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Crustal-scale tectonic wedging in the central Longmen Shan: Constraints on the uplift mechanism in the southeastern margin of the Tibetan Plateau

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A B S T R A C T

This study focuses on the upper–middle crust (UMC) deformation in the central Longmen Shan (LMS). The results of this study are constrained by the surface geology, typical seismic reflection profiles, previously available thermochronology, and deep geophysical data. Regional seismic profiles demonstrate a strata dip of about 2°, northwest trending, from the Sichuan Basin (SB) to LMS. The interpretation of shallow artificial seismic reflection data indicates that an unknown basement structure lead to the uplifting of the sedimentary cover by 3–4 km. A long and wide-angle reflection seismic profile presents evidence that the middle crustal-scale structure is involved in the deformation. Geophysical data support that there is an upper detachment (D1) at the depth of ~20 km. The other lower detachment (D2) could be generated at approximately 30–40 km depth in the low velocity zone. The ductile middle crust between the D1 and D2, has shortening and forming a wedge tip beneath the transition zone of the LMS and the SB. The deformation of the LMS frontal monocline belt is related to this crustal-scale wedging. Two different tectonic stages are distinguished in the Cenozoic through the axial surface analysis and chronological data. During the first stage, the crustal-scale tectonic wedge was developed between the upper and lower detachment, resulting in the uplift of the UMC. During the second stage, the middle crust could hardly be extruding and uplifting. The brittle upper crust was rapidly uplifted and shortened by the shallow major thrusts, which were developed on the D1. The D1 and D2 controlled the uplifting and shortening in the southeastern margin of the Tibetan Plateau. The lower crust (LC) may be decoupled from the D2 and subducted due to the resistance by the stable craton underlying the SB. The structural model manifests the importance of multi-detachments and the superimposed deformation in the LMS thrust belt. However, we emphasize that this crustal-scale tectonic wedging only discovered in the central LMS. The tectonic wedge is an important uplifting pattern that should be not neglected.

1. Introduction

The Longmen Shan (LMS) thrust belt lies along the southeastern margin of the Tibetan Plateau (Fig. 1). This location is crucial to understanding the applicability of a number of tectonic models that aim to explain the development of the Tibetan Orogen (Molnar and Tapponnier, 1975; Tapponnier et al., 1982; England and Houseman, 1986; Royden et al., 1997). The LMS thrust belt is well known for its high relief, with almost no tertiary foreland sedimentation and little evidence of Cenozoic tectonic shortening (Burchfiel et al., 1995; Chen et al., 1995; Densmore et al., 2007; Richardson et al., 2008). The Wenchuan Mw 7.9 earthquake, which occurred on May 12, 2008, produced two large surface ruptures along the Beichuan-Yingxiu fault (F2) and Pengguan fault (F3) and caused extensive uplifting and shortening of the upper crust (Xu et al., 2009; Liu-Zeng et al., 2009; Lin et al., 2009). The Lushan Mw 6.8 earthquake occurred on April 20, 2013 in the southern region of the LMS without surface ruptures (Xu et al., 2013). There are still many unanswered questions concerning the disastrous earthquakes along the LMS (Yin, 2010), such as the fast uplift dynamic mechanism, the relationship between the upper–middle crust (UMC) and the lower crust (LC). The tectonic evolution of LMS since the Early Cenozoic is not clear. Therefore, revising the

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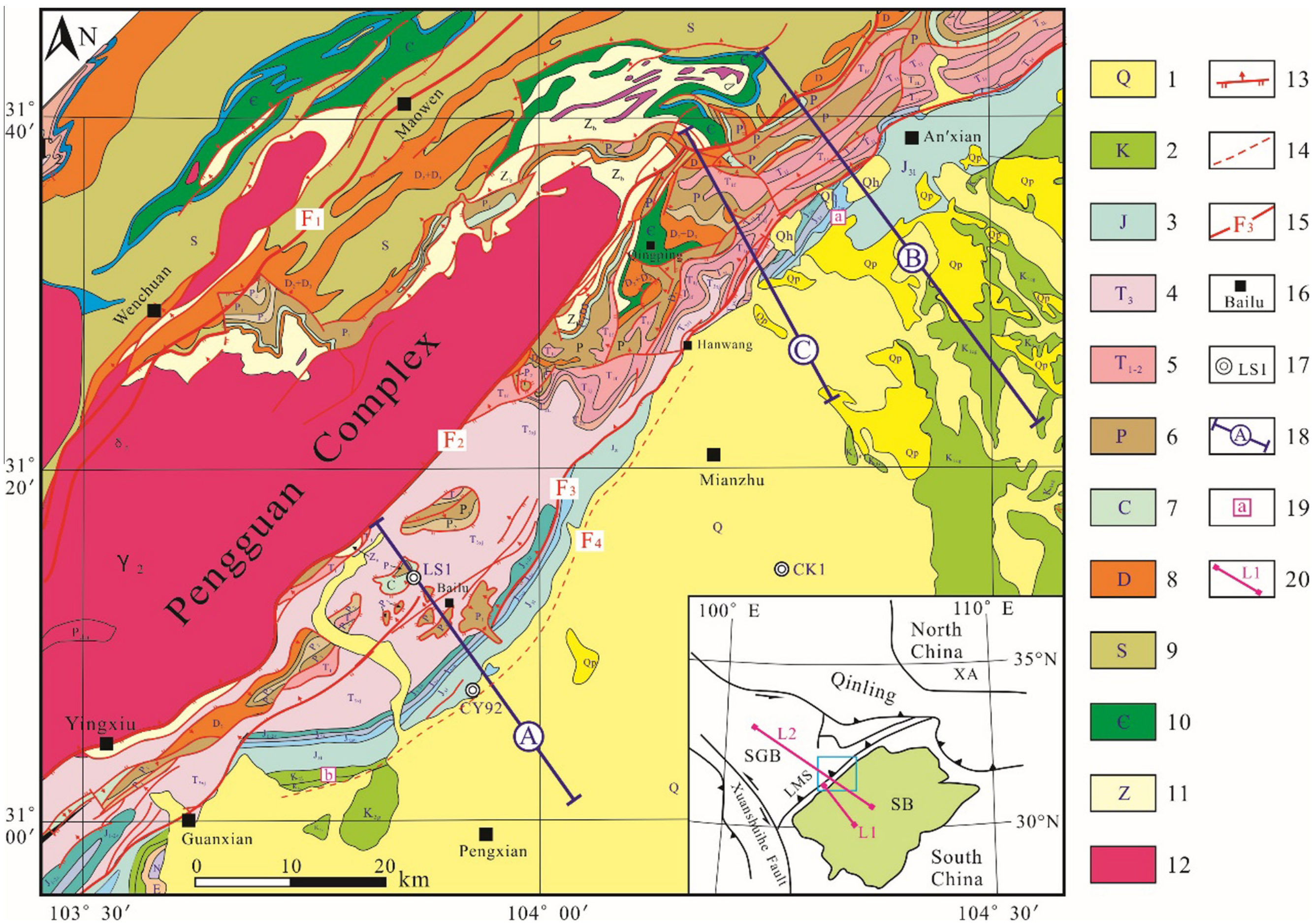

