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## Tectonic Background of the Wenchuan Earthquake

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### 1. Introduction

Since the occurrence of the Wenchuan Earthquake on May 12, 2008, several papers on its seismotectonics analysis have been published (Lei et al. 2009; Yue, 2010; Chen et al. 2009; Tang et al. 2009; Zhu et al. 2009). Although their opinions were not uniform, most authors believe that the source of the earthquake was the Central Longmen Mountain Range fracture with a length of about 230km. However, this hypothesis cannot explain the following phenomena: 1) the focus, of which the depth was provided by the State Seismological Bureau, cannot be projected to the central fracture but is located on the front range fracture; 2) the epicenter is not the center of the isoseismal contour; 3) the surface rupture along the front range fracture and its thrusting displacement are similar to the surface rupture and displacement along the central fracture, and 4) the area in which the aftershocks ( $M_s \geq 4.0$ ) occurred have a shape in the form of a '√'.

The ambiguity results from the complicated tectonic environment of northwestern Sichuan. People generally pay more attention to the large boundaries of the triangular block in northwestern Sichuan (SCNWTB in Fig 1), but neglect the effect of the Minshan block (MSB) in the geostress conditions. The present authors think the "bottle neck" geostress concentration in the Minshan block is the main controlling factor for the occurrence of the Wenchuan earthquake. The Minshan block is a sub-block of the northwest Block of Sichuan, it is bordered by Longmen Mountain Range fractures ((2) in Fig 1) in the south, the Huya fracture (5) in the east, the Maqin-Lueyang fracture in the north and the Mounigou Valley fracture (6) in the west. The block has been recognized earlier as an important tectonic element in the northwestern region of Sichuan (Tang et al. 2009; Jiang et al. 2004; Zhao et al. 1994a; Tang et al. 1991; Qian et al. 1999; Zhou et al. 2000). It not only includes the Minshan uplifted block in a narrow sense, but also the middle segment of the Longmen Mountain Range structural belt (Fig.1). Although the positions of the eastern and western block boundaries are still controversial, their existence and their recent activation are widely accepted. Analysis of seismological setting and the deformation data shows that the Minshan block has been activated by the north Mounigou Valley fracture ((6) in Fig 1) in the west, the Huya fracture (5) in the east, the back range fracture in the south and the Maqin-Lueyang fracture (1) in the north.

The whole middle segment of the Longmen Mountain Range structures has been strongly pushed along the southern boundary of the Minshan block since the Mesozoic. The Paleo-

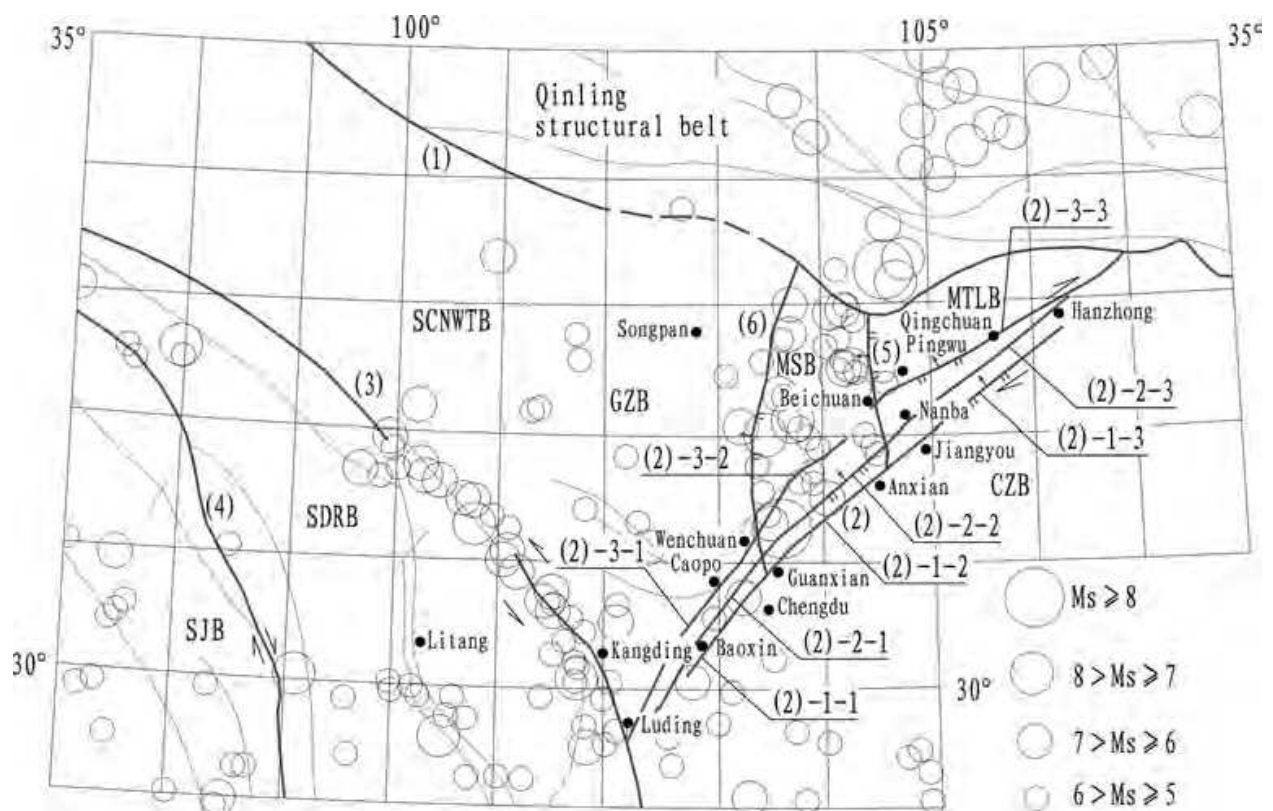
Peng(zhou)-Guan(xian) complex has been thrust over the lower Pleistocene, especially since the Quaternary. During this overthrusting, nappes in Longmenshan structural belt have been formed. The landform of the block shows a great contrast in elevation and relief. As a result of the uplifting of the Minshan block, strong erosion caused the deposition of a thick Quaternary accumulation in the Chengdu plain and formation of the Longquan mountain. Due to the repeated Minshan block lock-up→earthquake→geo-stress release (stick-slip) mechanism, the middle segment of the Longmen Mountain Range structural belt is more active than the southwestern and northeastern segments. The earthquake history of northwestern Sichuan reveals that the migration of seismicity in northwest Sichuan is around the Minshan block, and the seismic activities on the northern margin of the Minshan block created the conditions for the Wenchuan earthquake.

The aim of the Chapter is to present a new idea through the tectonic background analysis of Wenchuan earthquake, so that people pay more attention to the important role of the Minshan Block activities in the northwestern seismic tectonics.

## 2. The geological setting

### 2.1 The triangular block in northwestern Sichuan

The triangular block is bordered by the Longmen Mountain Range fractures in the south, the Maqin-Lueyang fracture in the north and the Xianshuihe fracture in the west (SCNWTB



(1) Maqin-Lueyang fracture; (2) Longmen Mountain Range fractures; (3) Xianshuihe Fracture, (4) Jinshajiang fracture; (5) Huya fracture; (6) Mounigou Valley fracture; SCNWTB: triangle block in the northwest of Sichuan; GZB: Ganzi Block; MSB: Minshan Block; FTLB: Motianling Block; CZB: central Sichuan block; CDRB: Chuan(Sichuan) -Dian(Yunnan) rhombic block; SJB: Sanjiang block

Fig. 1. Tectonic framework in the northwestern Sichuan

in Fig.1). The block used to be an ocean (geosyncline) and was folded and uplifted in the late Triassic. Pre-Cambrian rocks are outcropping in Pingwu county and Maowen county, they are composed of metamorphic intermediate-basic and intermediate-acid volcanic rocks, volcanic clastic rock, intercalated with little siliceous rock. Lower Proterozoic is outcropping along the boundary of the Block. Slightly metamorphic Devonian and Carboniferous clastic rocks and carbonates are exposed in the Pingwu-Maowen region; mainly composed of carbonate, intercalated with little volcanic rock in the south part of the Block. The Permian exposed near the northern boundary of the block (Animaqin) consists of flysh, intermediate-basic volcanic rocks and carbonates. The Triassic system is widely exposed in the block, and is mainly composed of flysh. The triangular block can be divided into three sub-blocks, they are Ganzi block (GZB), Minshan block (MSB) and Motianling block (FTLB) (Fig.1). According to geophysical survey (Wang Xuben, 2000), the lithosphere of the block can be divided into three layers vertically: Upper crust, low-velocity layer in the crust, and the lower lithosphere (Fig.2).

