($M_S \geq 7$) and exposed paleoearthquakes in North China.
1 Active fault; 2 Normal fault; 3 Thrust fault;
4 Paleoearthquake site; 5 $M \geq 8$; 6 $7.0 \leq M \leq 7.9$;
① Hongtong earthquake fault; ② Huaxian earthquake fault; ③ Tancheng earthquake fault; ④ Fault along northern border of Huailai–Zhulu basin; ⑤ Yuhuangmiao–Xiyangfang fault; ⑥ Tangshan earthquake fault; ⑦ Sanhe–Pinggu earthquake fault; ⑧ Haicheng earthquake fault; ⑨ Northern Mt. Wutai piedmont fault; ⑩ Heze earthquake fault; ⑪ Yidu fault; ⑫ Bohai seismic fault;
BJ Beijing; TY: Taiyuan; JN: Jinan; SJZ Shijiazhuang

(2) Earthquake intensity and recurrence interval are related with fault orientation, nature and deep structural conditions. The NNE– and NE–trending dextral strike–slip faults are

characterized by stronger seismic intensity and shorter recurrence interval; the NW-trending faults show their lower seismic intensity and longer recurrence interval. The seismogenic faults parallel with the trend of upper mantle upwelling zone show stronger seismic intensity and shorter recurrence interval, and those vertical to the upper mantle upwelling zone show lower seismic intensity and longer recurrence interval. For example, the NNE-trending seismogenic fault of Tancheng-Lujiang fault zone has recurrence interval of 3 000-4 000 a for $8 \le M \le 8\frac{1}{2}$ earthquakes and is parallel to the upper mantle upwelling zone[20]. The NW-trending Haicheng seismic fault has recurrence interval of 5 000 a for M 7 earthquakes and is vertical to the upper mantle upwelling zone[20].

(3) A large earthquake occurs every 40 a in a seismicity period, every 20 a in a seismicity episode, and every 2-7a in a time interval of an earthquake cluster. Three areas where large earthquakes occurred repeatedly in North China are: the Bohai Sea area in which two large earthquakes occurred in time interval of 81-291a, Linfen basin in which two large earthquakes occurred in time interval of 392a, and Weihe basin in which two large earthquakes occurred in time interval of 55a.

(4) The seismicity episodes are defined only from data of historic and recent earthquakes (Fig. 2) because of some uncertainties in dating of paleoseismic events. The recent seismicity period is determined from 1038 to now (the 70 B. C. M 7 earthquake and A. D. 512 M $7\frac{1}{2}$ earthquake are regarded as individual events in a seismically quiet period). The seismicity period can be divided into early activity, main activity and late activity episodes. The early activity episode is from 1038 to 1337, during which energy release is $6.78272416 \times 10^{16}$ J. The main activity episode is from 1484 to 1720, during which 1556 Huaxian M 8 earthquake, 1668 Tancheng M $8\frac{1}{2}$ earthquake, 1679 Sanhe-Pinggu M 8 earthquake and 1695 Linfen M 8 earthquake occurred with energy release of $4.17229634 \times 10^{17}$ J. The late episode is from 1815 to now, during which 1830 Cixian M $7\frac{1}{2}$ earthquake, 1888 Bohai M $7\frac{1}{2}$ earthquake and 1976 Tangshan M 7.8 earthquake occurred with energy release of $7.64245595 \times 10^{16}$ J. The energy release in main activity episode is as much as 6-7 times over those in early and late episodes. Analysis of seismicity period, episodes and intervals indicates that now the North China is in a time after the late seismicity episode.

