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Earthquakes Since 2008 in Longmenshan Mountain Range and Western Sichuan Basin, China

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The Wenchuan (Ms 8.0) earthquake of May 12, 2008, in the middle and northern segments of Longmenshan mountain range in China, is a direct manifestation of the active crustal shortening in the Longmenshan mountain range and front. From surface ruptures reported, it appears that this earthquake caused slip on two major parallel NE-trending faults (the Beichuan and Pengguan faults) within the imbricated thrust stack that ramp upward to the surface, and slip also transfer into the Sichuan basin on the detachment surfaces. The Wenchuan earthquake resulted in thrusting from NW to SE direction and dextrorotate slip from SW to NE direction in the Longmenshan structural belt. Coseismic deformation not only changed the topographical gradient and produced massive landslides and debris flows in Longmenshan mountains area, but also caused earthquakes (eg. Suining earthquake and Santai earthquake) in western Sichuan Basin and earthquake (eg. Lushan earthquake) in the southern segment of Longmenshan mountain range. Based on data of these earthquakes occurred after 2008, including the seismology record, field examination, focal mechanism solutions, seismic refraction profile, the aim of paper will focus on mechanism, seismotectonic environment, seismology analysis and tectonic mechanism of the earthquakes in Longmenshan mountain range and Sichuan basin. We consider that the earthquakes in the western Sichuan basin and in the southern part of Longmenshan mountain range were related with NW horizontal crust shortening and stress adjustment after the 2008 Wenchuan earthquake and earthquake probability with NE direction-propagation and SW direction-propagation will be increasing in Longmenshan mountain range and western Sichuan Basin. Here is the reason and evidence.

(1) The Suining (Ms5.0) earthquake located the center of Sichuan Basin (105.70° E, 30.30° N) with a stable geotectonic environment and a low-level historical

seismicity and happened at January 31, 2010. The focal depth of the earthquake is 10km. The earthquake intensity of the epicenter area is degree of VII, and the long axis of the isoseismal line trends in NE orientation. The focal mechanism parameters of the Suining earthquake were calculated by the Institute of Geophysics of the China Earthquake Administration using the waveform data of 20 stations and the P-wave onset of 125 stations, the results show that the Suining earthquake triggered by a reverse fault with NE trending. The earthquake focal mechanism solution and records of the near-field seismographic stations showed the earthquake occurred at the reverse fault at a depth 3-4km.

(2) The Santai (Ms4.7) earthquake located the western Sichuan Basin (105.2° E, 31.2° N) with a stable geotectonic environment and a low-level historical seismicity and happened at February 19, 2013. The focal depth of the earthquake is 10km. The focal mechanism parameters of the Santai earthquake were calculated by Earthquake Administration of Sichuan Province, the results show that the Santai earthquake triggered by a strike fault with EW trending.

(3) Many aftershocks of Wenchuan Earthquake (such as Pixian, Mianzhu, Shifang, Deyang) (Table 1) happened at western Sichuan Basin. These aftershocks should be triggered by Dayi-Pixian fault with reverse-type motion on a NE striking in western Sichuan Basin.

(4) Lushan Earthquake (Ms7.0) earthquake located the south part of Longmenshan mountain range (103.0° E, 30.3° N) and happened at April 20, 2013. The focal depth of the earthquake is 13km. The focal mechanism parameters of the earthquake were calculated by the Institute of Geophysics of the China Earthquake Administration, the results show that the earthquake is triggered by a reverse fault with NE trending. So we consider that the strong earthquake should be caused by the Pengguan fault with reverse-type motion on a NNE striking fault.

