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Strike-slip and Thrust Faults in Longmenshan Mountain and Chengdu Basin Constrained by the Terraces of Minjiang River

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Longmenshan Mountain lies along the east margin of Tibetan plateau. It is marked by steep mountain front, high relief and much limited foreland basin. Crust thickening in its west side is prominent, but shortening rate of GPS across is low. A strong earthquake of Mw 7.9 (named Wenchuan earthquake) ruptured the middle and north segment of the mountain in 2008 and formed a 240-km-long rupture zone with fault scarps several meters high, which shed lights on the mechanism of mountain uplifting but also remind us of the seismic risk in this area.

Longmenshan mountain is a thrust nappe and Chengdu basin is its foreland basin controlled by ramp thrusts. The main boundary faults , from hinterland to foreland, are respectively Wenchuan-Maowen fault, Beichuan-Yingxiu fault, Pengxian-Guanxian fault, Piedmont Buried fault, Pujiang-Xinjin fault and Longquanshan fault. The first three belongs to Longmenshan thrust nappe, the others belongs to foreland tectonics. Pengxian-Guanxian fault and Pujiang-Xinjin fault are the west and east boundary faults of Chengdu basin. According to the seismic reflection data, those faults rooted in a common gentle detachment ～20 km deep on the northwestern side, shallowing to no less than 6 km to the southeast.

Mingjiang is a 470-km-long river which originated from the east part of Tibetan plateau and runs from northwest to southeast across Longmenshan and its foreland. Its episodic downcutting formed a staircase of river terraces along the flanks of the valley. There are about eight levels of relict terraces along Minjiang river in the uplifting area. The top three levels are bedrock terraces, poorly preserved and can only see in the upper reach of river. The highest relict river terraces (T8 terrace) is about 580 meters high above the riverbed. T1 terrace, the lowest terrace, is an accumulation terrace. T2 terrace is strath or accumulation terrace. T3 to T5 terraces are strath terraces. The alluvial strata, ten to twenty meters thick, typically have a lower thick gravel layer and a upper thin fine-grained layer. There is loess deposited on the top of the older terraces. For T1 terrace, there is no loess. For T2 and T3 terrace, the loess is greyish yellow, a bit thicker on T3 terrace. On the top of T4 terrace, the lower part of loess is light brown red paleosol and the upper part is greyish yellow. Plenty of datings have been done on the upper fine-grained alluvia which may roughly representing the abandonment ages of the ancient riverbeds. The ages of T1 to T5 terraces are respectively ～7 ka BP, ～17 ka BP, ～40 ka BP., ～60 ka BP and ～85 ka BP. The ages of relict terraces of different reaches are consistent well, which means that the aggradation and downcuting of the river is synchronous and mainly controlled by climate changes. The relict terraces of different reaches were surveyed by the GPS and correlated based on the datings, elevations above riverbed and stratigraphic sequences (Fig. 1(d)).

The river terraces were tectonically deformed and recorded the tectonic processes. The slips of the main boundary faults were discussed based on surveyings of river terraces (Table 1, Table 2). Wenchuan-Maowen fault is a steep dextral fault with reverse component, but the others are dominantly thrusting with nearly no lateral slips. The details are as follows: (1) Wenchuan-Maowen fault is the west boundary fault of Longmenshan mountain which distributed along the west valleyside of Minjiang river. The fault did not rupture in 2008 Wenchuan earthquake, but it was active in late Quaternary(Fig. 1(a) ～ (b)). The T4 terraces of Minjiang river were displaced right-laterally by 95 to 110 meters, and vertically by 12 to 15 meters. The average dextral slip rate is about 1.6 to 1.8 mm/yr, and vertical slip rate is about 0.20 to 0.3 mm/yr. (2) Yingxiu-Beichuan fault is in the middle of Longmenshan mountain. The fault reversely displaced all levels of Minjiang river terraces with older ones having more vertical slips. The coseismic vertical slip of 2008 Wenchuan earthquake across Minjiang river was ～3.0 meters (Fig. 1(c)). All levels of river terraces has no visible lateral slips. Its average vertical slip rate in late Quaternary is ～0.4 to 0.7 mm/yr. (3) Pengxian-Guanxian fault is in the front of

