Earth and Planetary Science Letters 379 (2013) 72–80

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Imaging the crustal structure beneath the eastern Tibetan Plateau and implications for the uplift of the Longmen Shan range

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ARTICLE INFO

Article history:
Received 25 March 2013
Received in revised form 31 July 2013
Accepted 1 August 2013
Available online 28 August 2013
Editor: P. Shearer

Keywords:
eastern Tibetan Plateau
Longmen Shan block
deep seismic reflection profile
crustal structure
uplift of the Longmen Shan range

ABSTRACT

Competing models have been proposed to account for the unusual uplift of the Longmen Shan fault zone in the eastern Tibetan Plateau and resulting hazards. However, due to the terrain and thick sedimentary cover, the crustal structure of the eastern Tibetan Plateau remains uncertain. Therefore, testing these models has been difficult. In 2011, a 310 km long, SE-trending SinoProbe-02 deep seismic reflection profile was recorded in easternmost Tibet in order to study its regional crustal structure. The resulting image revealed the detailed crustal structure of eastern Tibet, which when combined with geological, GPS (Global Positioning System), and geochemical evidence, strongly suggests that Yangtze sub-continent crust extends beneath the region. The seismic profile also images the tremendously thick Triassic sedimentary cover in the Songpan-Ganzi terrane (SGT). These Triassic sediments vary considerably in thickness across several crustal blocks. In addition, both the Longriba fault zone of the northeastern SGT and the Longmen Shan fault zone show strong intracrustal reflections that terminate at a depth coinciding largely with the crust–mantle boundary (Moho). Accordingly, we propose a new tectonic model based on an integrated analysis of this seismic reflection profile and previous GPS measurements. In this model, crustal-scale deformation is suggested to have participated in the oblique extrusion and uplift of the easternmost edge of the Tibetan Plateau along the Longmen Shan. In a broader context, the lithospheric configuration imaged by the seismic reflection profile will advance our understanding of the tectonic response of the eastern Tibetan Plateau to the ongoing India–Eurasia collision and has new implications for the estimating seismic risk in the region.

1. Introduction

On 12 May 2008, the devastating Mw 7.9 Wenchuan Earthquake struck the Longmen Shan (LMS) thrust belt along the eastern margin of the Tibetan Plateau (Fig. 1a). This was the largest destructive earthquake in China in recent years. It caused ∼80,000 fatalities and physical damages of ∼$100 billion US. Although some researchers have recognized the long-term regional hazards (Densmore et al., 2007), the underestimated seismic risk and poor preparation for a large earthquake were attributed due to the relative quiescence of seismic events on the LMS fault zone (Figs. 1a and 1b). The LMS fault zone consists of a series of northwest dipping thrust faults, including the Wenchuan-Maowen fault in the northwest, the Beichuan fault in the middle and the Pengguan fault to the southeast. The Pengguan fault merges with the Beichuan fault and the Beichuan fault roots into a deep detachment at 15–17 km depth (Li et al., 2010). How far the Wenchuan-Maowen fault extends downward, so far, remains uncertain.

Even today, the cause of the LMS thrust-Nappe belt uplift and resulting large earthquakes remains uncertain. There are at least six end-member models proposed regarding the unusual uplift of the LMS fault zone (see review by Yin, 2010); (1) channel flow in the mid and lower crust (Royden et al., 1997, 2008; Zhao et al., 2012) (Fig. 2a), (2) upper-crustal deformation associating with a series of detachments (Hubbard and Shaw, 2009; Hubbard et al., 2010) (Fig. 2b), (3) pure-shear deformation of the whole Tibetan lithosphere (Robert et al., 2010; Yin, 2010) (Fig. 2c), (4) simple-shear shortening of the whole Tibetan lithosphere (Yin, 2010) (Fig. 2d), (5) uplift of the eastern Tibet is associated with westward underthrusting of the Yangtze crust beneath (Clark et al., 2005; Jiang and Jin, 2005) (Fig. 2e), (6) crocodile-type accommodated by indentation of rigid Yangtze crust into the weak SGT (Cai et al., 1996; Zhang et al., 2004) (Fig. 2f). Different models were proposed partly due to the uncertain crustal structure of the eastern Tibetan Plateau that is in general covered by the thick Triassic flysch cover (5–15 km) (Nie et al., 1994; Zhou and Graham, 1996). Testing these models has therefore been difficult. Although many primarily geological and geochemical studies have indicated the possible existence of the Yangtze sub-continental block (YB) beneath eastern Tibet (Burchfiel et al., 1995; Zhang et al., 2006;

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0012-821X/$ – see front matter
http://dx.doi.org/10.1016/j.epsl.2013.08.005