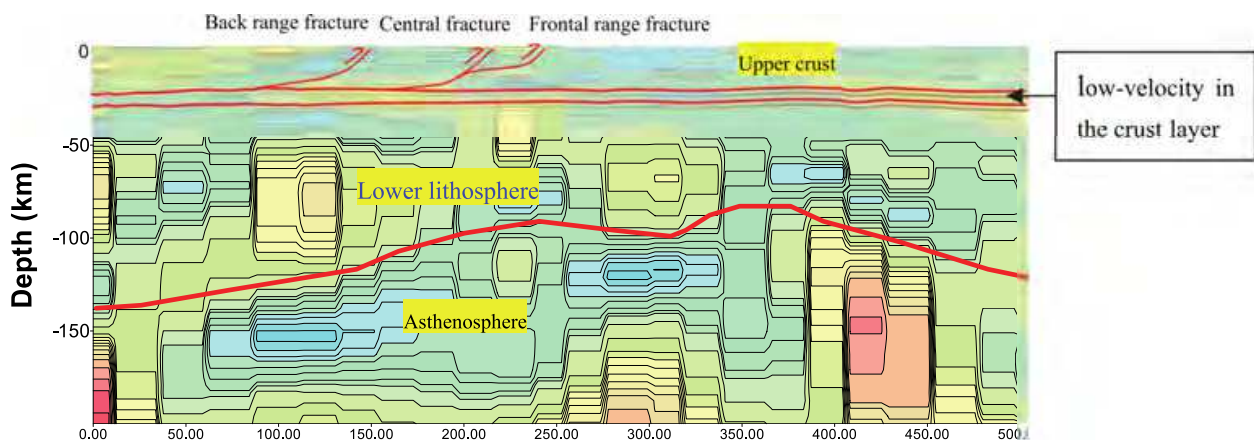


Fig. 2. Inversion result of the MT profile in northwestern Sichuan

## 2.2 The boundary fractures of the triangular block

The Xianshuihe Fracture is the most active fault with large magnitude ( $M_s6-7$ ) earthquakes and 30-40 years recurrence period, while the Longmen Mountain Range fracture and the Maqin-Lueyang fracture earthquakes occur with super magnitude ( $M_s8$ ) and low frequency (more than 2000 years).

**The Xianshuihe fracture** starts in Donggu, Ganzi, runs southeastward, via Luhuo, Daofu, Qianning, Kangding, Moxi, and ends in Tianwan. The strike of the fracture is NW in the north of Kangding, it is NNW in the south of Kangding, showing an arc shape. The dipping direction is SW, with medium- steep angles ( $45-80^\circ$ ). According to the satellite image and geological data, the fault is large in scale and clearly linear. Valleys such as of the Xianshuihe River are developed along this fracture, the total displacement along the fracture can reach 5000m. Since its formation in the Jurassic, it showed strong activity during the uplift of the Tibet plateau. The seismic activity along the fracture is high. Since 1725, 36 earthquakes with magnitude  $M_s \geq 5.0$  have been recorded, of which 13 had a  $M_s \geq 6.0$  and 6 had a  $M_s \geq 7.0$ . The strongest recorded earthquake with  $M_s 7.9$  of Luhuo happened on 6th of Feb., 1973, with a focal source depth of about 10-20km.

**The Maqin-Lueyang fracture:** starts at the Tuosuohu lake, and leads via Maqin, Maqu, Nanping, Kangxian, to Lueyang, with a length of over 2000km. The strike ranges from 290°, 270°, 70°, with a southward arc. 6 earthquakes with a magnitude larger than Ms7.0 happened along this fracture(see references: Gu Gongshu (1983); Liu Guangshun (1996); Seismic bureau of Qinghai Province (1999); Yi Guixi (2002); Xu Xiwei et al. (2005)). In Yangbuliang, Jiuzhai, Carboniferous-Permian metamorphic carbonate rocks have thrustured onto Triassic clastic rocks, forming nappes. There is basic rock and super-basic rock outcrop along the fracture in Langmusi.

**The Longmen Mountain Range fracture:** Longmen Mountain Range fracture belts are composed of three deep fractures. From the southeast to the northwest: the front range fracture, the central fracture and the back range fracture. The strike of the three fractures is NE-SW, with dipping direction towards the northwest. Since the Cenozoic, these fractures have experienced thrusting from the northwest to the southeast with some right-slip component. The front range fracture is composed of the Dachuan-Shuangshi fault, the Guanxian-Anxian fault, and the Jiangyou fault. The central fracture is composed of the Yanjing-Wulong fault, the Yingxiu -Beichuan fault and the Beichuan-Linyansi fault. The back range fracture is composed of the Longdong-Gengda fault, the Wenchuan-Maoxian fault and the Pingwu-Qinchuan fault(Fig.3).