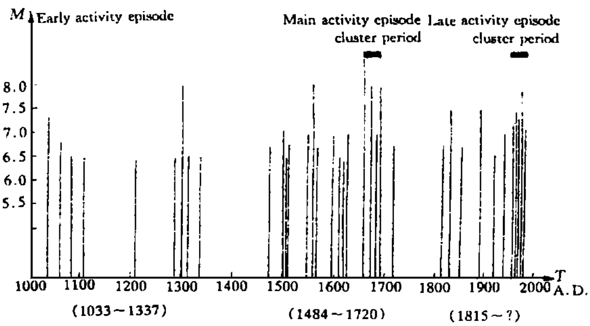

Fig. 2　Division of recent seismicity period into episodes and intervals in North China.

3　Characteristics of Earthquake Migration

Earthquake migration is determined from complete seismic data in a certain time domain. The seismicity period from 1038 to now is taken as a time domain and the Shanxi, Hebei plain, Tancheng-Lujiang and Yanshan-Bohai seismic zones in the North China are taken as units for study in this paper. For these zones the characteristics of earthquake migration in the seismicity period, three episodes, and time intervals of two earthquake clusters are discussed respectively. Analysis of earthquake migration patterns (Fig. 3 and Fig. 4) enables us to find the following characteristics of earthquake migration in North China.

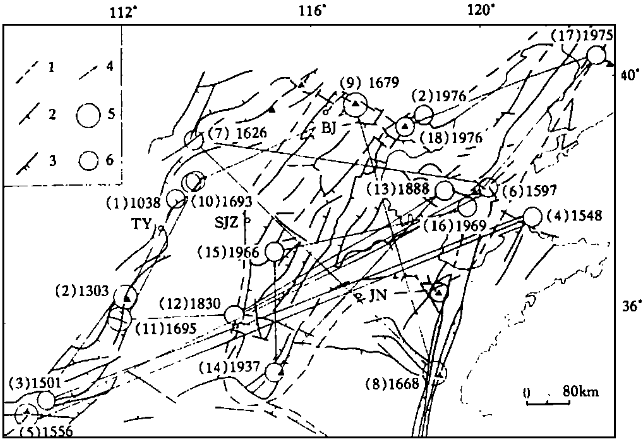

Fig. 3 Earthquake migration pattern in North China during the last seismicity period.
1 Active fault; 2 Normal fault; 3 Thrust fault; 4 Migration direction; 5 $M \geq 8$; 6 $7.0 \leq M \leq 7.9$;
BJ Beijing; TY: Taiyuan; JN: Jinan; SJZ: Shijiazhuang

(1) During the last seismicity period the earthquake activity migrated from west to east and from Shanxi to Hebei and Tancheng-Lujiang seismic zones. During the early seismicity episode earthquakes occurred only in Shanxi seismic zone. During main seismicity episode earthquakes migrated from the southern segment of Shanxi seismic zone, expressing alternative occurrence at vertex angles of fault blocks in Shanxi and Tancheng-Lujiang seismic zones and forming a five-pointed star pattern, and eventually stopped at the middle segment of Shanxi seismic zone, then a completely closed migration pattern is formed (Fig. 3). During the late seismicity episode from 1815 to now, earthquakes migrated from the southern segment of Hebei plain seismic zone along the vertex angles of fault blocks between Hebei and Tancheng-Lujiang seismic zones, forming a rhombic migration pattern. Recently, earthquakes migrated to the northern segment of Hebei plain seismic zone. So a completely closed migration pattern is formed (Fig. 3).

