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Three-dimensional seismic velocity structure across the 2008 Wenchuan Ms 8.0 earthquake, Sichuan, China

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ABSTRACT

We present three-dimensional (3D) seismic compressional wave velocity (V_p), shear wave velocity (V_s) and V_p/V_s models around the Longmen Shan fault, Sichuan, China region, using aftershocks associated with the 2008 Wenchuan Ms 8.0 earthquake. The velocity and ratio models are obtained using a new version of the double-difference seismic tomography code tomoDDPS (Zhang, 2003) to simultaneously solve for V_p, V_s, V_p/V_s and event locations. The data used in inversion include 73,013 P arrival times, 62,287 S arrival times and 61,823 S–P travel times recorded by 63 stations from both permanent and temporary networks in a region 400 km northeast-southwest by 200 km northwest-southeast. The velocity model shows structure heterogeneity both along and across the fault zone. Generally, the velocity model is consistent with the local geology, with older rocks having high velocity and younger rocks having low velocity. The Longmen Shan fault zone is a clear boundary in V_p, V_s and V_p/V_s ratio. Down to the depth around 15 km, higher V_p and V_s and lower V_p/V_s ratio exist to the west of the fault, corresponding to the Songpan–Ganze Fold System, while lower V_p and V_s and higher V_p/V_s ratio exist to the east, corresponding to the Sichuan Basin. Along the fault zone, the velocity structure is generally consistent with various rupture slip models, with two high velocity bodies corresponding well to the two large slip patches. This shows the structure control on the slip distribution along the fault plane.

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1. Introduction

On May 12, 2008, a magnitude Ms 8.0 destructive earthquake with an estimated hypocenter of longitude 103.4°E, latitude 31.0°N and depth 14 km occurred along the Longmen Shan fault (LMSF) zone, between the eastern margin of the Tibetan plateau to the west and the Sichuan Basin to the east (Fig. 1). The earthquake caused a huge loss in both life and property. The surface ruptured over a length of ~250 km to the northeast along the LMSF, with a substantial amount of aftershocks extending ~300 km along the fault. Coseismic slip, estimated up to ~10 m, consists of thrust- and right-slip components, with two large displacement centers located around Wenchuan and Beichuan (Ji and Hayes, 2008; Wang et al., 2008; Nishimura and Yagi, 2008). Reverse and right-slip components are of comparable magnitude along the southwestern portion of the rupture, but the right-slip component dominates in the northeastern portion of the rupture (Burchfiel et al., 2008; Teng et al., 2008; Zhang et al., 2008a; Liu et al., 2009). To understand the detailed structure of the fault zone and how it is related to the surface rupture, we derived the three-dimensional (3D) velocity structure around the LMSF using the aftershock data.

2. Data and method

The data used in inversion include 73,013 P and 62,287 S first arrival times from 7295 earthquakes recorded by 63 permanent and temporary stations in a region 400 km northeast-southwest by 200 km northwest-southeast. The arrival time data were provided by the Seismological Bureau of Sichuan Province, China. We use a new version of the double-difference (DD) seismic tomography code tomoDDPS (Zhang, 2003; Zhang et al., 2009). Compared to the original DD tomography code tomoDD (Zhang and Thurber, 2003), the new code is able to simultaneously solve for V_p, V_s, V_p/V_s and event locations using P, S, and S–P times. About 262,360

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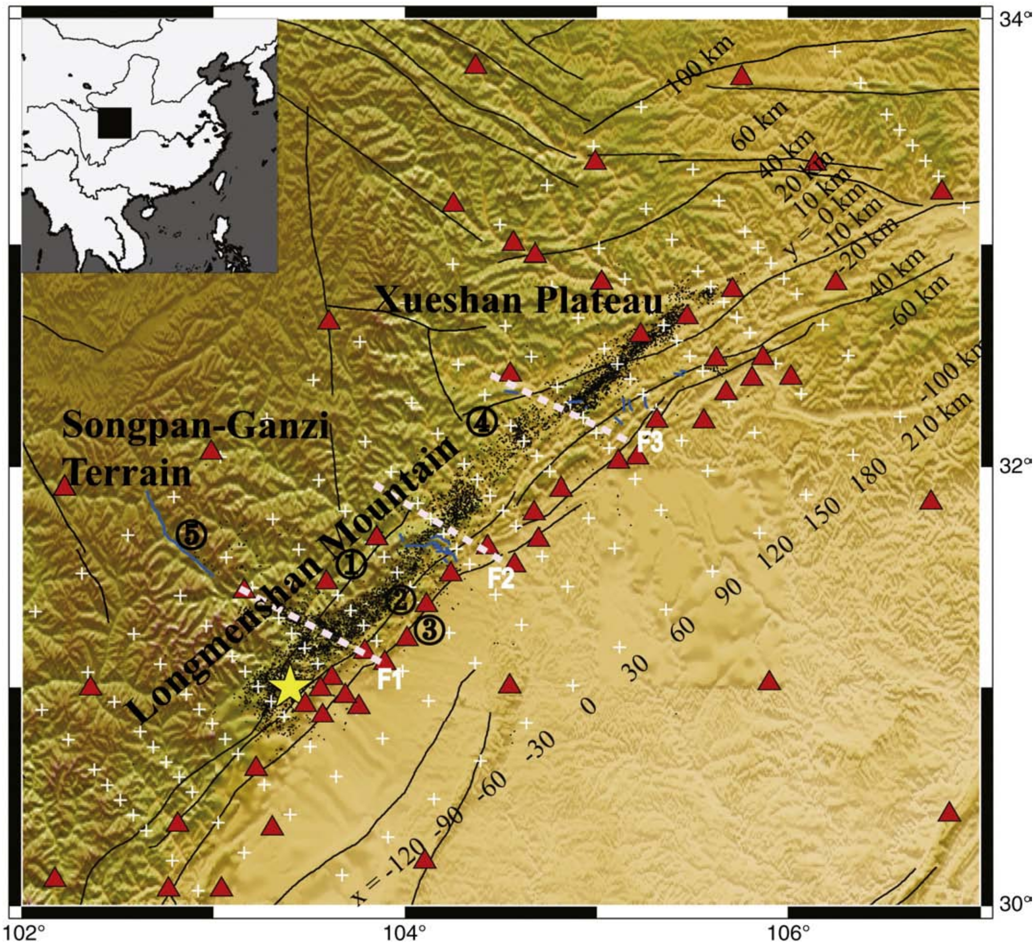