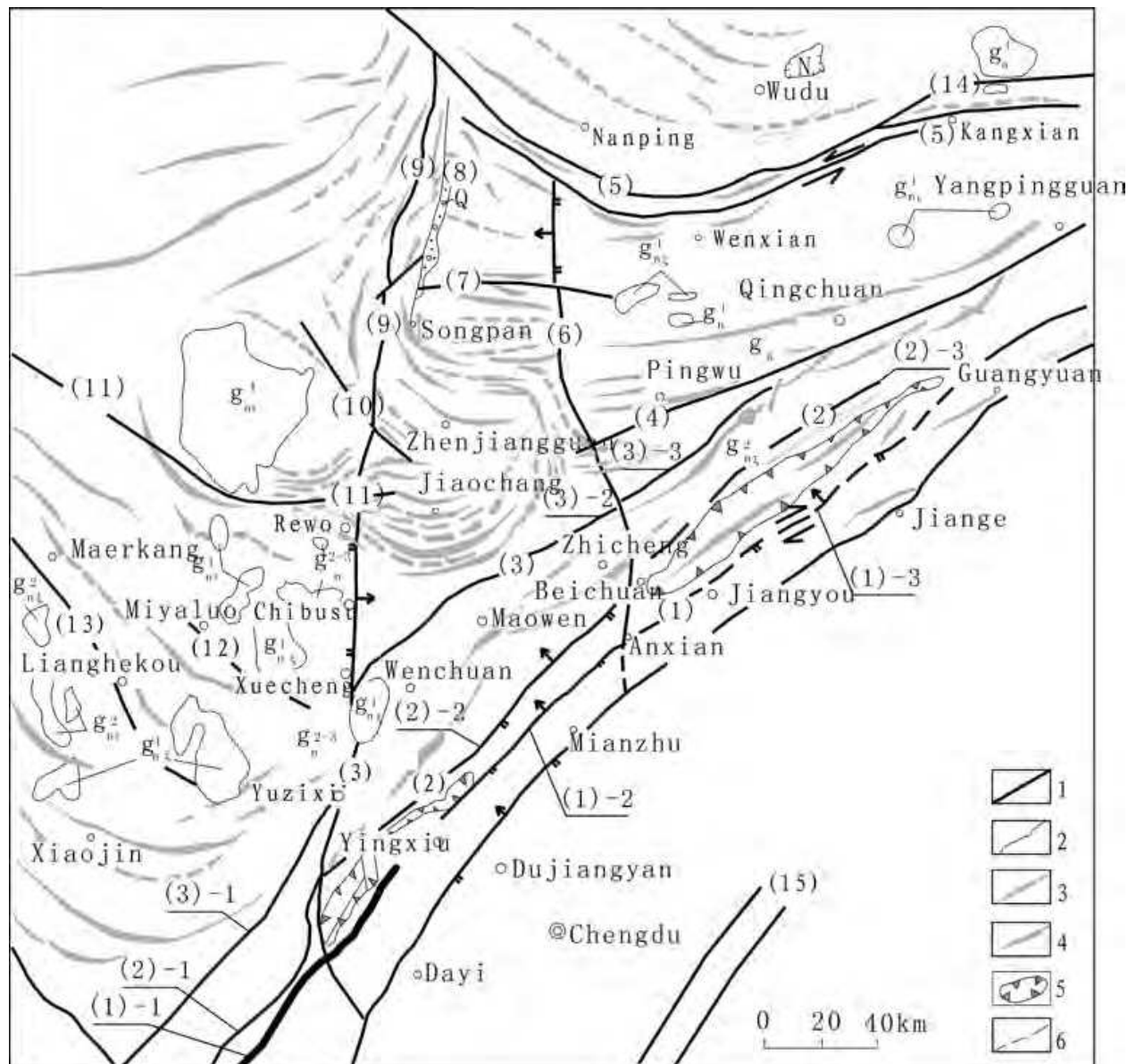
### 2.3 The Minshan Block

The Minshan Block is an important tectonic element in the northwest region of Sichuan. It not only includes the Minshan uplift in a narrow sense, but also the middle segment of Longmen Mountain Range structural belt (Fig.2, 3).

Although the west and east boundaries are still controversial, their existence and new activities are widely accepted. Analysis of seismic geological setting and the deformation data shows the Minshan uplift to be activated by the Mounigou Valley fracture in the west, Huya fracture and Leidong fracture in the east, back range fracture in the south and Maqin-Lueyang fracture in the north. Also the whole middle segment of the Longmen Mountain Range structures are especially strong active along south boundary since the Mesozoic, especially since Quaternary, namely, the Paleo-Peng(zhou)-Guan(xian) complex has been thrustured onto lower Pleistocene, nappes have been formed. There is great contrast in elevation and drop on the landform in the block. In addition strong erosion caused a thick Quaternary accumulation along the Chengdu plain and Longquan mountain was formed as a result of the uplifting of the Minshan block.

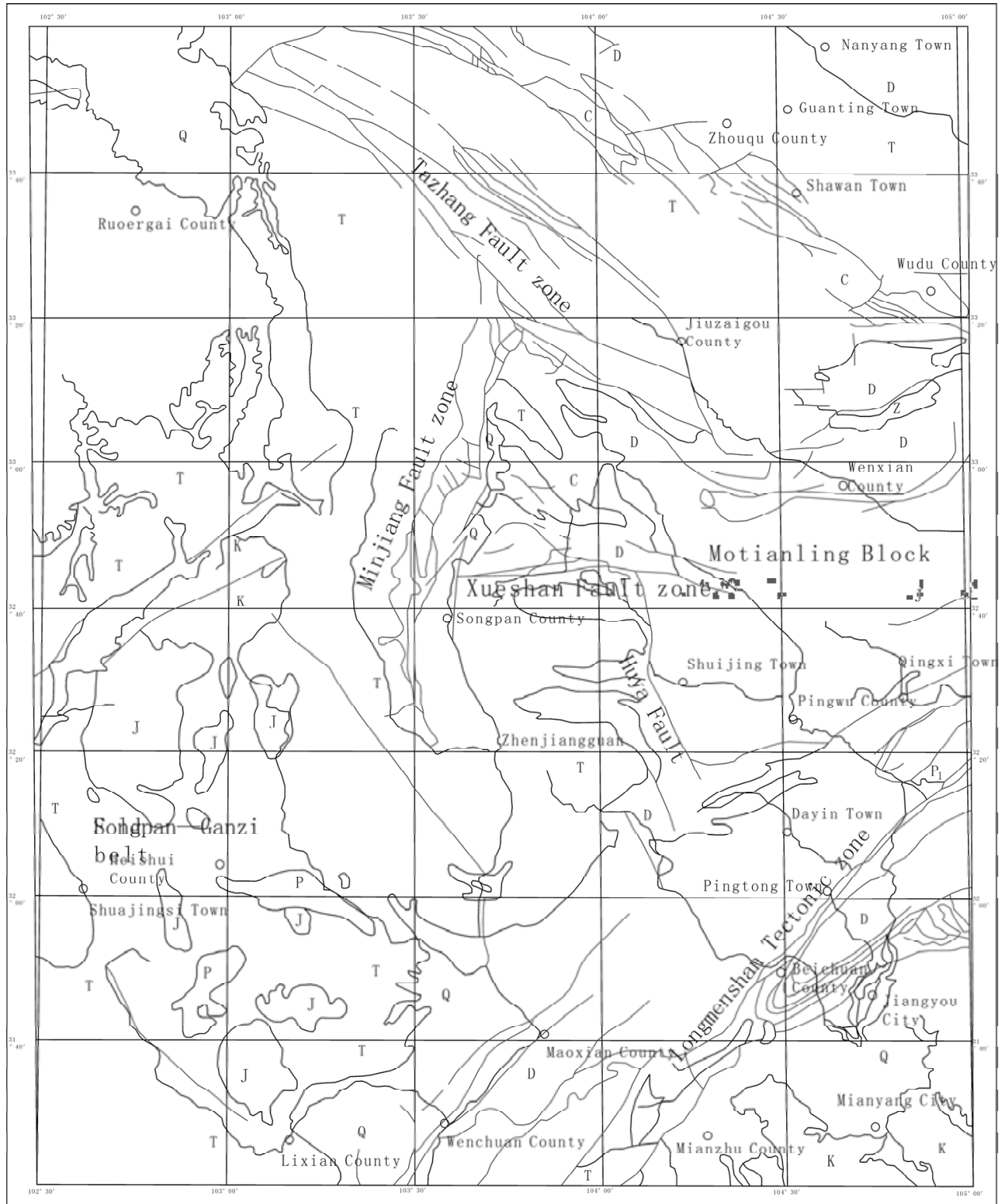
The northern part of the Minshan block (MSB in Fig. 3) is narrow (50 km wide) and it widens ( 90km ) towards the south. The SN length is about 200km (Fig.3); the three dimensional shape is narrow in the lower, deeper part and wider near the surface (Fig.4-9). The rigidity of the Block is stronger than that of the adjacent areas because the Vs ( $\geq 3.2$ ) of the Minshan Block is larger than that of the adjacent areas (Fig.5).

The main part of the Minshan block is composed of series of peaks such as Gonggaling, Hongxingyan, Xuebaoding, Xueguzhai, Maoheshan and Jiudingshan, whose summits are at about 4000-5000m a.s.l. The landform is intensively dissected and deep gorges are well developed. The Songpan plateau is situated to the west of the Minshan block and is slightly dissected while a peneplain(planation surface) with an elevation of about 4000m is preserved.



1. regional main deep fractures; 2. common fractures; 3. synclines; 4. anticlines; 5. nappes; 6. predicted fracture; (1) Guanxian-Anxian fracture; (2) Yingxiu-Beichuan fractures; (3)Maowen fracture; (4) Pingwu-Qingchuan fracture; (5) Maqin-Lueyang fracture; (6) Huya fracture; (7) Xueshan fracture; (8) Minjiang fracture; (9) Mounigou Valley fracture; (10)Songpinggou fracture; (11) Aba-Heishui-Jiaochang arc fracture, (12) Miyalu-Lixian fracture; (13)Maerkang-Lianghekou fracture; (14)Wudu-Chengxian fracture; (15) Longquan Mountain Range fracture; (1)-1 Dachuan-Shuangshi fracture; (1)- 2 Guanxian-Anxian fracture; (1)-3 Jianyou fracture; (2)-1 Yanjing-Wulong fracture; (2)-2 Beichuan-Yingxiu fracture; (2)-3 Beichuan-Linanshi fracture; (3)-3 Gengda-Longdong fracture; (3)-2 Maowen-Wenchuan fracture; (3)-3 Pingwu-Qingchuan fracture