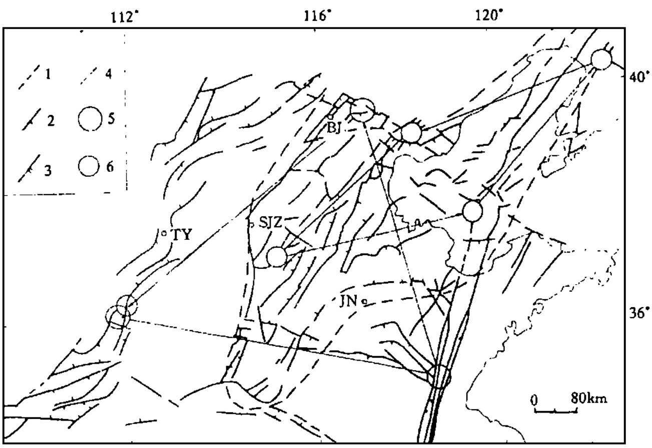

Fig. 4 Earthquake migration pattern during seismicity intervals for two earthquake clusters in North China.
1 Active fault; 2 Normal fault; 3 Thrust fault; 4 Migration direction; 5 $M \geq 8$; 6 $7.0 \leq M \leq 7.9$;
BJ Beijing; TY: Taiyuan; JN: Jinan; SJZ: Shijiazhuang

(2) A time interval for an earthquake cluster in main seismicity episode is defined from 1668 to 1695. During this time interval four M 7 earthquakes occurred in 1668, 1679, 1683 and 1695 separately. The earthquakes migrated from Tancheng-Lujiang seismic zone to Hebei plain and Shanxi seismic zones. Three M 8 earthquakes occurred at the sites which formed a

triangle, and migrated anticlockwise from one to another site (Fig. 4) at an equal distance about 600 km.

Another time interval for an earthquake cluster is from 1966 to 1976, during which the 1966, 1969, 1979 and 1976 great earthquakes occurred. They migrated from Hebei plain seismic zone to Tancheng–Lujiang seismic zone, eventually to Hebei plain seismic zone, forming an equilateral rhombus (Fig. 4). The earthquakes migrated anticlockwise along the vertices of the rhombus at distance about 400 km.

(3) In North China, earthquakes migrated anticlockwise in the early and main seismicity episodes of the last seismicity period and clockwise in the late seismic episode. The main seismicity episode and the intervals for two earthquake clusters are characterized by anticlockwise migration. The 512, 1038, 1303, 1501 and 1556 earthquakes in Shanxi seismic zone migrated from north to south, and the 1626, 1683 and 1695 earthquakes migrated also anticlockwise from north to south. In Yanshan–Bohai seismic zone, the 1548, 1597 and 1679 earthquakes migrated from east to west in main seismicity episode and the 1969 and 1976 earthquakes did anticlockwise from east to west in the late seismic episode. Four M 8 earthquakes (1556, 1668, 1679 and 1695) in main seismicity episode migrated anticlockwise. In Tancheng–Lujiang seismic zone, earthquakes in main seismic episode migrated anticlockwise from north to south and earthquakes in late seismicity episode migrated mainly clockwise. Large earthquakes occurring on the same seismogenic fault of Shanxi seismic zone migrated anticlockwise. For instance, the 1303 and 1695 earthquakes migrated from north to south, and the 512 and 1030 earthquakes migrated also from north to south. Earthquakes in Hebei plain seismic zone migrated clockwise, such as the 1937 Heze M 7 and M $6\frac{3}{4}$ earthquakes migrated from south to north and 1976 Tangshan M 7.8 and Luanxian M 7.1 earthquakes migrated also from south to north.

(4) Large earthquake migration is characterized by gap filling during a seismicity period. The positions for gap filling are the network nodes formed from the intersections of NNE- and NE-trending and NW-trending faults or the vertex angles of different-order blocks. The gap filling formed five-pointed star, triangle or rhombus migration patterns. Large earthquakes migrated along the vertex angles of these geometric patterns. It seems that earthquakes in every seismicity episode could form a complete geometric migration pattern, which marks an end of a seismicity episode or interval. The earthquakes in North China migrated from the southwestern vertex angle to northeastern vertex angle (in Bohai megaseism area) of the block in main and late seismicity episodes, indicating that the Bohai megaseism area is a sensitive seismic area.

4 Discussion on the Related Problems

Summarizing the described above, we can recognize the following characteristics of large earthquake activities in North China.