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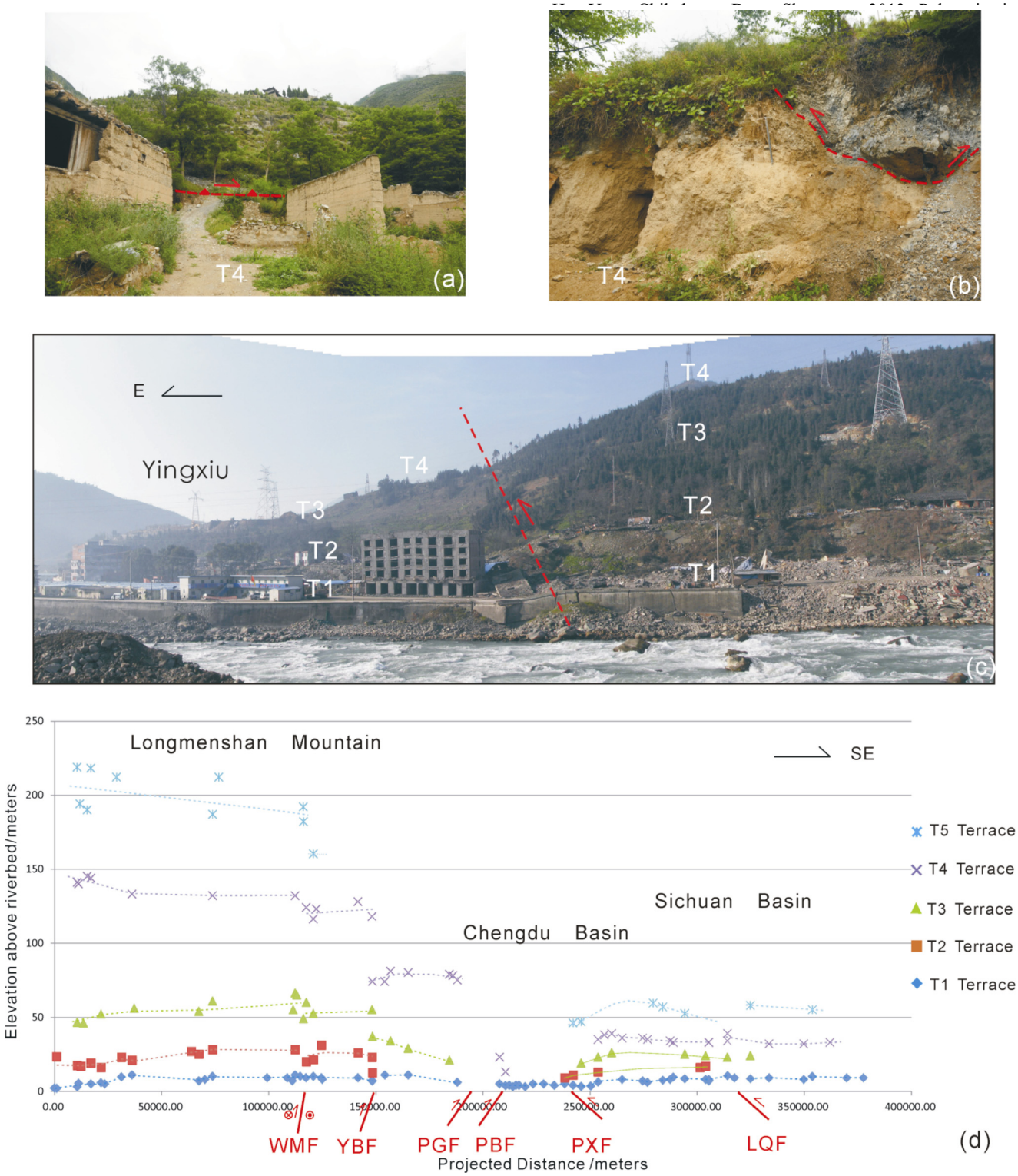