Fig. 3. Skeleton of the northwest block of Sichuan



S: Silurian System; D: Devonian System; D-T: Devonian-Triassic System; C: Carboniferous System; T: Triassic System; J: Jurassic System; K: Cretaceous System; Q: Quaternary System;  $\gamma$ : PreCambrian;

Fig. 4. The geological map of Minshan block

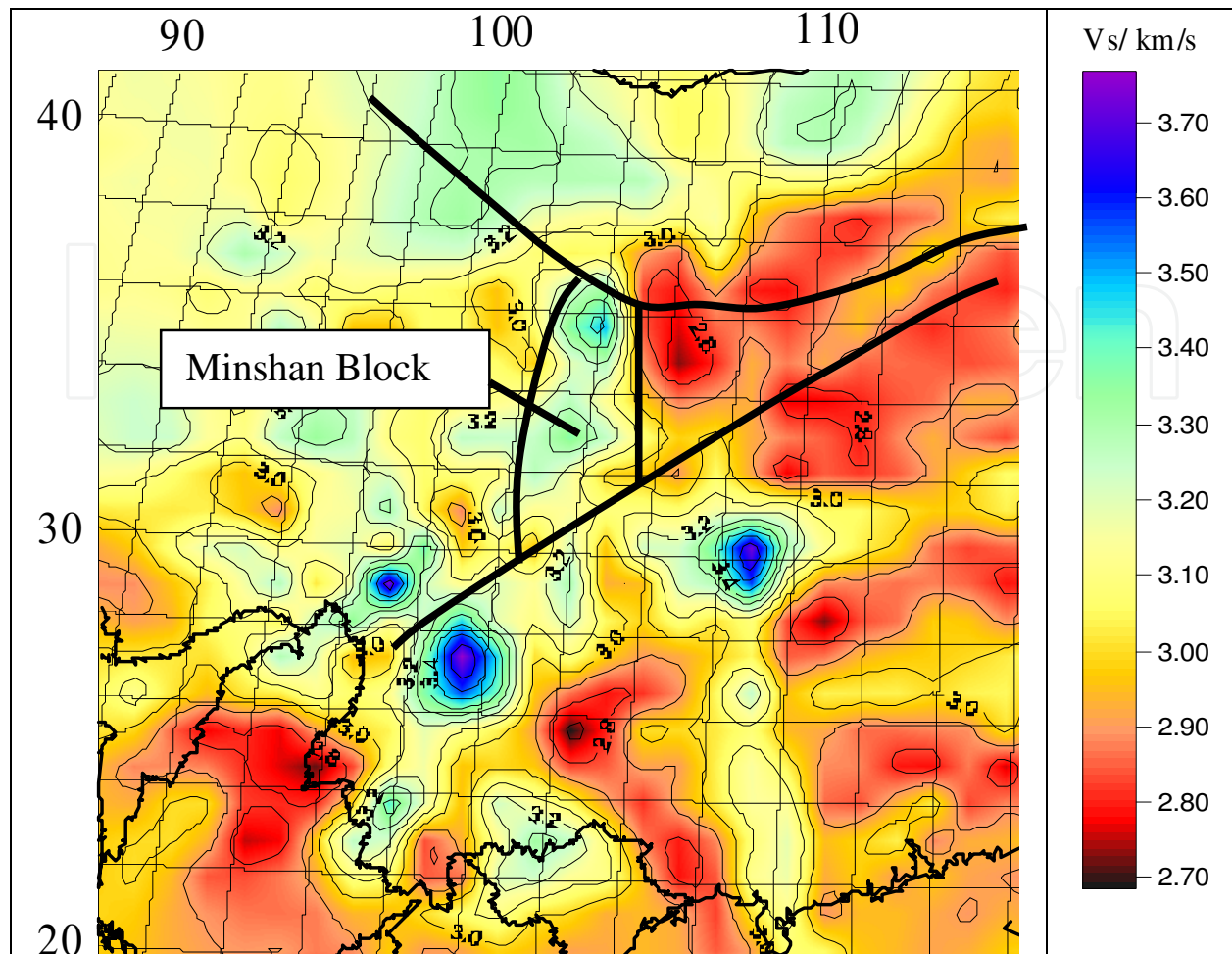


Fig. 5. Vs distribution of surface waves in the northwest of Sichuan (at depth of 8km. From Wang Xuben, personal communication ) **The coarse black line is the boundary fracture**

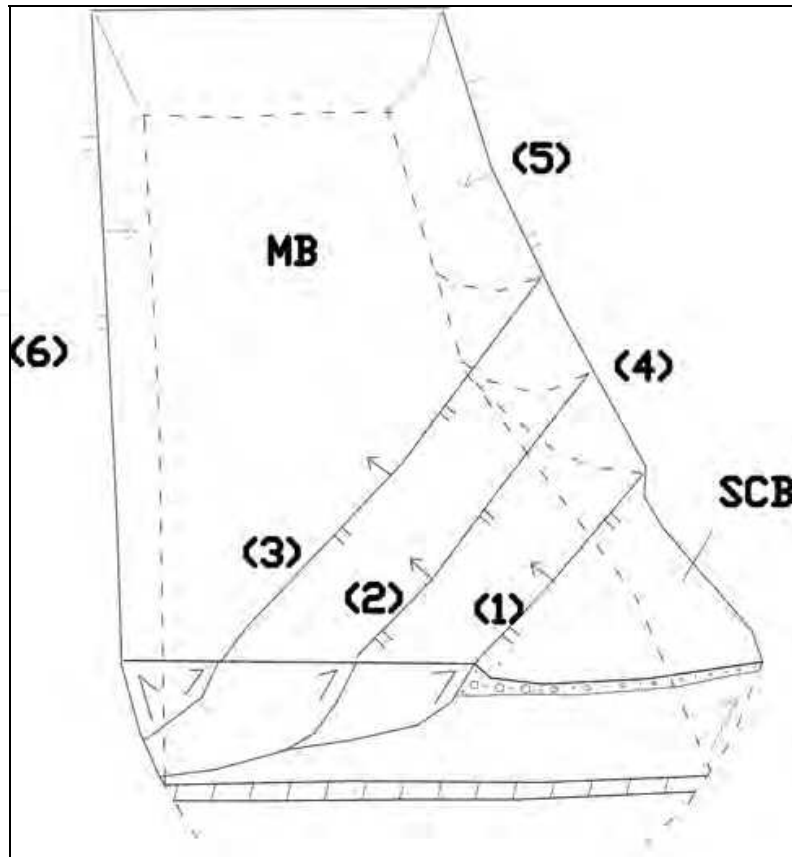
According to the activities and the distribution of Quaternary and landform characteristics, Minshan Block can be divided into three segments: the Gonggaling to Zhenjiangguan, Zhenjiangguan to Maoxian and Maoxian to Guanxian segments.

The Gonggaling to Zhenjiangguan segment is composed of a series of peaks with an elevation of about 4500m and the mountain range is with SN strike, the highest peak being Hongxingyan (5010m) with outcropping Devonian-Triassic limestone, dolomite, metamorphic sandstone and slate. Its boundary fractures are active and a thick Quaternary accumulation is developed in the Zhangla basin.

The Zhenjiangguan to Maoxian segment is composed of peaks with an elevations of about 4500m and deeply eroded valleys. The summits follow a SN strike direction, and have Tertiary metamorphic sandstone, phyllite, slate and Devonian Weiguan Group schist, Silurian Maoxian Group phyllite, and slate and quartzite as its bedrock (Fig.4).

The Maoxian to Guanxian segment is located in the area with superimposed SN and NE structures. The strata are striking is NE direction and the general elevations is over 2000m. The highest peak is Jiudingshan (4989m), the next highest peak is Qianfoshan (3033m), and the area has 2000-4000m in elevation differences with respect to the Chengdu plain. The landform is deeply dissected and the tectonic deformation is intensive. The bedrock consists of Precambrian granite, granodiorite, Silurian schist and quartzite, Triassic sandstone and mudstone.





