Tectonophysics 630 (2014) 43–53

Contents lists available at ScienceDirect

Tectonophysics

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

Structural model of the central Longmen Shan thrusts using seismic reflection profiles: Implications for the sediments and deformations since the Mesozoic

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ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 30 April 2014
Accepted 5 May 2014
Available online 11 May 2014

Keywords:
Beichuan fault
Wenchuan earthquake
Multiple detachment
Structural wedge
Basement structure
Longmen Shan thrust belt

ABSTRACT

The structural setting and deformation history are very important aspects of understanding the frequent earthquakes and assessing the hazards. In this paper, we interpret two new seismic profiles that were collected after the Wenchuan Mw7.9 earthquakes occurred on May, 2008. Our interpretation has integrated four wells, three seismic profiles and the surface geology to reveal structural characteristics of the central Longmen Shan thrust. The drilled wells reveal that there are two detachments within the upper Triassic and the lower Triassic at the Longmen Shan thrusts. The shallow detachment fault transferred its slip to the basin and made another deformation inner the Sichuan basin. Between the shallow detachments, many faults developed and the major structures at the thrust front have formed as structural wedges. Both the drilled wells and seismic interpretation show the upper Triassic repeated in the depth. The shortening at the central Longmen Shan thrust is approximately 30%–37%. According to geological survey and the seismic interpretation, the foreland basin was developed during the late Triassic and the angular unconformity between the lower Jurassic and the upper Triassic at the Longmen Shan front. Several different tectonic events can be identified since the Mesozoic, which indicated that the Longmen Shan has a complex evolution history. In our model, the major Beichuan fault (F2) and the Pengguan fault (F3) at the central Longmen Shan dip steeply near the surface but are more gentle-dipping at depth. Both of the shallow thrusting and the basement shortening made contribution to the rapid uplift of the Longmen Shan during the Cenozoic. The co-seismic ruptured fault is like a branchy fault that developed on the major fault system. The Wenchuan Mw7.9 earthquake and the Lushan Mw6.7 earthquake may be related to the reaction of the basement structures.

1. Introduction

The Longmen Shan thrust belt, located at the eastern margin of the Qinghai–Tibet Plateau (Fig. 1), has a long, complicated tectonic evolution history that continues to the present day (Deng et al., 1994; Liu et al., 1996; Luo et al., 1994; Tapponnier et al., 2001; Zhang et al., 2013). The Wenchuan Mw7.9 earthquake occurred on May 12, 2008 and produced two large surface ruptures along the Beichuan–Yingxiu fault (F2) and Pengguan fault (F3) that caused extensive damage and loss of life (Xu et al., 2008, 2009). Numerous aftershocks last occurred in recent years at the southeastern margin of the Qinghai–Tibet Plateau. The April 20, 2013 Lushan Mw6.7 earthquake happened at the southern segment of Longmen Shan (Wang et al., 2013a; Xu et al., 2013), indicating that the faults of the southern segment is active.

After the occurrence of the 2008 Wenchuan earthquake, many tectonic and geodynamic models of the Longmen Shan area have been proposed in the literature (e.g. Burchfiel et al., 2008; Guo et al., 2013; Hubbard and Shaw, 2009; Royden et al., 2008; Xu et al., 2009; Zhang et al., 2010). These published models have been constrained by seismic reflection profiles (Jia et al., 2010), seismological and gravity data (Robert et al., 2010), magnetotelluric data (Zhao et al., 2012), regional seismic tomography models (Pei et al., 2010), and seismic cycle deformation modeling (Luo and Liu, 2010). Of these studies, seismic reflection profiles have provided the clearest constraint on the detailed upper crustal structure of the Longmen Shan (Hubbard et al., 2010; Jia et al., 2006; Li et al., 2010). However, it's little known about the sedimentary–tectonic background of the Longmen Shan since the Mesozoic. In particular, the relationship between the surface co-seismic ruptures and the deep structures is unclear. The Lushan earthquake was a case