(1) The recurrence interval is the shortest (2 000–2 500 a) in Shanxi seismic zone, longer (3 000–3 500 a) in Tancheng–Lujiang seismic zone and the longest (5 000–7 000 a) in Hebei plain seismic zone. The NNE- and NE-trending faults are characterized by higher seismic intensity and shorter interval and the NW-trending faults by lower seismic intensity and longer interval.

(2) Seismic activity in Shanxi seismic zone is higher than that in Hebei plain seismic

zone. The seismic intensity is higher in eastern and western parts and relatively lower in the middle part of North China.

(3) Seismogenic faults in Shanxi seismic zone are dextral normal faults with large displacement (10.4 m). The faults in Hebei plain seismic zone are also dextral normal faults with small displacement. The faults in Tancheng-Lujiang seismic zone are dextral thrust or normal faults with large displacement (8–10 m).

(4) Large earthquakes in North China migrated generally from west to east and mainly along vertex angles of the block. Earthquakes migrated anticlockwise (sinistrally) in early and main seismicity episodes and clockwise in late seismicity episode.

Some problems concerned with earthquake places in North China are discussed as follows.

4.1 Dynamic Problem of Earthquake Activity in North China

The reduction and migration of fault and earthquake activities in North China reflect a dynamic process of crustal movement. The mode of stress action determined the nature of fault movement, the earthquake reduction and migration. In general, tectonic stress can accumulate and release on the fault near tectonic force, but activity of the another fault parallel to it delays or reduces[21]. The seismicity in North China reduces from its eastern and western parts to middle part, indicating that faulting and seismicity in the region took place firstly in its eastern and western parts and then migrated eastward. It is shown that stress from west could control the seismicity in the region. The movement nature of seismogenic faults in Shanxi, Hebei plain and Tancheng-Lujiang seismic zones shows the existence of sub-latitudinal tensile force in the middle part of North China, Hebei plain seismic zone.

Based on these facts, we can formulate a dynamic model for faulting and seismicity in North China. A combining action of the stress transmitted by subduction of Indian plate beneath Eurasian plate and collision of Pacific plate with Eurasian plate and the tensile stress generated by upwelling of the upper mantle in the North China fault depression constitutes the dynamic process of faulting and seismicity in North China. Shanxi seismic zone is mainly affected by the stress generated by eastward squeezing of Qinghai-Xizang crust. The southern end of Shanxi seismic zone and the Fenwei graben were in the front of stress action[22]. Thus, three M 8 earthquakes occurred along the periphery of Fenwei graben. The join line of the southern end of Shanxi seismic zone, the southern end of Hebei plain seismic zone and the Bohai area of Tancheng-Lujiang seismic zone is consistent with the orientation of stress front and hence caused earthquake migration from the southwestern part affected by near stress to the northeastern part affected by far stress. Tancheng-Lujiang seismic zone is mainly affected by the stress generated by collision of Pacific plate with Eurasian plate. The stress is transmitted from east to west, releases firstly in Tancheng-Lujiang seismic zone, and then transmitted westward, and hence caused westward earthquake migration pattern in North China[23]. Hebei plain seismic zone is in the middle part of the region acted by stress from east and west. The parallel reduction led faulting and seismicity of the Hebei plain seismic zone to be generally weaker than those of the Shanxi and Tancheng-Lujiang seismic zones. Under the slow combination of stresses from east and west, the gradual upwelling of upper mantle materials forms upper mantle uplift zone, generates stress in the middle and upper crust, thus causes North China depression and seismogenic faults with tensile normal faulting.