(1) front range fracture, (2) central fracture, (3) back range fracture, (4) Leidong fracture, (5) Huya fracture, (6) Mounigou fracture, MB Minshan block, SCB Sichuan basin

Fig. 6. 3D structural diagram of the Minshan block



Fig. 7. Western boundary fracture of the Minshan block, (camera facing south) The fault zone is composed of cataclastic rock and fault gouge Carbonization is obvious, fault zone width 20-30m



Fig. 8. East boundary of Minshan block, (camera facing north) The fault zone is composed of cataclastic rock and fault gouge Carbonization is obvious, fault zone width 120m.



Fig. 9. Schematic cross section of the Minshan Block and its eastern, and western boundary, (The direction of the cross section:  $N31^{\circ}50'$ )

The Minshan block is a part of China's SN seismic belt. Seismic events are frequent inside the block and along its boundaries. GPS measurement data indicate that the block moves eastward and that its southern boundary moves towards the southeast.

### 3. General characteristics of the seismicity in the region

About 100 earthquakes with magnitude over 4.7 have occurred in the region, since the Wudu, Wen County magnitude 7.0 earthquake which occurred in 186 BC. 18 Earthquakes with a magnitude over 6.0 and 7 earthquakes with a magnitude over 7.0 have occurred since 186 BC (Fig.9, Table.1). The magnitudes of Serial number 1-7 are determined according to the historical earthquake description of local chronicles and field survey of historical earthquakes. As there were no instrumental records, the value is not accurate. The distribution of seismic activity has obvious features of zoning (Fig.10). The area can be divided into three division zones and 8 subdivisions (Table.2).

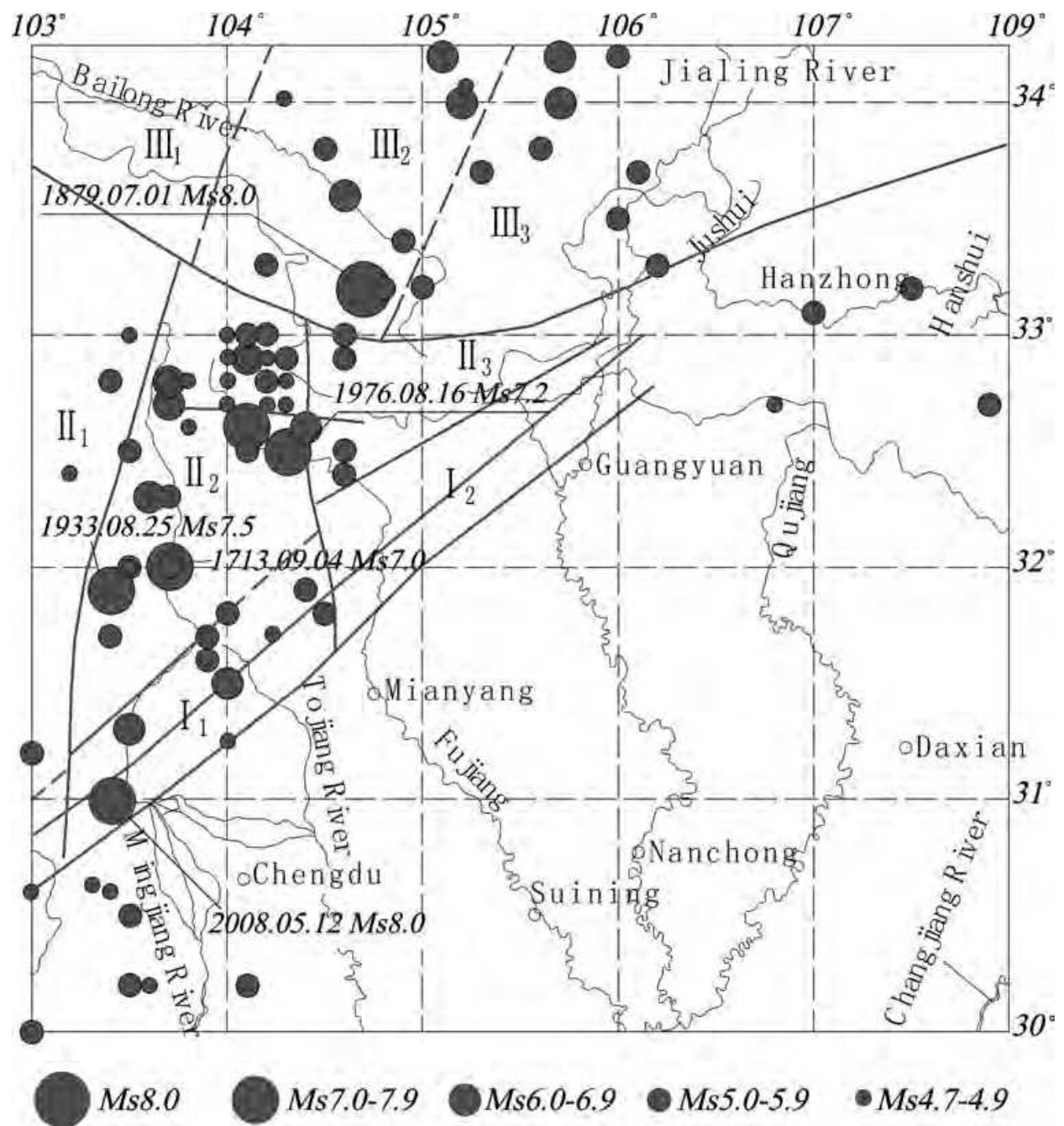


Fig. 10. Historical earthquakes in northwestern Sichuan (from Hu Xingping et al 2008 modified)

Serial number	date	Epicentral coordinate			Magnitude (Ms)	Depth (km)
		°N	°E	Reference sites		
1	186.2.22 BC	33.4°	104.8°	Wudu, Wenxian	7	–
2	1630.1.16	32.6°	104.1°	Songpan-Pingwu	6.75	–
3	1657.4.21	31.5°	103.6°	Wenchuan	6	–
4	1713.9.4	32.0°	103.7°	Diexi, Maoxian	7	–
5	1879.6.19	33.2°	104.7°	Wudu, Wenxian	6	–
6	1879.7.1	33.2°	104.7°	Wudu, Wenxian	7.5	–
7	1881.7.20	33.6°	104.7°	Zhouqu, Gansu	6.5	–
8	1933.8.25	32.0°	103.7°	Maoxian, Diexi	7.5	20 km
9	1938.3.14	32.3°	103.6°	Zhenjiangguan	6	32 km
10	1941.10.8	32.1°	103.3°	Heishui county	6	20 km
11	1958.2.8	31.8°	104.0°	Maoxian county	6.2	–
12	1960.11.9	32°47'	103°40'	Zhangla, Songpan	6.75	–
13	1970.2.4	30°36'	103°12'	Dayi county	6.25	15 km
14	1973.8.11	32°55'	103°55'	Huanglong, Songpan	6.2	20 km
15	1976.8.16	32.7°	104.2°	Songpan- Pingwu	7.2	9 km
16	1976.8.22	32.6°	104.15°	Songpan- Pingwu	6.7	15 km
17	1976.8.23	32.5°	104.1°	Songpan-Pingwu	7.2	17 km
18	1989.9.22	31.58°	102.47°	Lianghekou, Xiaojin	6.3	14 km

Notes: the magnitude of Serial number 1-7 is according to the description of annals of local history

Table 1. Strong earthquake catalogue of northwestern Sichuan ( $M_s \geq 6.0$ )

Division	Subdivision
Seismic activity zone of Longmenshan Mountain structural belt(I)	The weak seismic activity sub-region in the north section(I <sub>1</sub> )
	The strong seismic activity sub-region in the south and intermediate section(I <sub>2</sub> )
Seismicity zones inside the inverted-triangle-shaped fault block in the northwest of Sichuan(II)	The weak seismic activity sub-region of western inside the fault block(II <sub>1</sub> )
	The strong seismic activity sub-region of Minshan block(II <sub>2</sub> )
	The weak seismic activity sub-region of eastern inside the fault block(II <sub>3</sub> )
Seismic activity zones of western of Qinling tectonic seismic belt(III)	The weak seismic activity sub-region in the west section(III <sub>1</sub> )
	The strong activity sub-region in the middle curved tectonic section(III <sub>2</sub> )
	The strong seismic sub-region in the east section(III <sub>3</sub> )