Fig. 1. Distribution of receivers (triangles) and relocated aftershock locations (black dots). The yellow star is the main shock of the Wenchuan Ms 8.0 earthquake. The black lines represent faults (Deng et al., 2007) and the blue lines represent some small faults from the geological map of China (1:200,000). Major faults: ① — Wenchuan–Maowen fault; ② — Yingxiu–Beichuan fault which is the Lumenshan main fault; ③ — Guanxian–Jiangyou fault; ④ — Qingchuan fault; ⑤ — Miyaluo fault. The white crosses are the inversion grid nodes of the model noted by *X* and *Y* in Cartesian coordinate in kilometer. The inferred faults F1, F2 and F3 are shown as dashed white lines. The index map is shown in top-left.

differential P times and 211,098 differential S times were derived for event pairs that are separated smaller than 30 km but greater than 0.5 km based on catalog locations. In addition, 61,823 S–P times and 209,200 differential S–P times were also included in the inversion.

We set up the coordinate system so that the *X* axis and *Y* axis are almost normal and parallel to the major fault strike, respectively (Fig. 1). The inversion grid node spacing is 30 km in the *X* direction and 10 to 20 and 40 km from the fault zone to the model margin in the *Y* direction (Fig. 1). In the *Z* direction, the inversion grid nodes are positioned at −1, 0, 2, 5, 10, 15, 20, 25 and 30 km. The inversion started from a 1D velocity model, based on the previous study of crustal structure around the LMSF zone (Fig. 1; Zhao et al., 1997). After nine iterations of simultaneous inversion of V_p, V_s, V_p/V_s and event locations, the unweighted root mean square (RMS) residual value decreased from 0.865 s to 0.318 s, a 63% reduction. The model resolution was assessed using a checkerboard test. We applied positive and negative perturbations of 3% to each grid node in both V_p and V_s, with opposite signs so that the V_p/V_s perturbations are of about 6%. The synthetic travel times were calculated with the same ray distribution as the real data. Fig. 2 shows the recovered checkerboard patterns for V_p at depth of 15 km, along $X = -120$ km and $Y = 0$ km. The checkerboard test shows that the resolution is relatively good in the range of $X = -200$ to 200 km, $Y = -50$ to 50 km, and $Z = 5$ to 25 km. The resolutions in V_s and V_p/V_s are similar to that of the V_p.

3. Result and discussion

We present the horizontal slices of the V_p, V_s, and V_p/V_s models at depth 14 km and the corresponding cross-sections across the main shock in Figs. 3–5, respectively. Based on the checkerboard resolution test, only relatively well resolved areas are shown. In general, the velocity model obtained in this study is consistent with the regional scale model by Wang et al. (2009) but shows more detailed structures.

3.1. Horizontal slices of V_p, V_s and V_p/V_s model at depth 14 km

In Fig. 3, it can be seen that the belt of aftershocks is a clear boundary between high and low V_p, V_s, and V_p/V_s in southwestern segment of the LMSF zone between $x = -130$ and ~80 km. While for the northeastern part between $x =$ ~80 and ~180 km, the fault looks like cutting off the block with high velocity and low V_p/V_s. In addition, the whole aftershocks belt has low velocity and high V_p/V_s with ~300 km in length. The surface ruptures are consistent with the surface mapped Yingxiu–Beichuan fault and Guanxian–Jiangyou fault in the southwestern part of the LMSF zone (Fig. 1). The aftershocks belt is wider and farther away from the surface rupture in southwest than in northeast. This suggests that the main fault plane dips in southwest and is nearly vertical in northeast, which is consistent with the reverse and strike-slip components of coseismic displacement in southwest and mainly strike-slip components in northeast (Zhang

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