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Crustal structure across Longmenshan fault belt from passive source seismic profiling

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[1] We analyse receiver functions from 29 broad-band seismographs along a 380-km profile across the Longmenshan (LMS) fault belt to determine crustal structure beneath the east Tibetan margin and Sichuan basin. The Moho deepens from about 50 km under Songpan–Ganzi in east Tibet to about 60 km beneath the LMS and then shallows to about 35 km under the western Sichuan basin. The average crustal Vp/Vs ratios vary in the range 1.75–1.88 under Songpan–Ganzi in east Tibet, 1.8–2.0 under the LMS, and decrease systematically across the NW part of the Sichuan basin to less than 1.70. A negative phase arrival above the Moho under Songpan–Ganzi and Sichuan basin is interpreted as a PS conversion from the top of a low-velocity layer in the lower crust. The very high crustal Vp/Vs ratio and negative polarity PS conversion at the top of lower crust in east Tibet are inferred to be seismic signatures of a low-viscosity channel in the eastern margin of the Tibetan plateau. The lateral variation of Moho topography, crustal Vp/Vs ratio and negative polarity PS conversion at the top of the lower crust along the profile seem consistent with a model of lower crust flow or tectonic escape. **Citation:** Zhang, Z., Y. Wang, Y. Chen, G. A. Houseman, X. Tian, E. Wang, and J. Teng (2009), Crustal structure across Longmenshan fault belt from passive source seismic profiling, *Geophys. Res. Lett.*, *36*, L17310, doi:10.1029/2009GL039580.

1. Introduction

[2] The continental collision between India and Eurasia in the Cenozoic has resulted in large crustal shortening across Asia [*Molnar and Tapponnier*, 1975; *Molnar and Chen*, 1978; *Houseman and England*, 1993; *Kind et al.*, 2002; *Royden et al.*, 2008; *Li et al.*, 2008]. GPS measurements confirm that crustal material is moving eastward in the east Tibetan Plateau [*Zhang et al.*, 2004] and is obstructed by the rigid Sichuan basin of the Yangtze block [*Copley and McKenzie*, 2007]. The abrupt (4-km) topographic relief across the Longmen-shan (LMS) belt between Eastern Tibet and the Sichuan basin has been interpreted as indicating: (1) The middle/lower crust of Tibet flows and thrusts to the surface as a channel to form the LMS fault system [*Royden*, 1996; *Royden et al.*, 2008; *Clark and Royden*, 2000; *Klemperer*, 2006]; (2) Lithospheric-scale escape [*Wang et al.*, 2008] coupled with subduction of Sichuan basin mantle and underthrusting of its crust beneath Eastern Tibet [*Xu et al.*, 1992; *Tapponnier et al.*, 2001]; or (3) The rigid crust of the Sichuan basin is wedged into the lower crust of the Songpan–Ganzi block [*Cui et al.*, 1996]. In order to evaluate the above-mentioned models and deepen our understanding of the interaction between Tibetan plateau and basin, we recorded teleseismic events on a profile across the LMS fault. The Mw 8.0 Wenchuan earthquake of 12 May 2008 happened along the LMS fault belt [*Burchfiel et al.*, 2008] and further motivates our study of crust and upper mantle structure in the area.

2. Seismic Acquisition and Receiver Function Image

[3] Our passive seismic experiment was carried out along a profile between Aba in east Tibet and Longquan (LQ) Mts. in the western Sichuan basin (Figure 1) between August 2006 and July 2007. In this experiment, 29 seismographs (nine Reftek-130 and 20 Reftek-72A data loggers and Guralp CMG3-ESP sensors of 50 Hz–30 s) were deployed. Stations S01–S07 are located in the western Sichuan basin, S08–S12 cross the LMS thrust faults zone with a station interval of 10 km, and S13–S29 are located on the Songpan–Ganzi block in east Tibet (station coordinates are provided in Table S1 of the auxiliary material).[4] During the one year observation, 264 earthquakes with magnitude greater than Ms 5.0 in the distance range between 30 and 90 degrees (see Figure S1) were recorded.