4.2 Block Frame Motion and Earthquake Migration

In order to understand the characteristics of strong earthquake migration in North China, a concept of block frame motion is suggested in the paper. The principle of the concept is that in the process of fault movement the fault-confined block can rotate to a certain extent, causing stress change at vertex angles of the block and inducing earthquakes. The block confined by two dextral strike-slip faults rotates anticlockwise and the block confined by two sinistral strike-slip faults rotates clockwise. The major tectonic lines in North China are NNE-, NEE-, NWW-, and NNW-trending, their intersections make the North China form different-order bolocks (Fig. 5). The intersection of NNE- and NEE-trending tectonic lines formed two major NNE-oriented blocks in the east and the west. The NWW- and NW-trending tectonic lines further cut the eastern and western blocks into next-order blocks. The intersections of second-order NE- and NEE-trending tectonic lines made the blocks form lower order rhombic blocks. In North China, four $M \geqslant 8$ earthquakes occurred at the vertex angles of first-order bolcks, M 7 earthquakes occurred at the vertex angles of second-order blocks. Earthquake migration along the vertex angles of blocks reflects the characteristics of block motion. The vertex angles of different-order blocks are the intersection positions of faults in two or more directions. As the block moves, its vertex angle becomes sensitive position for stress accumulation and release. Thus, most earthquakes occurred at the vertex angles of the bolcks. The larger the block dimension, the higher the strain energy at its vertex angle. Therefore, larger earthquakes occurred at the vertex angles of first-order blocks, smaller earthquakes occurred at the vertex angles of lower-order blocks. As shown in Fig. 5, dextral strike-slip faulting in Shanxi, Hebei plain and Tancheng-Lujiang seismic zones led to anticlockwise rotation (frame motion) of the block confined by two faults. A rhombic block confined by the Xingtai, Bohai, Haicheng and Tangshan earthquakes rotated anticlockwise under the effect of dextral strike-slip movement of NNE- and NE-trending faults. The anticlockwise block frame motion (rotation) determined the anticlockwise migration of strong earthquakes along vertex angles of blocks in North China.

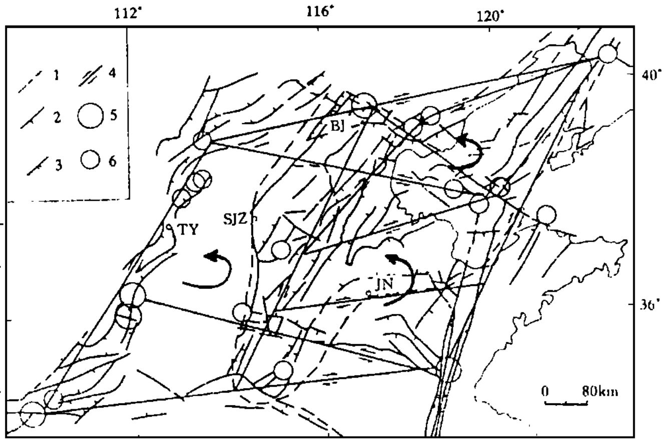

Fig. 5 Frame motion of different-order blocks and distribution of large earthquakes in North China.
1 Active fault; 2 Normal fault; 3 Thrust fault;
4 Block boundary and movement direction; 5 $M \geqslant 8$; 6 $7.0 \leqslant M \leqslant 7.9$;
BJ: Beijing; TY: Taiyuan; JN: Jinan; SJZ: Shijiazhuang

The characteristics of earthquake migration in North China reflect in a sense the frame motion of different-order blocks in the region. This block frame motion determines the migration pattern of earthquakes.

4.3 Prediction of Seismic Tendency in North China

On the basis of the study we can make a prediction of seismic tendency in North China from the aspects of seismicity period, episodes, recurrence interval, earthquake migration and gap filling.