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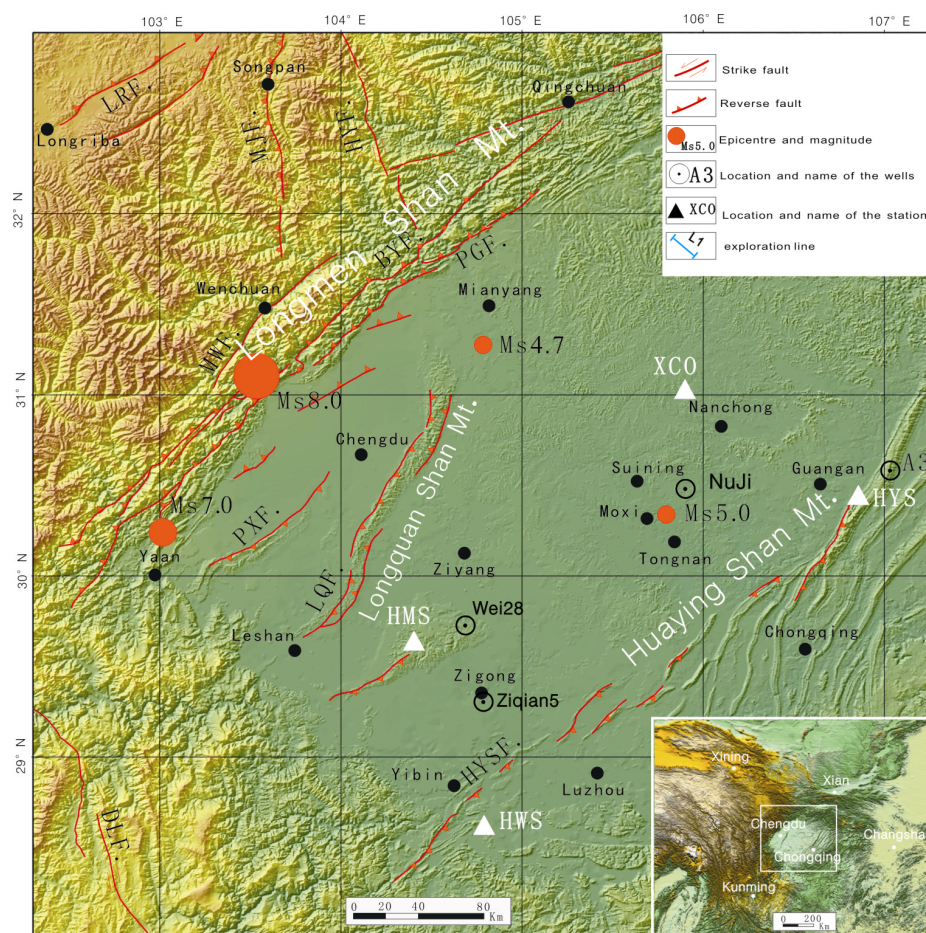


Fig. 1. Earthquakes since 2008 in Longmenshan mountain and Sichuan basin
XCO: Xichong station; HYS: Huaying Shan station; HMS: Mahuashi station; HWS: Hanwang Shan station;
LRF.: Longriba fault; MJF.: Minjiang fault; HYF.: Huya fault; MWF.: Maowen-Wenchuan fault; BYF.:
Beichuan-Yingxiu fault; PGF.: Pengguan fault; PXF.: Pujiang-Xinjin fault; LQF.: Longquanshan fault; HYSF.:
Huayingshan fault.; DLF.: Daliang Shan fault

Table1 Earthquakes and aftershocks of Wenchuan Earthquake in western Sichuan Basin and the southwestern part of Longmenshan mountain

Time	Longitude	Latitude	Depth	Ms	Epicenter	Fault	Location
2008-05-13	103.9°	30.8°	33km	5.0	Pixian		
2008-05-13	104.0°	30.8°	33km	4.0	Pixian		
2008-05-13	104.5°	31.6°	33km	4.5	Anxian		
2008-05-13	104.2°	31.2°	33km	4.3	Deyang	Dayi-Pixian fault, reverse-type motion on a NE striking fault	Western Sichuan Basin
2008-07-15	104.0°	31.6°		5.0	Mianzhu		
2009-06-30	104.1°	31.4°	20km	5.6	Mianzhu		
2009-11-28	103.9°	31.3°	21km	5.0	Shifang		
2010-01-31	105.7°	30.3°	10km	5.0	Suining	Reverse-type motion on a NE striking fault	Center of Sichuan Basin
2013-02-19	105.2°	31.2°	10km	4.7	Santai	Striking-type motion on a EW striking fault	Western Sichuan Basin
2013-04-20	103.0°	30.3°	13km	7.0	Lushan	Pengguan fault, reverse-type motion on a NNE striking fault	Longmen Shan mountain range

(5)The SE direction-propagation from Longmenshan to Sichuan Basin. The 2010 Suining earthquake and 2013 Santai earthquake in Sichuan Basin were preceded by the 2008 Wenchuan (Ms8.0) earthquake. There are many aftershocks in western Sichuan Basin, and there are many eruption sand and water along Dayi-Pixian fault and Pujiang-Xinjin fault in western Sichuan Basin. This devastating earthquake not only cause the about 10m uplift and 4.5m horizontal crustal shortening and tectonic

loading (eg. $2.6 \pm 1.2 \text{ km}^3$, Marcello de Michele, 2010) immediately in the Longmenshan range, and the horizontal crustal shortening and tectonic loading in turn to cause flexural subsidence and crustal shortening in western Sichuan Basin. So we consider that the tectonic mechanism of the earthquakes in Sichuan Basin is driven by the horizontal crustal shortening and stress adjustment on a shallow detachment after the Wenchuan (Ms 8.0) earthquake. Deformation from Longmenshan thrust belt to