[4] We estimated receiver functions by a time-domain iterative deconvolution of vertical and radial seismograms [*Ligorria and Ammon*, 1999]. We have visually selected records with high signal-to-noise (S/N) ratio for each station, ensuring that the PS conversions from the Moho and its two later multiple phases are present. In total, we have obtained 1823 receiver functions for all 29 stations along the profile. We present radial- and transverse-component receiver functions from Stations 4 and 21 located in Sichuan basin and Songpan-Ganzi, respectively (Figures 2a and 2b). All the radial-component receiver functions are included in Figure S2. The P and PS phases from the Moho can be seen clearly from those receiver-functions along the profile. The delay time between P and PS converted phases under the Sichuan basin is about 5.5 s and under the Songpan–Ganzi block is about 7 s. The change in delay times from 5.5 to 7 s, and the complicated conversion pattern under stations 8–12

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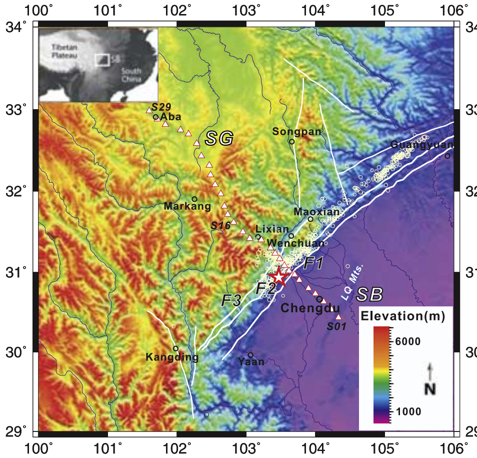

Figure 1. Tectonic and location map of the seismic stations of the east Tibet programme. The triangles are stations. Star is the epicenter of Mw 8.0 Wenchuan earthquake, and circles are 461 aftershocks Ms > 4 which occurred along the LMS faults and its neighboring areas till 6 June 2008. (SG, Songpan–Ganzi block; SB, Sichuan basin; LQ Mts, Longquan Mountains; F1, Pengguan fault; F2, Yingxiu-Beichuan fault; F3, Wenchuan-Maoxian fault). Inset map: geographic map to show the study area.

suggest an abrupt variation in crustal structure under the LMS fault belt, comparable to variation observed across major crustal sutures further to the west on the Plateau [*Vergne et al.*, 2002] and in northern Tibet [*Zhu and Helmberger*, 1998].

3. Migrated Receiver Function Image Along the Profile

[5] In order to construct a depth-domain crustal conversion image, a migration scheme is used to focus the converted signal from the time series of each receiver function to its relevant conversion point. Figure 3a presents the migrated receiver-function section to the depth of 150 km along the profile, using the imaging method of *Yuan et al.* [1997] and the IASP91 model [*Kennett and Engdahl*, 1991]. On the image, there are two remarkable features: strong variations in Moho depth and a consistent negative polarity converted phase in the mid to lower crust of the Songpan-Ganzi region.

[6] Figure 3a demonstrates distinct crustal seismic conversion signatures beneath the LMS (Longmenshan belt), separating the Songpan-Ganzi block and the western Sichuan basin. A clear Moho signal can be recognized at a depth of ~53 km along the NW part of the profile (to 102.7E, at ~200 km on Figure 3a). The Moho PS conversion phase deepens to about 62 km from 102.7E to 103.2E. Under the LMS belt, the Moho signature shallows abruptly from the deeper levels of the Songpan-Ganzi to the shallower levels of