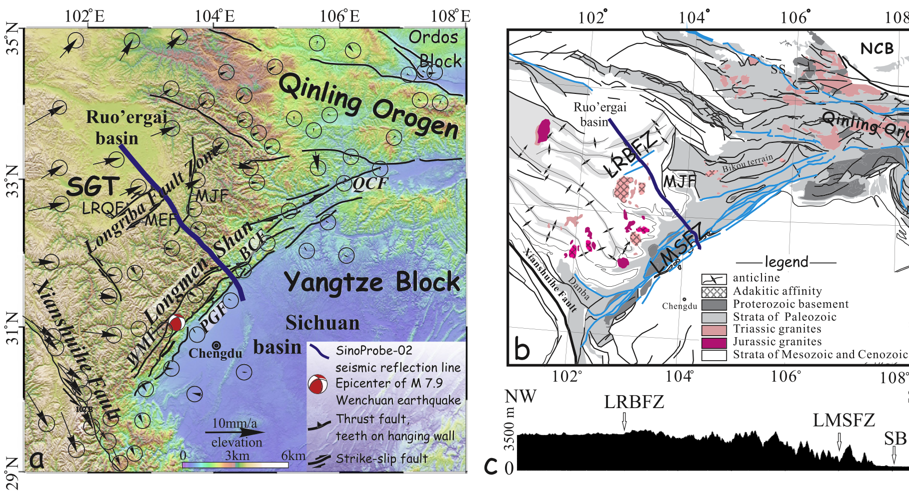

Fig. 1. (a) Topographic map of the eastern Tibetan Plateau and Sichuan basin, showing the location of SinoProbe-02 deep seismic reflection profile as a purple line. GPS velocity vectors (Shen et al., 2005, 2009; Zhu and Zhang, 2010) are plotted relative to the Yangtze block. (b) Generalized geological map of the research area based on the 1:2.5 million scale geological map of China. (c) Topographic relief along the seismic reflection line; SGT: Songpan-Ganzi Terrane; WMF: Wenchuan-Maowen Fault; BCF: Beichuan Fault; QCF: Qingchuan Fault; PGF: Pengguan Fault; LRBFZ: Longriba Fault Zone; LRQF: Longriqu Fault; MEF: Mao'ergai Fault; MJF: Minjiang Fault; LMSFZ: Longmen Shan Fault Zone; SB: Sichuan Basin.

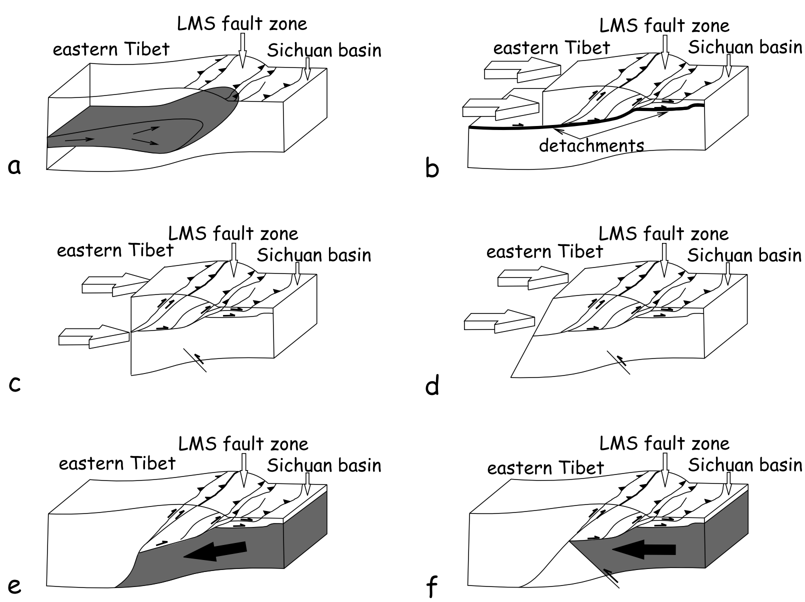

Fig. 2. Previously proposed tectonic mechanism to account for the unusual uplift of the Longmen Shan fault zone; (a) the lower crustal flow model; (b) the upper-crustal deformation model; LMS: Longmen Shan; (c) Pure-shear model; (d) Simple-shear model; (e) Underthrusting of the Yangtze crust beneath the Songpan-Ganzi terrane; (f) Indentation of the Yangtze crust beneath the Songpan-Ganzi terrane.

Roger et al., 2010), the westward extent of the Yangtze crust and crustal structure of eastern Tibet have never been fully imaged. Thus, an important constraint on the uplift mechanism of the LMS thrust belt and subsequent natural hazards is lacking. The purpose of this study is to provide needed information on crustal structure beneath eastern Tibet, which is essential to advance our understanding on the tectonic responses to the ongoing Himalayan orogeny and to assess natural hazards.

2. Tectonic setting

During the early Mesozoic, prior to the Indosinian orogeny (Late Permian – Early Jurassic), the Songpan-Ganzi terrane (SGT) was originally a remnant ocean that was filled with thick Triassic flysch derived from adjacent orogenic belts (e.g., Yin and Nie, 1993). This remnant ocean was juxtaposed against the passive margin of the YB to the east with onlapping deposition of Triassic flysch onto the margin of the YB (Harrowfield and Wilson, 2005). During the onset of the Indosinian orogeny, the Songpan remnant ocean and its sedimentary fill experienced intense deformation because it was trapped between coeval subduction zones in the north and southwest (e.g. Reid et al., 2005, 2007; Roger et al., 2011). Triassic lithospheric delamination occurred (Zhang et al., 2007) after the crust of the NE Tibetan Plateau thickened to 45 ± 5 km (Lease et al., 2012). As a result, Triassic syn-tectonic adakitic-type granitoids are widely distributed in the eastern SGT (Fig. 1b), which are likely sourced from the partial melting of an underlying Proterozoic basement that is part of the YB (Roger et al., 2010; Zhang et al., 2006). In addition, as a convergent zone between the SGT and YB, the LMS thrust-Nappe belt was initiated in the Late Triassic as a sinistral transpressive fault zone (Burchfiel et al., 1995) (Figs. 1a and 1b) due to the compression of the SGT and contemporaneous southeast-directed crustal shortening and thrusting towards the western passive margin of the YB (Roger et al., 2004,