Table 2. The seismic activity zoning

### 3.1 Spatial distribution of seismic activity

The seismicity in this region is mainly concentrated at the western side of "tectonic bottle neck zoning" of Wudu, Wen County - Pingwu, Qingchuan, in the area of  $103^{\circ} \sim 105^{\circ}\text{E}$ , which is a nearly S-N banded zone. The main seismogenic structures were the boundary faults in the north and south parts and the faults within the Minshan block. However, the earthquake frequency and maximum earthquake magnitude inside the fault block are higher than those along the Maqin-Lueyang fracture and the Longmen Mountain fault zone (Fig.10). Compared with the southern boundary zone, the seismic intensity in Maqin-Lueyang fracture is far larger (Table.3). The main causative faults inside the block triggered by a nearly E-W regional tectonic stress-strain field are:

1. the Huya fault, striking nearly N-S, it is the source of reverse fault earthquakes;
2. the Songpinggou fault, in NW-SE, it is the source of left-lateral strike-slip earthquakes ;
3. the Dongmengou fault in NEE-SWW, it is the source of right-lateral strike-slip earthquakes.

### 3.2 Migration pattern of the large magnitude earthquake sources

According to the historical seismic data (Table.1), the general pattern in this region is that the large magnitude seismicity migrates from the boundary faults to the triangular-shaped fault block in northwestern Sichuan in nearly N-S direction, then migrates to the boundary faults. There are some differences between the migration patterns before 1900 and after 1900.

1. The migration laws of strong seismic activities before 1900 is: earthquake in north boundary fault (186 BC, February 22, Wudu, Wen County magnitude 7.0 earthquake)→(to the south) earthquake inside the fault block (January 16, 1630, Songpan and Pingwu magnitude 6.7 earthquake)→(to the south) earthquake in the Longmen Mountain fault in the southeast boundary (April 21,1657, Wenchuan magnitude 6.5 earthquake) →(to north) earthquake inside the fault block (September 4,1713, Diexi magnitude 7.0 earthquake) →(to the north) earthquakes in the north boundary fault (June 19,1879, Wudu magnitude 6.0 earthquake, and July 1,1879, Wudu, Wen County magnitude 7.5 earthquake, and Zhouqu, Wudu magnitude 6.5 earthquake in 1881). Generally speaking, the seismic activity began in the north boundary fault, finally returned to north boundary fault again after the north-south round-trip before 1900. Seismic activities mainly occurred inside the fault block or along the north boundary fault.
2. The migration laws of strong seismic activities after 1900 is: earthquake inside the fault block(August 25, 1933, Diexi magnitude 7.5 earthquake) →(internal adjustment) earthquakes inside the fault block(two adjustable strong seismic activities: March 14, 1938, Zhenjianguan magnitude 6.0 earthquake, and October 8,1941, Heishui magnitude 6.0 earthquake) →(to south)earthquake of Longmen Mountain in southeast fault block (February, 1958, Maoxian magnitude 6.2 earthquake)→(to north)earthquake inside fault block(November 9, 1960, Zhangla magnitude 6.7 earthquake)→(to south) earthquakes in southeast boundary fault block(February 24, 1970 Dayi magnitude 6.25 earthquake)→(to north)earthquakes inside fault block (August 11, 1973, Songpan, Huanglong magnitude 6.2 earthquake, and 1976 August 16~August 23 Songpan, Pingwu magnitude 7.2 swarm earthquake)→(to south)(internal adjustment)earthquake

inside fault block (in the southwest area of Lianghekou in Xiao Jin), and this belongs to the adjustable phase of seismicity. Obviously, strong seismicity has presented the trend of migration to internal of fault block, and southward. Seismic activities mainly occurred inside the fault block or along the southeast boundary fault.

In summary, these migration patterns suggest that the triangular-shaped Minshan fault block is transferred along the deep fault zones on both sides of the boundary faults in an irregular process. As the northern boundary fault zone is the main impedance boundary for eastward movement, every cycle of eastward fault-seismic activity started at the northern zone, and then migrated into the fault block and towards the southeastern block boundary fault.

### 3.3 Periodicity of large magnitude seismicity

Analysis of the historical seismic data in this region shows that their seismicity has been alternating active and quiet periods since 1920 (Fig.11).

1924-1941 was the first active period in the 20<sup>th</sup> century, which lasted about 18 years; largest earthquake during this period with magnitude 7.5 occurred in Diexi on August 25, 1933. This high activity period was followed, by the first quiet period in the region, which lasted about 10 years (1941-1952).

From 1952-1978, the second active period occurred in the region, which lasted about 26 years; its strongest earthquakes are the 2 Songpan-Pingwu magnitude 7.2 earthquakes on August 16 and 23, 1976. This period was followed by the second quiet period in the region, which lasted about 10 years (1978-1989). From 1989 to the present, we experience the third active period, which may last until 2012( $\pm 8$ ). Wenchuan earthquake magnitude 8.0 occurred during this period, whose epicenter is south boundary of the Minshan block (Table 3).

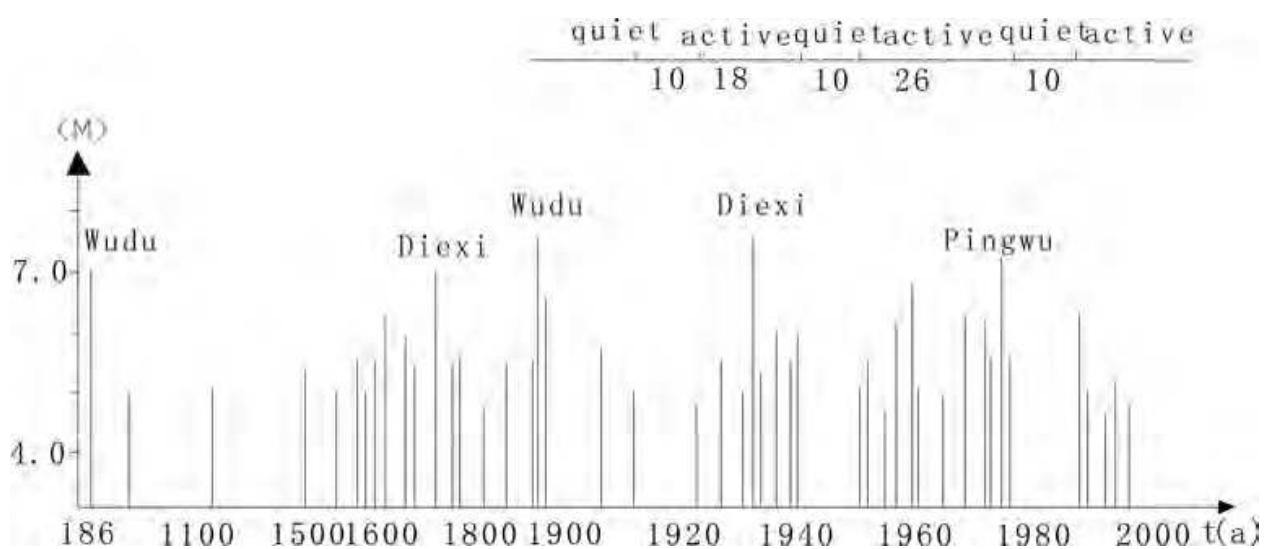


Fig. 11. M-t diagram of the strong earthquakes in northwestern Sichuan

The names of fault zones	The times of earthquakes		Occurring interval, and times
	Magnitude between 6.0 and 6.9	Magnitude over 7.0	
The north boundary fault zone	2	2	Before 1900, 4 times
The Minshan block	7	4	Before 1900, twice After 1900, 9 times
The south boundary fault zone	3	0	Before 1900, once After 1900, twice

Table 3. Location and period of occurrence of strong earthquakes in northwestern Sichuan

### 3.4 Recurrence interval of strong earthquakes ( $M_s \geq 7.0$ )

Table 4 shows that the time interval between strong earthquakes in the region (the recurrence interval) is shortening in a slightly exponential way.