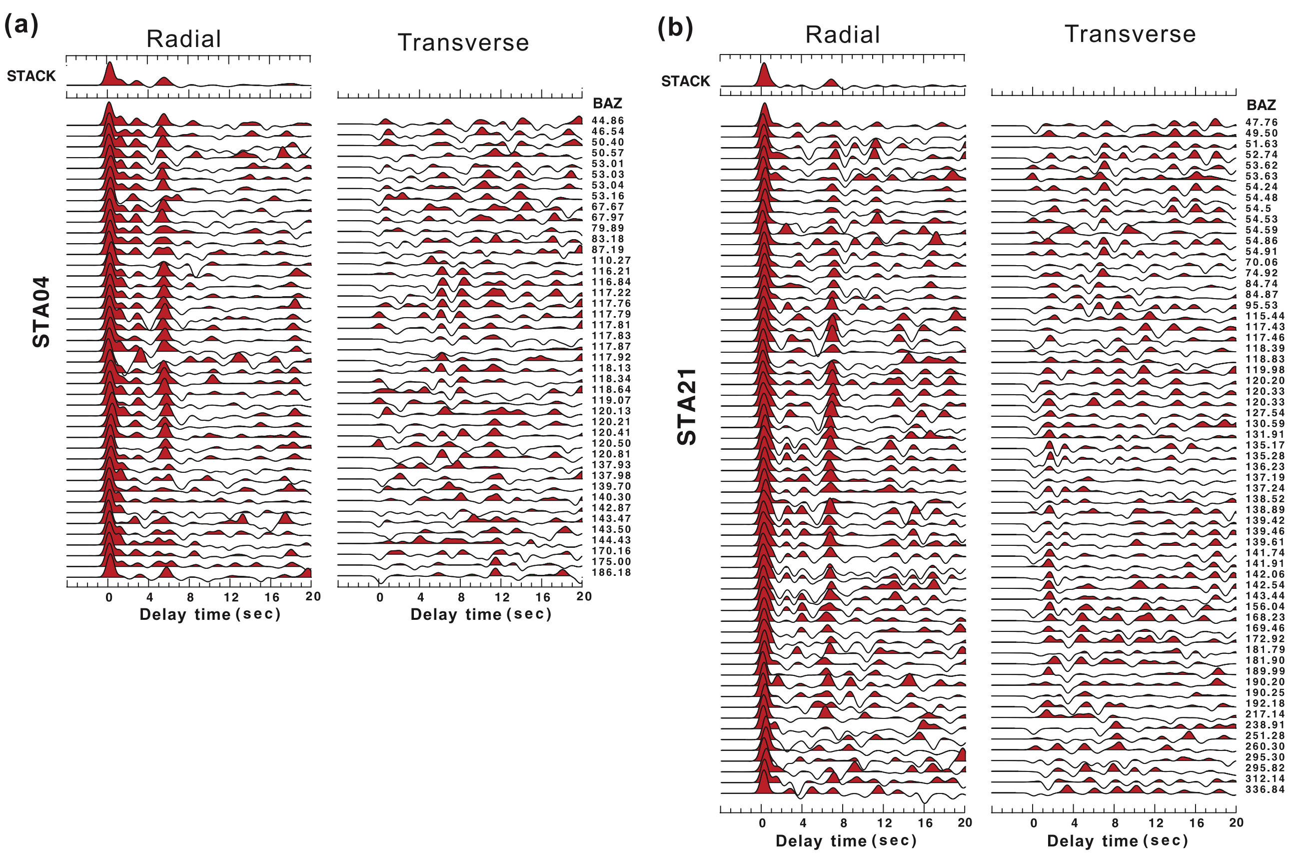

Figure 2. (a) Receiver functions of station 4 and (b) station 21 which are located at Sichuan basin and Songpan-Ganzi, respectively. The traces are move-out corrected, equally spaced and, for each station, ordered by increasing back-azimuth. The Moho is seen on almost all the traces and the summed trace at the top of the corresponding figure.

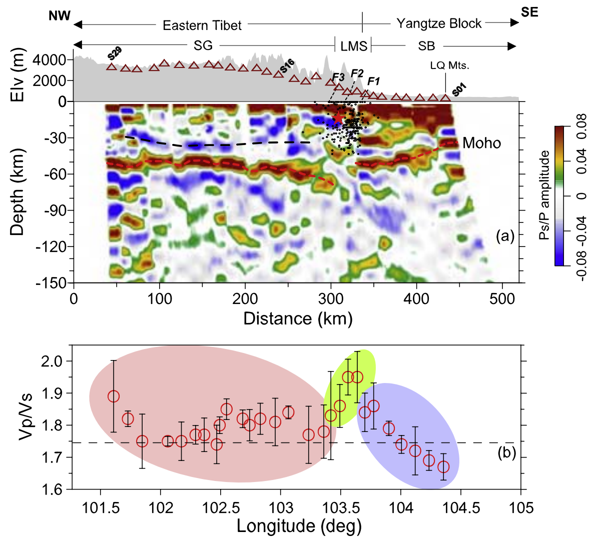

Figure 3. (a) The migrated crustal receiver function image along Aba-Longquan Mountains profile. It shows Moho depth shallowing from Songpan-Ganzi to west Sichuan basin and offset under the LMS belt, different PS conversion signature between the tectonic units either side of the LMS belt. The small triangles at the top indicate seismograph locations. Red colors represent positive receiver-function amplitudes, which are related to the increase of velocity with depth, and blue colors indicate negative amplitudes. The red star is the location of Mw 8.0 Wenchuan earthquake, and black circles are 256 aftershocks within 50 km projected on to the section. Aftershocks are located at depths <20 km and between F1 and F3. The dashed line refers to the negative polarity PS conversion in the lower crust beneath Songpan-Ganzi. (b) The average crustal Vp/Vs ratio (with error bars) under stations along the survey line.

the Sichuan basin (part of the Yangtze block). Clearly there are two strong positive phases at ~55 and ~35 km depth respectively on the NW edge of the Sichuan block. The deeper phase, interpreted as the Moho of the Sichuan Block, continues to the SE as it shallows from about 55 km at 103.6E to about 35 km at the SE end of the profile. The shallower phase, commencing at 35-km depth parallels the deeper Moho signature, and may be followed upward to the SE where it merges into the signature of the sediments in the vicinity of the Longquan Mountains (LQ Mts). The shallower phase, at 35-km depth is of similar amplitude to the Moho signal, and could represent a segment of Moho in a basement block which is upthrust to the SE over the Sichuan basin on a shear zone or thrust fault that outcrops in the vicinity of the LQ Mts. Alternatively, the 35-km depth phase could be interpreted as an interface between felsic upper crust and more mafic lower crust [*Cui et al.*, 1996; *Li and Mooney*, 1998]. Wide angle refraction analysis further south in the western Sichuan Basin has revealed step-like increases in crustal velocity at depths of 20 and 30 km [*Wang et al.*, 2007].