Fig. 1. Local geological map (see Data and Resources section) indicating the position of the seismic reflection profiles and the drilled wells used in this study. 1 – Cenozoic; 2 – Cretaceous; 3 – Jurassic; 4 – Upper Triassic; 5 – Lower Triassic; 6 – Permian; 7 – Carboniferous; 8 – Devonian; 9 – Sinian; 10 – Cambrian; 11 – Sinian; 12 – Pengguan Complex; 13 – Major faults; 14 – Blind faults; 15 – Fault number (F1: Qingchuan-Maowen Fault; F2: Beichuan-Yingxiu Fault; F3: Pengguan Fault; F4: Blind Fault); 16 – Local names; 17 – Drilling Wells; 18 – Seismic Reflection profiles; 19 – Outcrop; 20 – Regional seismic and velocity profiles (see the small rectangle box); SGB: Songpan-Ganze Block; LMS: Longmen Shan; SB: Sichuan Basin.

LMS structural framework and then assessing the earthquake risk is of great importance.

The Himalayan-Tibetan Orogen resulted from a collision initiated ~50 Ma years ago (Molnar and Tapponnier, 1975; Royden et al., 2008; Thatcher, 2009; Huang et al., 2014). Low-temperature thermochronology has been applied to the apatite (U–Th)/He and apatite fission track analysis, on samples collected from the Southeast Tibetan Plateau. Their results indicate that the latest LMS tectonic event occurred since 15 Ma (Arne et al., 1997; Kirby et al., 2002; Richardson et al., 2008; Godard et al., 2009; Wilson and Fowler, 2011; Cook et al., 2013; Tan et al., 2014; Guenthner et al., 2014). Some thermochronology data also indicates that the rapid uplift and exhumation of the central LMS occurred 30–25 Ma years ago (Wang et al., 2012). However, the deformation process and the uplift mechanism of the LMS thrust belt since the Cenozoic still remain a mystery.

Multiple crustal-scale models have attempted to explain the geological and geophysical observations across the LMS thrust belt (Royden et al., 1997, 2008; Clark and Royden, 2000; Tapponnier et al., 2001; Burchfiel et al., 2008; Hubbard and Shaw, 2009; Xu et al., 2009; Zhang et al., 2010a; Robert et al., 2010; Guo et al., 2013). In particular, after the 2008 Wenchuan earthquake, many tectonic and geodynamic models made predictions about the behavior of the lower and upper crust and the surface processes in this area (Richardson et al., 2008). There are still many uncertain factors and disputes regarding these models on the deformation mechanism of the LMS thrust belt. These structural models require the incorporation of more detailed geological constraints.

The shallow structural deformation of the LMS thrust belt reveals its sedimentary–tectonic evolution. The artificial seismic reflection profiles have provided details on the upper crust (Jia et al., 2006; Hubbard et al., 2010). In this study, we interpret three seismic reflection profiles from the central LMS thrust belt, constrained by surface geology and subsurface data from drilling wells (Fig. 1). Some seismic data were interpreted in previous study (Jia et al., 2010), but some important details should not be ignored. In this paper, fault-related folding theories and axial surface analysis are used to perform the seismic profile interpretation (Suppe, 1983; Shaw et al., 2004). Integrated with two already published geophysical profiles (Jia et al., 2014; Liu et al., 2014) and previous thermochronology data (Kirby et al., 2002; Wang et al., 2012; Li et al., 2012; Guenthner et al., 2014), this study elucidates the LMS deformation process and presents a crustal-scale structural model for the southeastern margin of the Tibetan Plateau.

2. Geological setting

The LMS thrust belt is located between the Songpan-Ganze Block (SGB) and the Sichuan Basin (SB) (Fig. 1). The Songpan-Ganze terrane is characterized by the presence of a thick Triassic