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Rediscussion on the geodynamics of the 2008 Wenchuan earthquake: New seismic reflection evidence for crustal structure of the Longmenshan

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ABSTRACT

New evidence concerning the middle and upper crustal structure of the Longmen Shan range where the May 12, 2008 M7.9 Wenchuan earthquake occurred is presented on the basis of seismic reflection surveys. The results of seismic reflection profiles clearly show a relatively complete stratigraphic sequence of the Upper Yangtze Basin since the Cambrian. Folding deformation, along with movements along numerous detachment layers, took place in the strata among the Wenchuan–Maoxian Fault (WMF), the Yingxiu–Beichuan Fault (YBF), and the Guanxian–Anxian Fault (GAF). The WMF is steep in the shallow strata, turning gentler gradually from a depth of 4 km, and more so at depths beyond 7 km. The WMF imbricates with the YBF and GAF, and they do not converge within the top 15 km of the crust. This interpretation disagrees with the viewpoint that the YBF and GAF extend with subvertical trend to a depth of 20 km with a robust relationship between the hypocenters and the subsurface faults and fold geometries. We conclude that the sub-horizontal detachment layers where most aftershocks occurred are the major causative fault, instead of the YBF. The YBF might be an earthquake-propagating fault according to our seismic reflection data and the distribution of aftershocks. The overlying rigid and rootless Pengguan complex (~3–4 km) might aggravate the damage to the YBF. Furthermore, there exists a new high-angle, listric structures vertical coseismic fault, which is able to link the seismogenic detachment layer and the shallow YBF together and resulted in huge damage of the YBF.

1. Introduction

Since the continental collision between India and Eurasia, the Tibetan Plateau has undergone large-scale uplift, leading to violent emergence of the plateau margins (Tapponnier et al., 2001; Xu et al., 2011). On the eastern margin of the Tibetan Plateau, the Longmen Shan fault (LMSF) zone rises 6000 m above the Sichuan Basin (SB) (Burchfiel et al., 1995; Xu et al., 2008; Densmore et al., 2010). The LMSF is composed of three major thrust faults oriented from west to east: the Wenchuan–Maoxian Fault (WMF), the Yingxiu–Beichuan Fault (YBF) and the Guanxian–Anxian Fault (GAF) (Fig. 1). However, the Longmen Shan range exhibits greater topographic relief than anywhere else on the plateau, and the east–west crustal shortening across the range is very limited (< 3 mm/yr), as observed from the absolute plate motion (GPS) data (Wang et al., 2001; Shen et al., 2005). Although the uplift, structures, and evolution of the Longmen Shan range have been the subject of long-standing debate in the past three decades (Deng et al., 1994; Jia et al., 2010; Robert et al., 2010; Luo and Long, 1992; Qiao et al., 2012; Wang et al., 2008a; Yuan et al., 2000), they are difficult to simply ascribe to thrust faulting and crustal shortening because of the lack of a typical foreland basin (Burchfiel et al., 1995), and the small amount of shortening across the range and low levels of seismicity prior to the Wenchuan earthquake (Deng et al., 1994; Wen and Yi, 2003).

After the disastrous Wenchuan Mw 7.9 earthquake on May 12, 2008 (Fig. 2), there came a new stage of discussions about the subsurface geologic structures of the Longmen Shan range and the relationship between the hypocenters and the Longmen Shan thrust belt (Xu et al., 2008; Xu et al., 2009; Hubbard and Shaw, 2009; Li et al., 2010). There are two entirely different perspectives about the fault geometries and tectonic evolution of the Wenchuan earthquake in the Longmen Shan: (1) the ramp-steep geometry of the YBF connecting directly from the hypocenter to the surface rupture (Deng et al., 1994, 2011; Xu et al., 2008; Lou et al., 2008; Lü et al., 2008; Zhang et al., 2010); (2) weak relationships between the displacements in Wenchuan earthquakes and

