Tectonophysics 619-620 (2014) 159–170

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

High-angle fault responsible for the surface ruptures along the northern segment of the Wenchuan Earthquake Fault Zone: Evidence from the latest seismic reflection profiles

Chan Wu [a,b,*], Haibing Li [a,b,**], Philippe Hervé Leloup [c], Changqing Yu [a,b], Jialiang Si [a,b], Dongliang Liu [a,b], Jiawei Pan [a,b], Marie-Luce Chevalier [a,b], Zheng Gong [a,b]

[a] State Key Laboratory of Continental Tectonics and Dynamics, Beijing 100037, People's Republic of China
[b] Institute of Geology, Chinese Academy of Geological Sciences, No. 26, Baiwanzhuang Road, Beijing 100037, People's Republic of China
[c] Laboratoire de Géologie de Lyon: Terre, Planètes et Environnement, UMR CNRS 5276, Université Claude Bernard — Ecole normale supérieure de Lyon, 2 rue Raphaël Dubois, 69622 Villeurbanne, France

ARTICLE INFO

Article history:
Received 13 March 2013
Received in revised form 7 September 2013
Accepted 11 September 2013
Available online 17 September 2013

Keywords:
Wenchuan earthquake fault zone
Yingxiu-Beichuan fault
Surface rupture
Seismic reflection profile
Focal mechanism

ABSTRACT

The inverse/right-lateral Yingxiu–Beichuan fault ruptured during the Wenchuan earthquake for ~270 km. We investigated the northeastern segment of that fault by analysing 3 newly acquired and 3 older seismic lines that cross the fault. We combine this analysis with that of the surface ruptures and of the regional geology in order to discuss the geometry, the style and the amount of motion of the fault. We conclude that the Yingxiu–Beichuan fault is very steep (~70°) at the surface and has still a dip > 45° at 6 km depth. The fault offsets all previous structures and particularly the Tangwangzhai nappes from which a vertical offset of 3 to 6 km is evaluated. The right-lateral component of motion along the Yingxiu–Beichuan fault appears to be larger at the surface than at depth and increases only slightly towards the NE. We suggest that the Yingxiu–Beichuan fault is continuous at depth between its northern and southern segments.

1. Introduction

The 12th May 2008 Wenchuan earthquake (Mw 7.9), which occurred in the Longmen Shan (LMS) fold–thrust belt at the eastern margin of the Tibetan Plateau, was one of the largest intracontinental thrust event ever recorded, and a major disaster with more than 80,000 deaths and thousands of people missing (e.g., Stone, 2008). The earthquake created an ~240–270 km-long, coseismic rupture zone with typical surface vertical and right-lateral offsets up to 7 m, with exceptional offsets of 11 m in Beichuan (e.g., H.B. Li et al., 2008a, 2008b, 2010; Lin et al., 2009; Liu et al., 2008; Liu-Zeng et al., 2012; Xu et al., 2009). Such large reverse/right-lateral motion was not expected because geodetic measurements (e.g., Chen et al., 2000; Meade, 2007; Shen et al., 2005; Zhang et al., 2004) and some geomorphologic observations (Densmore et al., 2007) were implying limited, if not negligible (≤4 mm/year), shortening across the range (e.g., Stone, 2008). This appeared to be confirmed by a relatively low historical seismicity (e.g., Chen et al., 1994). Furthermore, despite the fact that the LMS range corresponds to the steepest topographic margin of the Tibetan plateau and shows evidences of Miocene exhumation (e.g., Arne et al., 1997; Godard et al., 2009; Wang et al., 2013), the absence of a typical foreland basin have led to the assertion that during the Cainozoic the LMS range was mostly the site of NE–SW right-lateral transpression (e.g., Burchfiel et al., 1995; Densmore et al., 2007) and/or the result of lower-crustal channel flow buttressing against the Sichuan basin (e.g., Burchfiel et al., 1995, 2008). This was at odds with interpretations seeing the LMS range as resulting from ongoing shortening between the Tibet and Sichuan since the Oligo-Miocene (e.g., Avouac and Tapponnier, 1993; Hubbard and Shaw, 2009; Tapponnier et al., 2001).