T. Matsuda[24] has suggested a rate of earthquake time elapse (D):

$$D = A / T$$

where T is recurrence interval of great earthquakes, A is the elapsed time since the last earthquake. $A / T \geqslant 0.5$ is taken as a quantitative index for long-term prediction of earthquake recurrence risk. The D value for some seismogenic faults in North China is listed in Table 3. Analysis of data in Table 3 shows that the rate of earthquake time elapse only for Yuhuangmiao-Xiyangyu fault along the northern border of Yanqing basin is larger than 1. The earthquake risk must attract our attention because of the higher probability of earthquake occurrence. The rates of earthquake time elapse for Hongtong seismogenic fault, northern Huailai-Zhulu basin border fault, northern Mt. Wutai piedmont fault and Yidu fault are 0.3-0.4, do not reach 0.5, the rate of earthquake time elapse for seismic risk. The rates of earthquake time elapse for rest faults are smaller. Analysis of rates of large earthquake time elapses shows that the probability of earthquake occurrence is higher only for Yuhuangmiao-Xiyangyu fault on the northern border of Yanqing basin in North China.

Table 3 D values for some seismogenic faults in North China

Seismogenic fault	T(a)	A(a)	D value	Predicted risk
Hongtong fault	2 170	691	0.32	Fault with lower seismic risk
Huaxian fault	1 500-3 000	438	0.29-0.15	Ditto
Tancheng fault	3 000-4 000	326	0.1-0.08	Ditto
Northern border fault of Huailai-Zhulu basin	5 000-7 800	less than 1 600	0.32-0.215	Fault with certain seismic risk
Yuhuangmiao-Xiyangyu fault	5 100-5 700	5 700	more than 1	Fault with high risk
Tangshan fault	7 200-7 600	18	0.0025-0.0024	Fault without large earthquake risk
Sanhe-Pinggu fault	3 800-8 000	315	0.0955-0.0394	Fault with lower seismic risk
Haicheng fault	5 850	19	0.0032	Fault without large earthquake risk
Northern Mt. Wutai piedmont fault	2 330	956	0.4103	Fault nearing earthquake risk
Heze fault	5 130	57	0.111	Fault without large earthquake risk
Yidu fault	5 800	2 064	0.3559	Fault with certain seismic risk
Bohai fault	3 000-4 000	397	0.1323-0.993	Fault without large earthquake risk

Analysis of earthquake migration and gap filling in the last seismicity period indicates that the seismicity in North China has generally completed its full earthquake migration trajectory and formed a fully closed migration pattern. All vertex angles of different-order blocks have been subjected to $M \geqslant 7$ earthquakes except the zone around Yanqing basin where the Shanxi and Yanshan-Bohai seismic zones intersect and no M 7 earthquakes had occurred. Thus we predicted that the probability of a M 7 earthquake occurrence here is higher and consistent with that predicted from rate of earthquake time elapse. Division of seismicity period and analysis of stress release indicate that the North China is now in the late seismicity episode of the seismicity period and at the end of seismic energy release. A M $6\frac{2}{2}$ earthquake occurred 25a after time interval of earthquake cluster of the seismicity period. If the main seismicity episode can be analogous with the late seismicity episode, a $6\frac{0}{0} \leqslant M \leqslant 6\frac{2}{2}$ earthquake will occur 25 a after the time interval of 1966–1976 earthquake cluster in North China, i. e. before A. D. 2000.

Summarizing the above-described results, we suggest that individual M 7 earthquake may occur in North China in the future and the earthquake location may be the Yanqing basin zone where the Shanxi seismic zone intersects the Yanshan-Bohai seismic zone in the northwest.

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中国华北地区大地震复发周期及迁移特征

王华林
(山东省地震局,济南 250021)
张 杰
(中国地震局兰州地震研究所,兰州 730000)
李海泉
(山东省安丘市地震局,安丘 262100)
燕乃玲
(山东省地震局,济南 250021)

摘要

以古地震、历史地震和现代地震作为时间域,以华北地区、山西地震带、河北平原地震带和郯庐地震带为单元,分析和研究了华北地区大地震复发周期和迁移特征.在此基础上,讨论了华北地区地震活动的动力学问题、块体框动、地震迁移和地震活动趋势.

主题词 华北 地震复发周期 地震迁移 地震活动趋势 块体框动

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第一作者简介: 王华林,男,1958年 1月出生,副研究员,从事地震工程和地震地质研究工作.