[7] Figure 3a also shows a consistent negative polarity converted phase in the lower crust, about 10–15 km above the Moho under Songpan–Ganzi. This phase is best interpreted as the top of a low velocity zone, possibly involving high temperatures, fluids, and/or partial melt. It is tempting to correlate this lower layer with a low-viscosity channel suggested by *Royden* [1996].

4. Distinctive Crustal Vp/Vs Ratio Difference Between East Tibet and Sichuan Craton

[8] We have estimated the average crustal Vp/Vs ratio using the H-κ stacking method [*Zhu and Kanamori*, 2000], in which we have summed the amplitudes of receiver functions at predicted arrival times of PS converted phase and its multiples in order to improve signal to noise ratio. The trade-off between Moho depth and crustal Vp/Vs ratio can be seen in Figure S3. Figure 3b summarizes the depth-averaged Vp/Vs ratio in the crust along the profile. The differences in crustal thickness estimated from the migrated receiver function and from the H-κ stacking method are tabulated in Table S1. Such differences may arise from Moho undulation (illustrated by a clear moveout of the Moho conversion at the station STA12) or anisotropy (obvious seismic energy and azimuthal dependence in the lower crust at the station STA21 in Figure 2b) [*Bianchi et al.*, 2008]. The Songpan–Ganzi block and the western Sichuan basin exhibit distinct velocity ratios, indicative perhaps of different crustal compositions. Relatively high values are observed under the LMS fault zone (1.8 to 2.0), compared to values typically in the range 1.75–1.88 under Songpan–Ganzi, and values that decrease systematically across the NW part of the Sichuan basin to less than 1.70. High Vp/Vs ratios (>1.80) under Songpan-Ganzi and the LMS belt (compared to global averages [*Christensen and Mooney*, 1995; *Christensen*, 1996]) could be attributed to ultramafic or eclogitic bodies thrust upwards [*Cui et al.*, 1996] with the Tibetan lower crust. They could also be attributed to fluids in the lower crust [*Yuan et al.*, 1997; *Makovsky et al.*, 1996], which decrease the average crustal shear wave velocity, increase Vp/Vs ratio, and would promote the low-viscosity channel flow suggested by *Royden* [1996].

5. Discussion and Conclusion

[9] The huge topographic relief across the LMS has been attributed to (1) low-viscosity channel flow [*Royden*, 1996] obstructed by a rigid Sichuan Basin block; (2) tectonic escape similarly obstructed [*Xu et al.*, 1992; *Tapponnier et al.*, 2001; *Wang et al.*, 2008], or (3) Sichuan basin subduction [*Cui et al.*, 1996]. The first two models imply that the LMS fault system is developed from middle/lower crust of the Songpan–Ganzi block. Convergence in the mantle layer is accommodated in model (1) by downwelling of Tibetan Mantle, in model (3) by downwelling of Sichuan Basin mantle and in model (2) presumably by downwelling of mantle from both sides. The negative polarity PS conversion at the top of lower crust in our receiver function crustal structure image and relatively higher average crustal Vp/Vs ratio beneath Songpan-Ganzi and LMS support the concept of a lower crustal layer. Magnetotelluric surveys further to the south of our profile show low resistivity layers beneath Songpan-Ganzi and LMS [*Zhao et al.*, 2008] and also support the interpretation of a fluid-dominated lower crustal layer which could accommodate channel flow. Our interpretation may be consistent with models (1) or (2) above if we accept

that the Sichuan block itself may have shortened by thrust and shear on a structure which outcrops at the LQ Mts and dips into the LMS fault zone. In either case mantle downwelling must occur in the mantle beneath the LMS belt in order to accommodate the convergence. The receiver-function image shows a possibly continuous structure that dips to the NW, from the LQ Mts. at the surface, to the base of the Songpan–Ganzi crust west of the LMS, along which strike-slip and thrust motion are inferred. In addition, the Moho under the NW Sichuan basin appears to be deflected downward to accommodate the overthrust block. The negative signal between these two positive receiver function signals could be explained by Sichuan block mantle attached to a thrust block which has broken off and pushed over lower crust of the Sichuan block further to the SE. Although this profile indicates that the Sichuan block may have been shortened by faulting, it does not support the idea that the Sichuan block has subducted beneath eastern Tibet.

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