The Wenchuan earthquake raises several questions on how long-term deformation is taken up at the eastern margin of the Tibetan plateau. One aspect is that the Wenchuan earthquake rupture pattern is quite complex with simultaneous slip on the two sub-parallel Yingxiu–Beichuan and Guanxian–Anxian faults. The Yingxiu–Beichuan (Y–B) fault is the longest and shows an oblique reverse/right-lateral motion. Focal mechanisms (Huang et al., 2008; Wang et al., 2009), seismic source inversion (Chen et al., 2008; Nakamura et al., 2010), surface offsets (e.g., An et al., 2010; Fu et al., 2008, 2011; C.Y. Li et al., 2008; H.B. Li et al., 2008a, 2008b, 2010; Lin et al., 2009; Liu-Zeng et al., 2008, 2012; Xu et al., 2009) and SAR interferometry (De Michele et al., 2010) suggest that the proportion of horizontal motion increases from the SW to the NE. Because the LMS topography is more subdued to the NE, some have inferred

* Correspondence to: C. Wu, Institute of Geology, Chinese Academy of Geological Sciences, No. 26, Baiwanzhuang Road, Beijing 100037, People's Republic of China. Tel.: +86 13691031590.
** Correspondence to: H.B. Li, Institute of Geology, Chinese Academy of Geological Sciences, No. 26, Baiwanzhuang Road, Beijing 100037, People's Republic of China. Tel.: +86 13910386056.
E-mail addresses: wuchan10@126.com (C. Wu), lihaibing06@163.com (H. Li).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.09.015

that the long-term deformation pattern mimics the Wenchuan earthquake surface rupture (e.g., Jia et al., 2010). If this is true, it is not clear if strike-slip motion takes place on thrusts with classical type flat-ramp geometry or on steeper faults. It is also unclear what would be the cause for such unusual oblique slip on such a large fault.

In this paper, we discuss the possible geometry of the Y–B fault at depth in the Beichuan–Nanba area in the northern LMS where the fault seismic offsets have a large horizontal component. We use three new, and three published seismic reflection profiles perpendicular to the fault, published focal mechanisms, as well as surface geology to discuss how the short-term and long-term deformation were taken up in this area and the implications for the LMS tectonics.

2. Tectonic setting

The NE–SW trending Longmen Shan (LMS) fold–thrust belt (~500 km long and 30–50 km wide), lies at the transition zone between the ~4000 m high Tibetan Plateau and the ~500 m high Sichuan basin (Fig. 1). The plateau corresponds to a wide zone of folded Triassic sediments, usually referred to as the Songpan–Ganzi flysch (e.g., Jia et al., 2006; Mattauer et al., 1985; Sengör and Hsü, 1984; Xu et al., 1992), whilst the basin is filled with a thick Mesozoic detrital sequence spanning from Triassic to Cretaceous topped by limited Tertiary sediments (e.g., Burchfiel et al., 1995). The LMS culminates at 4989 m (Jiuding Shan) and exhibits three main NW dipping faults affecting the