The names of earthquakes	Earthquake magnitude	The time of occurrence	The time interval between two strong earthquakes
Wudu, Wen County earthquake	7.0	February 22, 186 BC	
Diexi earthquake	7.0	September 4, 1713	1898 years
Wudu, Wen County earthquake	7.5	July 1, 1879	166 years
Diexi earthquake	7.5	August 25, 1933	54 years
Songpan, Pingwu earthquake	7.2	August 16~23, 1976	43 years

Table 4. The recurrence interval between strong earthquakes ( $M_s \geq 7.0$ )

From this time series, it may be assumed that the time interval until the occurrence of the next over magnitude 7.0 earthquake is about 40 years. In fact, it only took 32 years from Pingwu earthquake to Wenchuan earthquake. The accelerating tendency of strong seismicity in the region is obviously closely related to the triangular tectonic system controlling strong earthquakes.

### 3.5 Fractal characteristics of the seismic magnitude/frequency pattern

Aki(1981) shows that the G-R relation ( $\log N = a - bM$ , Gutenberg-Richter, 1954) is equivalent to the definition of fractal distribution (Chen Chunzai, 1997). D. L. Turcotte (1989) suggested that there is a quantitative relationship between the value  $b$  and the fractal dimension,  $D_f$ , from the point of seismic wave energy and seismic distance, that is  $D_f = 2b$ , and then revealed the fractal characteristics of the G-R relation, i.e. the  $D_f$  stands for the frequency of the earthquake occurring. The equation of  $\log N = a - bM$  shows that, if the value of  $D_f$  is smaller, the region is more prone to large magnitude earthquakes.

We conducted a special fractal study of the southern and middle part of the Longmen Mountain (I), the Minshan Block (II<sub>2</sub>), and the tectonic seismic belt of west Qinling (III). The results show that the seismicity fractal dimension ( $D_f$ ) of the zone (I) is the highest: 1.2105;

that ( $D_f$ ) value of the zone (II<sub>2</sub>) is the lowest: 0.913; and that the ( $D_f$ ) value of the zone (III) has an intermediate value: 0.9788. This suggest that, the magnitude level of seismicity of the Minshan block is the largest; and the south and intermediate section of Longmen Mountain has the lowest number of large magnitude earthquakes.

For the region as a whole, the fractal value ( $D_f$ ) is 1.0054, close to 1, meaning that the seismic activities of all magnitudes in the region were controlled by a scale-independent earthquake mechanism. This proves that an triangular block tectonic system controls the earthquakes in the region (Table 5).

Zone	N	Ms				b	$D_f=2b$	r
		≥4.7	≥5.0	≥6.0	≥7.0			
Longmen Mountain fault zone(I)		20	10	3	0	0.6053	1.2105	0.9998
The uplift belt of Minshan (II)		44	30	9	4	0.4565	0.9130	0.9992
Western of Qinling tectonic seismic belt(III)		22	19	6	2	0.4889	0.9778	0.9999
$\Sigma$		86	59	18	6	0.5072	1.0054	0.9997

Table 5. The results of fractal analysis of seismic activity in northwestern Sichuan

#### 4. The seismotectonics analysis of the Wenchuan earthquake

As the Indian plate pushes strongly toward the Qingzang Plateau, different blocks in southwestern China have different movement directions (Fig.12), The northwestern block of Sichuan mainly moves towards the east. In the movement process, due to the Minshan block lock-up →earthquake→geo-stress release (stick-slip) cyclic process, the middle segment of the Longmen Mountain Range structural belt is more active than the southern and northern segments.

Both the geophysical survey and the geological analysis strongly suggest that the three fractures in the southern part of the Minshan block converge into an intracrust low velocity layer and form a slip plane (Fig.2). The stress accumulation in the southern part of the Minshan block caused a high stress concentration along the Yingxiu-Beichuan and Guanxian-Anxian fractures, and they became a rupture point that probably could be fractured at anytime. According to the hypocenter parameters of the 5.12 Wenchuan Earthquake (epicenter at Niumiangou with depth of focus 14 km), the initial focus is located at the front range fracture. At the surface, the bottle-neck's lock-up of the Minshan block is small in the front and large in the tail; vertically, it is small in the lower part and big near the surface (Fig.5). Because of the restriction in the northern and southern boundaries, together with the blockage in the east, the dextral strike-slip action of the block requires thrusting movement at the southern boundary to provide enough space. Thus, the movement of the



Minshan block is mainly characterized by vertical thrusting in combination with a small strike slip. The transient variation of stress and the sudden release of tremendous amounts of strain energy forced movement in the Yingxiu-Beichuan fracture (just above the focus) and induced large scale rupture toward the northeast. Because of the obstacle (at the block's east boundary) around Beichuan County, the consequent progressive failure released large amounts of strain energy. After the thrusting movement occurred along the southern boundary of the Minshan block, the lock-up effect was lost instantly. The powerful pushing from the west was immediately transmitted to the eastern (Motianling) block, which was under lower levels of stress because of the barrier action from the Minshan block. This caused continuous aftershocks in the Motianling block and the northern segment of Longmen Mountain Range which up to then were fairly calm. Because of the eastward movement of the Minshan block, the stress level at the southern segment of the western boundary fracture changed significantly. The stress adjustment caused relative movements of both sides along the boundary, which led to continuous aftershocks along the Yuzixi - Lixian-Chibusu and the '√' shape distribution of aftershocks (Fig.12) (Zhao et al. (1994b); Chen et al. (1994a); Chen et al. (1994b); Hua et al. (2009); Hu et al. (2008)). The secondary geological hazard anomaly zone has similar shape too.