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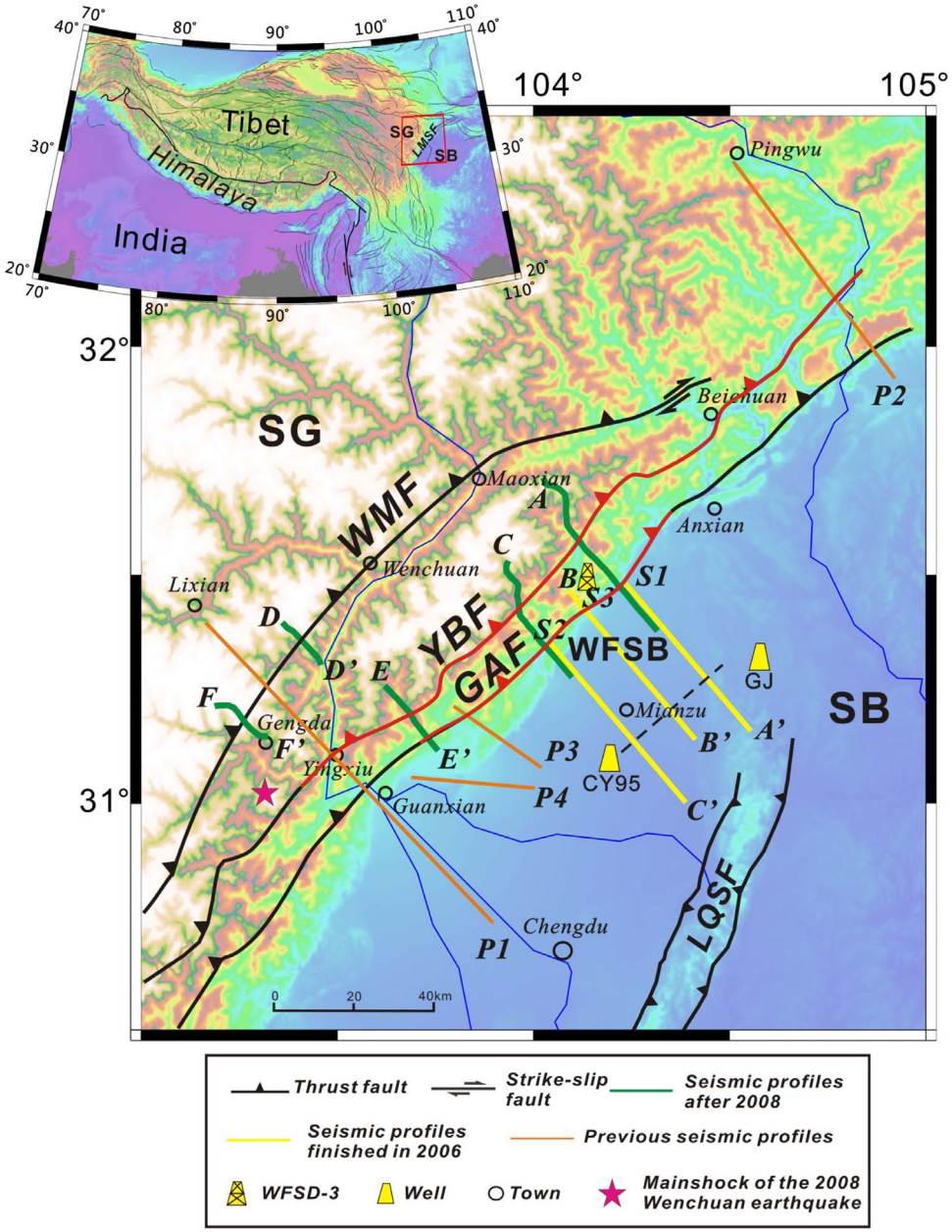

Fig. 1. Location Map of Longmen Shan fault and profiles. Black lines are major active faults (Burchfiel et al., 1995; Xu et al. 2008) and red lines represent coseismic ruptures caused by the 2008 Mw 7.9 Wenchuan earthquake (Zhang et al., 2010). LMSF = Longmen Shan fault; WMF = Wenchuan–Maoxian Fault; YBF = Yingxiu–Beichuan Fault; GAF = Guanxian–Anxian Fault; LQSF = Longquanshan Fault (border fault of uplifted foreland basin); SG = Songpan-Ganzi terrane; SB = Sichuan Basin; WSFB = Western Sichuan Foreland Basin; AA' = Hanwang seismic reflection profile; BB' = the second West Sichuan profile; CC' = Mianzhu seismic reflection profile; DD' = North Hongkou seismic reflection profile; EE' = South Hongkou seismic reflection profile; FF' = Gengda seismic reflection profile; CY95 = Chuanya 95 Well; GJ = Guanji Well. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the subsurface fault and fold geometries (Xu, 1993; Lu et al., 2010; Jia et al., 2003). However, the differences between the southern and northern segments are highlighted by integrating geological investigations, relocated aftershocks, and seismic reflection profiles (Jia et al., 2010; Li et al., 2010). For example, Jia et al. (2010) suggested that coseismic surface ruptures coincided with both YBF and Pengguan faults in the southern segment, which become incorporated into the deep main detachment and extend directly to the hypocenter of the Wenchuan main shock, whereas low-angle thrust faults existed in the northern segment that ramp up either directly from the main detachment or from higher level ones; and (3) Seismogenic faults occurred along relatively high-angle structures that cross-cut the low-angle imbricate fold-and-thrusts. For example, Zhang et al. (2015) recently presented an analysis of aftershocks following the 2008 Wenchuan event. The results suggest that these aftershocks occurred along relatively high-angle structures and the geometry of the coseismic fault dips greater than 40°.

The Wenchuan Earthquake Fault Scientific Drilling (WFSD) project, initiated as an extremely rapid response to the Wenchuan earthquake, provides a unique opportunity to investigate the faulting mechanism (Li et al., 2013). The YBF near the surface exhibits a high-angle thrust feature, which has a dip angle of 68°–73° above ~760 m-depth, as evidenced by analysis of drill core data from WFSD-1 (Li et al., 2013). According to WFSD-3, the dip angle of the GAF is ~46° at a depth of 506 m and ~38° at a depth of 1250 m, indicating that the GAF is probably a listric thrust fault with low dip angle (Yang et al., 2012). As an efficient method to reveal a deeper geologic structure in the upper crust, we conducted five seismic reflection profiles across the LMSF

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