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http://dx.doi.org/10.1016/j.tecto.2014.05.003
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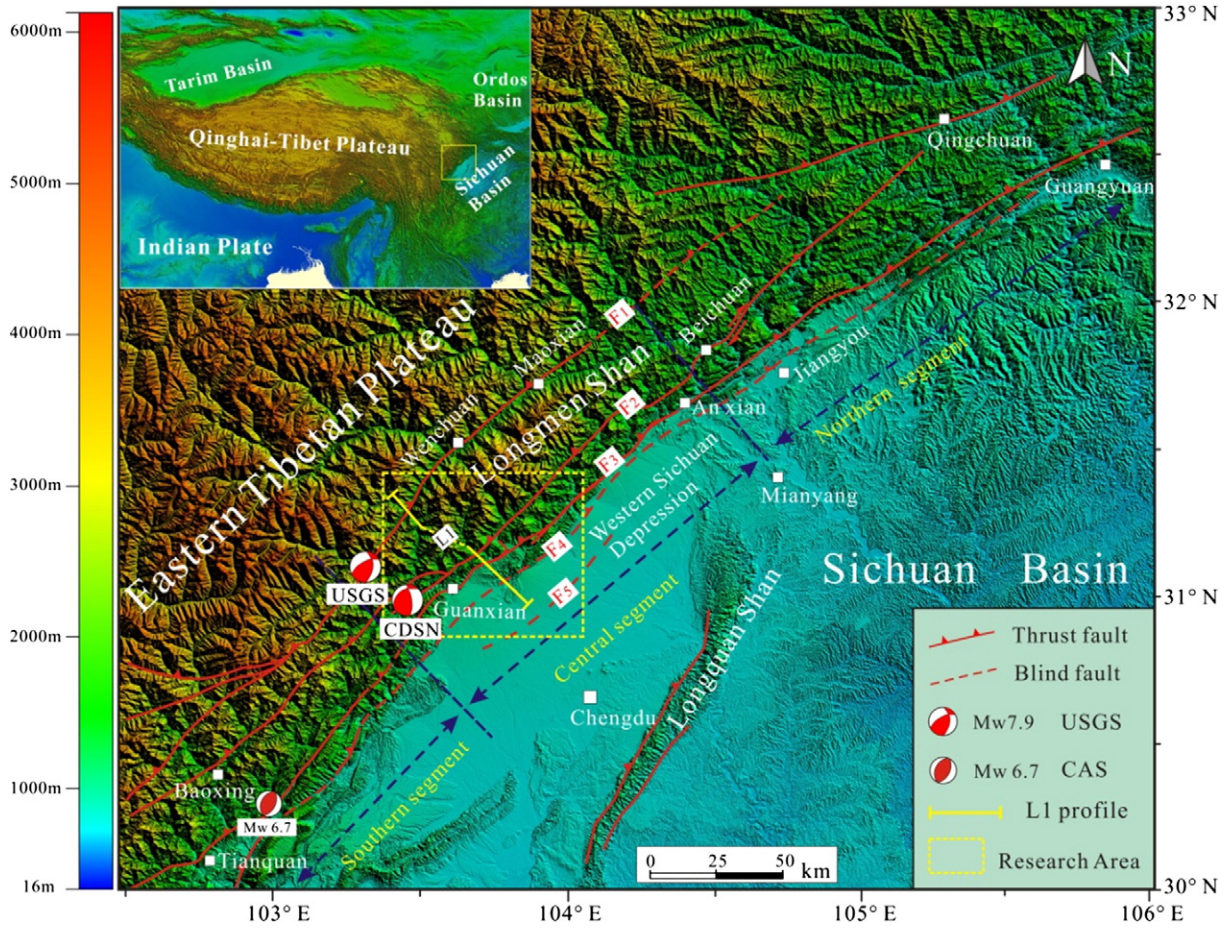

Fig. 1. Digital elevation (DEM) map showing major thrust faults in the Longmen Shan and location of the 2008 Wenchuan earthquake and 2013 Lushan earthquake (modified from Xu et al., 2013). Inset map shows position of the study area relative to Tibet. F1: Qingchuan–Maowen fault; F2: Beichuan–Yingxiu fault; F3: Pengguan fault; F4: Guankou blind fault; F5: Pengxian blind fault (the same to below legends).

and indicated previously undetected seismogenic hazards at the Longmen Shan (Ren et al., 2012; Wang et al., 2013b; Xu et al., 2013).

In this paper, we interpret two new seismic reflection profiles that were collected to study the Wenchuan earthquakes and specifically design to reveal the detailed structure of the Longmen Shan thrusts. For comparison, we also interpret a seismic profile extracted from 3D seismic data. In comparison to 2D seismic profiles, 3D seismic data have the advantage that seismic reflectors are generally more accurately positioned (Cartwright and Huuse, 2005). The seismic interpretation presented here is further constrained by surface geology and subsurface geology revealed by four well penetrations. These four wells include the Wenchuan Fault Scientific Drilling project wells WFSD-1 and WFSD-2 that targeted the Beichuan fault zone structure and provided important constraints from the basin to the thrust belt (Li et al., 2013, 2014; Nie et al., 2013; Zhang et al., 2012). Fault-related folding theories and axial surface analysis were used to constrain the seismic interpretation (Shaw et al., 2004; Suppe, 1983). These data and constraints are integrated to present a new structural model for the central segment of Longmen Shan thrusts.

2. Geological setting

The Longmen Shan thrust belt experienced at least two major periods of contractional deformation in the Late Triassic and Cenozoic (Burchfiel et al., 1995; Godard et al., 2009; Jia et al., 2006; Yin, 2010). During the Late Triassic, the tectonic setting changed from a rifted passive margin to a foreland setting in response to the final closure of the Paleo-Tethys and the continent–continent collisions of the North China, South China and Qiangtang blocks (Chen et al., 1995; Liu et al., 2009). During the Cenozoic, the tectonism in the Longmen Shan was reactivated by the India–Asia collision (Royden et al., 2008), and caused thrusting, dextral shear and dramatic uplift (Chen and Wilson, 1996; Densmore et al., 2007). The Longmen Shan thrust belt is at present composed of a series of NE striking thrust sheets bounded by several NW-dipping thrusts (Fig. 1).

The Longmen Shan thrust belts are to the north of Guangyuan (Fig. 1). It crosses Jiangyou, An'xian and Guan'xian to Tianquan in the south, and has a total length of about 400 km (Lin and Wu, 1991; Zhao et al., 1994). Generally, the Longmen Shan thrusts were distinguished by the Qingchuan–Maowen fault (F1), the Beichuan–Yingxiu fault (F2), the Pengguan fault (F3). The Guankou blind fault (F4) and the Pengxian blind fault (F5) look like the blind faults at the frontal mountain and inner basin (Luo et al., 1994). The longmen Shan thrusts are divided into three segments along the strike: the north segment, the central segment and the south segment (Bai et al., 2010; Li et al., 2012).

In our research area (Figs. 1 and 2), the outcrops include Sinian to middle Triassic shallow marine clastics and carbonate rocks and Late Triassic to Cretaceous non-marine clastics (Liu et al., 1996; Ma and Yang, 2001). The WFSD-2 well is located on top of the Pengguan Complex. Many klippes have formed on top of the upper Triassic. The Beichuan–Yingxiu fault (F2) and the Pengguan fault (F3) ruptured co-