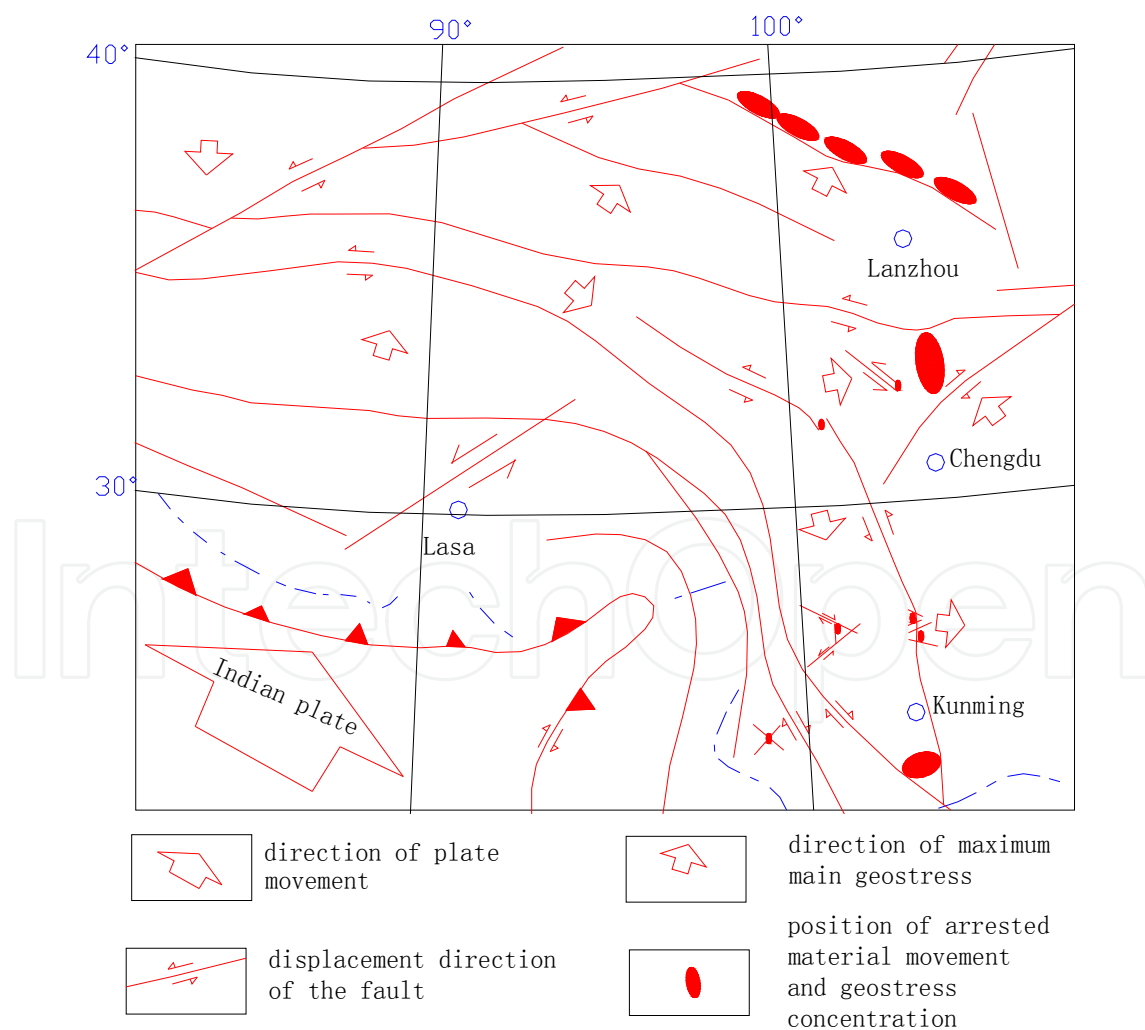


Fig. 12. Regional geostress directions in southwestern China

According to historical earthquake records, since 186 B.C the spatial distribution of earthquake in northwestern Sichuan was constrained by the Minshan Block. The earthquake record in the Minshan block demonstrates a higher magnitude and frequency than along its southern boundary, the middle-segment of the Longmen Mountain Range structural belt. Historically, there was no earthquake with a magnitude over 7.0. The occurrence of the magnitude 8.0 earthquake in Wenxian in 1879 was the consequence of stress accumulation, which led to the migration of seismicity from north to south. Earthquakes with a magnitude larger than 6.0 occurred several times along the boundaries and in the interior of the Minshan Block, and earthquakes larger than 5.0 magnitude are frequent. Except for the 5.0 magnitude earthquakes that occurred in Beichuan, Dayi and Mianzhu counties in 1999, the seismic activity along the southern boundary was historically not frequent. In other words the stress accumulation that can cause a magnitude 8.0 earthquake takes a long time to develop, more than 2000-4000 years.

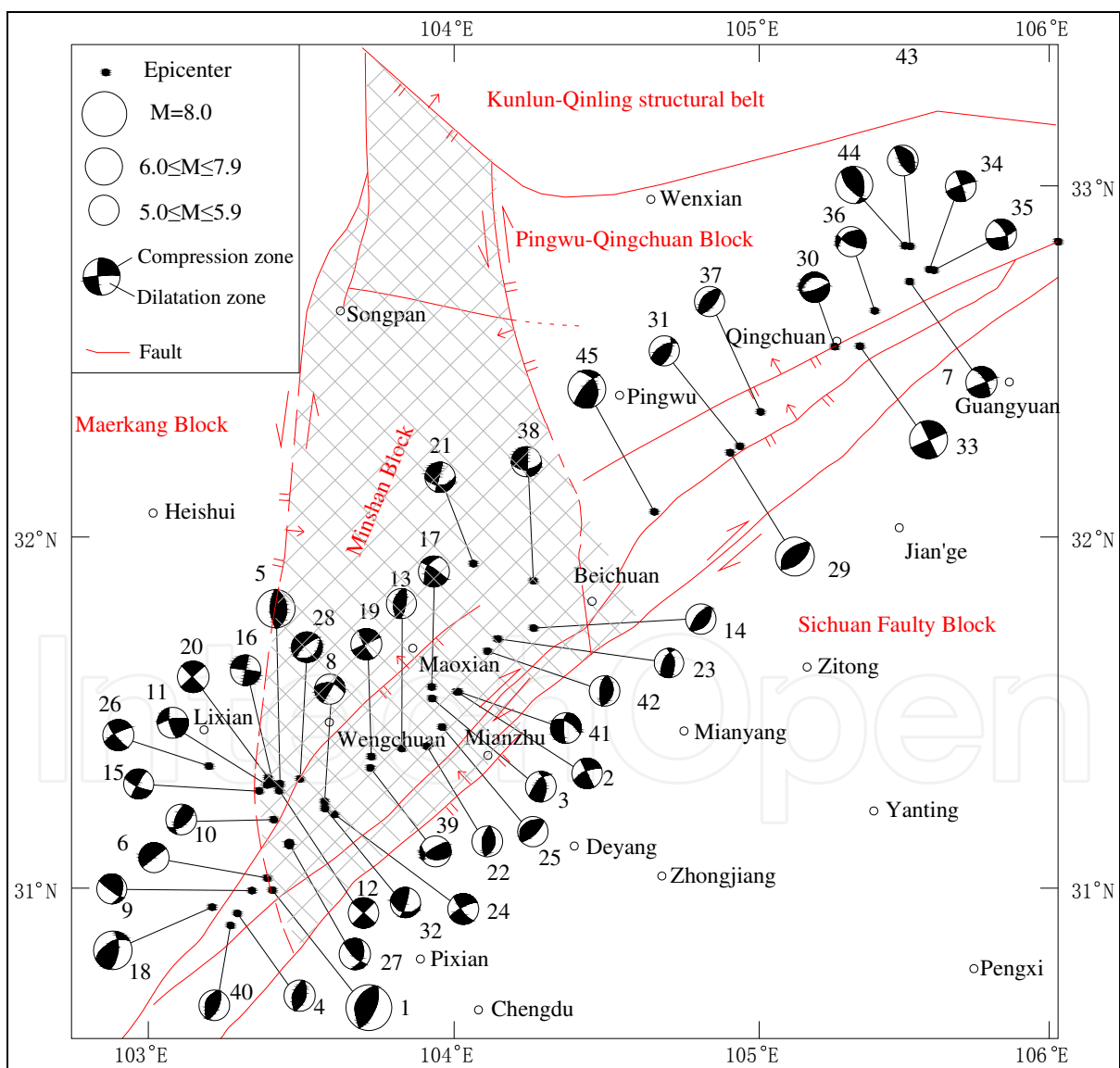


Fig. 13. The structural framework and focal mechanism solution for the Wenchuan earthquake and its aftershocks (from Hu Xingping et al 2008 modified)

## 5. Conclusion

On the basis of the presented analysis, we can draw the following conclusions: (1) the Minshan block is an important tectonic element with larger rigidity than that of the surrounding areas; (2) This unique tectonic framework caused a bottle-neck effect in the Minshan block. Exactly the effect which causes stress concentrations along the boundary and in the interior of the block which lead to frequent earthquakes; (3) Before the nineteenth century, the earthquakes were concentrated on the northern, western and eastern Minshan block boundaries. A magnitude 8.0 earthquake occurred in the Wenxian county in 1879 and triggered another round of large-scale reverse faulting and strike-slip movements. Against this background, the movement of the southern boundary of the Guanxian-Anxian fracture induced the 5.12 Wenchuan Earthquake; (4) The fracture just above the focus, the Yingxiu-Beichuan fracture, was forced to act strongly; (5) The release of the Minshan block lock-up lead to a high stress level in eastward direction causing continuous aftershocks in the northern segment of the Longmen Mountain Range structural belt and in the Motianling block. (6) Further aftershocks will occur in the middle and northern segment of Longmen Mountain Range structural belt and the southern segment of the Mounigou Valley fracture.

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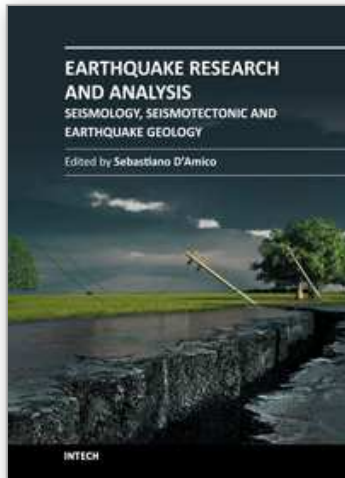
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