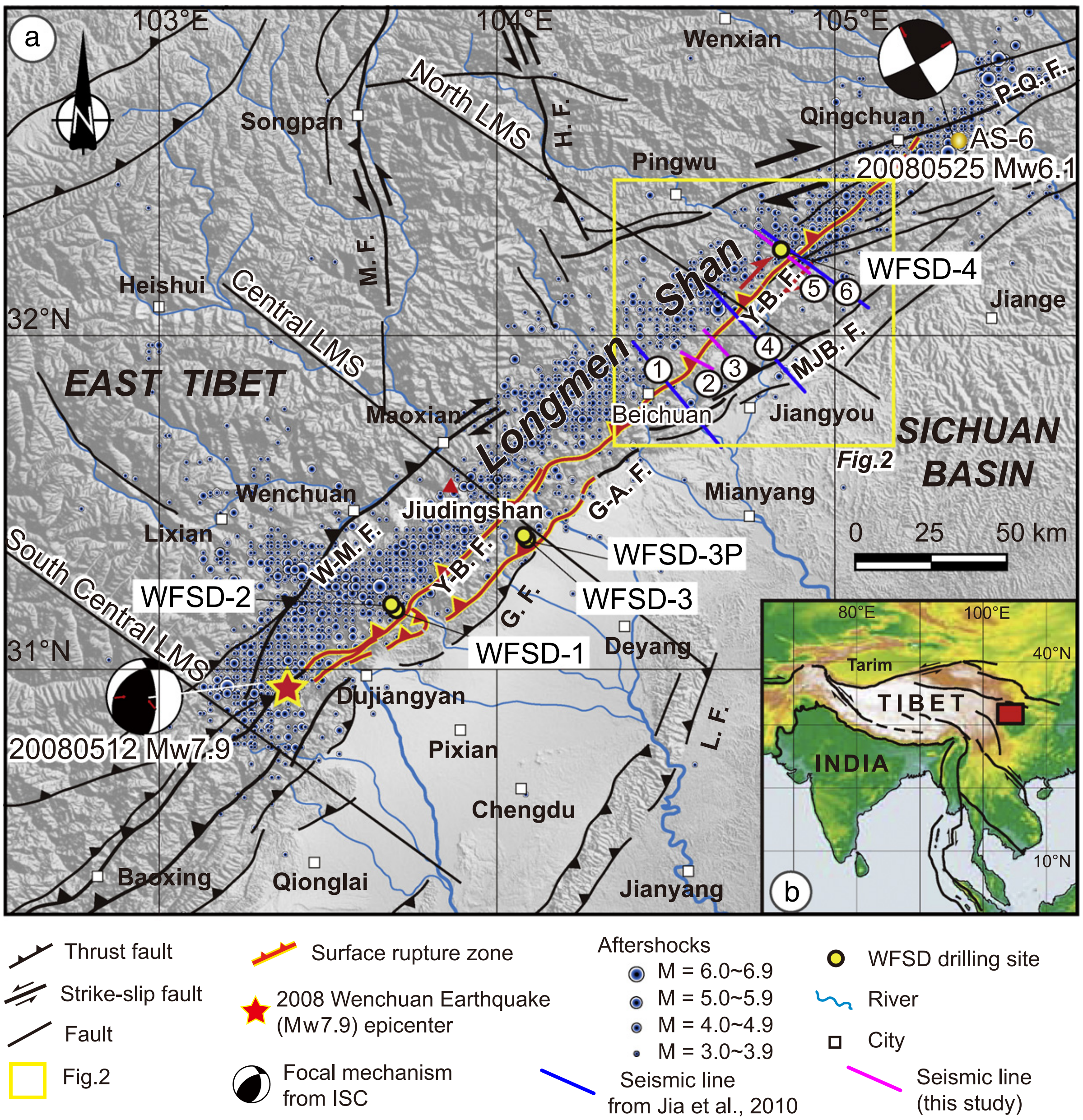

Fig. 1. Active tectonics of the Longmen Shan fold–thrust belt. (a) Faults considered as active from geomorphological arguments (black lines, H.B. Li et al., 2009), Wenchuan earthquake surface rupture (red line from H.B. Li et al., 2008b), and aftershocks (M ≥ 3 for 2 years after the main shock, from USGS and CNC data). The focal mechanisms of the two largest earthquakes are plotted (ISC data, http://www.isc.ac.uk/event_bibliography, lower hemisphere). Faults names: M. F. — Minjiang fault; MJB. F. — Majiaoba fault (the northern segment of the Guanxian–Anxian fault); H. F. — Huya fault; L. F. — Longquan Shan fault; W–M. F. — Wenchuan–Maoxian fault; P–Q. F. — Pingwu–Qingchuan fault; Y–B. F. — Yingxiu–Beichuan fault; G–A. F. — Guanxian–Anxian fault; G. F. — Guankou fault. Yellow circles locate the WFSD drilling sites and blue and pink straight lines indicate the seismic lines (the blue ones from Jia et al., 2010). The yellow box corresponds to Fig. 2. (b) Inset map showing location of the Longmen Shan belt. Red box corresponds to panel a. All stereographic projections are Schmidt lower hemisphere.