the western Sichuan basin can be separated into six northeast-southwest-striking domains. From west to east, these are ① Longmen Shan thrust belt and related Pengguan fault, Beichuan fault, Wenchuan-Maowen fault; ② the Longmen Shan foothills and related Dayi-Pixian fault, ③ the Xiong Po anticline and related Pujiang-Xinjin fault, ④ the Longquan Shan anticline and faults, ⑤ the Weiyuan anticline, and ⑥ a set of broad folds, referred to as the Huayin Shan folds. The strata exhibit a regional west dip of two to three degrees towards the Longmen Shan in west of the Weiyuan anticline. This dip may be related to loading of the crust by the Longmenshan mountain belt. The longitudinal axis of each domain is parallel to the NE-SW strike of the Longmenshan thrust belt. So we consider that the tectonic deformation of Sichuan Basin is characterized by a series of anticlines and synclines alternately arranged in NE direction. The five major structural trends in the Sichuan Basin are formed by fault-bend or fault propagation folds rooted in detachments, which are triggered by shortening from the Longmenshan mountain belt towards the east into the Sichuan basin. By the seismic reflection data, we can identify three detachment surfaces as the base of the thrust sheets, including: ① a shallow detachment 3–5 km below the surface, ② an intermediate detachment 5–7 km below the surface, ③ a deep detachment 6–15 km below the surface. Geophysical and drilling data near the epicenter area indicate that there exists an underground buried anticline and backthrust faults rooted in detachments between 3630 m and 5934 m. Basing on seismic refraction profile and borehole, we consider that the earthquake is triggered by the backthrust fault of Moxi anticline rooted in detachments at a depth 3–4 km. The backthrust fault in the Moxi anticline are of a good consistency with the focal mechanism results and isoseismal map. So we consider that the buried NE striking backthrust faults (eg. Suining Earthquake) and EW striking faults (eg. Santai earthquake) rooted in detachments are primary driver for the earthquakes in Sichuan basin. The horizontal tectonic shortening caused by Wenchuan Earthquake will result structural deformation on detachment surface. This implies that upper-crustal deformation, decoupled from the lower crust by a series of detachments, is the primary mechanism for generating uplift, folding, faulting and topography in the foothills of the Longmenshan mountain and the five major structural trends in Sichuan Basin. The dynamic pressure drove the backthrust, which rooted on the shallow detachment surfaces, react and trigger the earthquakes in Sichuan Basin.

(6) The SW direction-propagation of earthquake in Longmenshan mountain belt. The Wenchuan earthquake resulted in dextrorotary slip from SW to NE direction in

the Longmenshan structural belt. So after the Wenchuan Earthquake, many geologists pointed that there are different style of faulting between northern and southern part of the Longmenshan mountain, and there is a seismic GAP in the southern part of Longmenshan mountain. We consider that the 2013 Lushan (Ms7.0) Earthquake is triggered by stress adjustment and SW direction-propagation of Wenchuan Earthquake.

(7) The eastern margin of Tibet is marked by an extremely steep mountain front with relief of over 5 km. From the Cenozoic on, the India-Asia collision continuously acted on the Longmenshan thrust belt, and caused thrusting and right-lateral strike-slipping at the Longmenshan thrust belt. Such deformation also had significant impact on the deformation performance of the Sichuan Basin and resulted in fold deformation of the Cretaceous and Paleogene strata. The tectonic shortening in the Sichuan Basin may be caused by the Tibetan Plateau moving to Sichuan Basin in the SEE direction (Molnar and Tapponnier 1975, Tapponnier et al. 1976). The total shortening measured by line length on these structures totals 25.8 km (Hubbard J and Shaw J H. 2009). Evidence for active thrusting, however, is sparse and equivocal, and geodetic surveys constrain active shortening in the Longmenshan to $0 \pm 5 \text{ mm y}^{-1}$ relative to the Sichuan Basin. The lack of a late Cenozoic foreland basin adjacent to the margin is also inconsistent with major thrusting in the margin ranges. But after the 2008 Wenchuan earthquake, the earthquake probability will be increasing in Longmenshan mountain and western Sichuan Basin. The Longmenshan mountain are very weak as a result of the 2008 Wenchuan earthquake. When we say that geohazards are increasing, we usually mean landslides, weather hazards, mudslides, debris flow. Are we being too limited? Could earthquake probability be increasing in Longmenshan mountain and western Sichuan Basin? Could we consider "Lushan earthquake, Suining earthquake, and Santai earthquake" as a "long aftershock" result of the Wenchuan earthquake. Is there a possibility, even very remote, that this one can trigger others?

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Key words: earthquake, active faults, tectonic mechanism, horizontal crustal shortening, backthrust fault, detachment, longmenshan mountain range, western Sichuan Basin, China