Fig. 1 Minjiang river terraces displaced by the boundary faults of Longmenshan thrust nappe and its foreland basin
(a) Fault scarp of Wenchan-Maowen fault along the rear edge of T4 terrace of Minjiang river on the west valleyside near Qiaoqiaocun village, saw teeth on the red dash line point to hangingwall; (b) Outcrop of Wenchan-Maowen fault, Proterozoic limestone thrusted on late Quaternary colluvial deposits at the top of T4 terrace of Minjiang river near Qiaoqiaocun village. (c) Terraces of Minjiang river were displaced by Yingxiu-Beichuan fault at Yingxiu town. (d) Longitudinal profiles of river terraces of Minjiang projected along N45°W orientation. WMF-Wenchuan-Maowen fault; YBF-Yingxiu-Beichuan fault; PGF-Peingxian-Guanxian fault, PBF-Piedmont Buried fault; PXF-Pujiang-Xinjin fault; LQF-Longquanshan fault

Table 1 Vertical displacements of different levels of river terraces (meters)

Fault Name	T1 Terrace	T2 Terrace	T3 Terrace	T4 Terrace	T5 Terrace
Wenchuan-Maowen F.			7±4	13±2	27±4
Yingxiu-Beichuan F.	3±0.5	10±1	16±1	40±2	
Guanxian-Anxian F.				61±6	
Piedmont Buried F.				≧13	
Pujiang Xinjin F.		≧6	≧20	≧34	≧42
Longquanshan F.				5±2	13±2

Table 2 Average vertical slip rates of faults（vertical displacement of river terraces divided by their abandonment ages）(m/ka)

Fault Name	T1 Terrace	T2 Terrace	T3 Terrace	T4 Terrace	T5 Terrace
Wenchuan-Maowen F.			～0.18	～0.2	～0.3
Yingxiu-Beichuan F.	～0.4	～0.6	～0.4	～0.7	
Guanxian-Anxian F.				～1.0	
Piedmont Buried F.				≧0.2	
Pujiang Xinjin F.		≧0.4	≧0.5	≧0.6	≧0.5
Longquanshan F.				～0.1	～0.18

Longmenshan mountain. This fault has no obvious surface rupture across Minjiang river during 2008 Wenchuan earthquake, but show coseismic thrust faulting not far to northeast. Its average vertical slip rate in late Quaternary is ～1.0 mm/yr. (4) The Longmenshan Piedmont Buried fault transverses the upper part of Minjiang alluvial fan from southwest to northeast. On its upthrown side (west side), the T4 terrace is ～13 meters above riverbed, but on its downthrown side (east side), the corresponding sediment is buried by younger alluvium. The vertical slip is more than 13 meters. So the average vertical slip rate in late Quaternary is no less than ～0.2mm/yr. (5) The Pujiang-Xinjin fault was formed along the west wing of Xiongpo anticline. It displaced all levels of Minjiang river terraces. The corresponding sediments of terraces on the downthrown side (west side) were buried by younger alluvia. Its average vertical slip rate in late Quaternary is no less than ～0.4 mm/yr. (6) The Longquanshan fault was formed along the west wing of Longquanshan anticline. It displaced all levels of Minjiang river terraces but the vertical slips is smaller than Pujiang-Xinjin fault. Its average vertical slip rate in late Quaternary is ～0.1 to 0.2 mm/yr.

The elevation differences of Minjiang river terraces between Longmenshan mountain and Sichuan basin indicate that the uplifting rate of Longmenshan mountain to Sichuan basin in late Quaternary is ～1.5 mm/yr. Although the 2008 Wenchuan earthquake only caused surface rupture on two faults, considering all the faults mentioned above have roughly equivalent slip rates, the seismic hazard of other faults should be concerned about. Wenchuan-Maowen fault is dominantly dextral slipping with a reverse component, which doesn't support the extrusion proposal between Wenchuan-Maowen fault and Yingxiu-Beichuan fault under the mechanism of lower crust channel flow.

Key words: thrust slip, dextral slip, river terraces, uplifting

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