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Tectonic-geomorphology of the Litang fault system, SE Tibetan Plateau, and implication for regional seismic hazard

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ABSTRACT

The Litang fault system (LTFS) in the eastern Tibetan Plateau has generated several large (7.5 > M > 7) historical earthquakes and has exhumed granitic peaks rising >1700 m above the mean elevation of the plateau, despite being located within a tectonic block surrounded by highly active faults. We study horizontally offset moraine crests from the Cuopu basin and a vertically offset alluvio-glacial fan from the eastern Maoya basin. We determine a left-lateral rate of 0.09 ± 0.02 mm/yr along a slowly slipping secondary fault at Cuopu, while the main active fault at present is the normal range-front N Cuopu fault, along which we determined a left-lateral rate of 2.3 ± 0.6 mm/yr since 173 ka. At Maoya fan, matching the vertical 12 ± 1 m cumulative offset with the 21.7 ± 4.2 ka fan age yields a vertical (normal) rate of 0.6 ± 0.1 mm/yr. This rate is very similar to that recently determined at the same location using low-temperature thermochronology (0.59 ± 0.03 mm/yr since 6.6 ± 0.5 Ma). Left-lateral rates along the main faults of the LTFS range between 0.9 and 2.3 mm/yr at all time-scales from a few years to ~6 Ma. The facts that the LTFS is highly segmented and that at present, the Cuopu, Maoya and South Jawa segments are mostly normal (while the Litang and Dewu segments are left-lateral/normal), could prevent the occurrence of M > 7.5 destructive earthquakes along the LTFS, as is generally assumed. However, motion on the normal faults appears to be linked with motion on the strike–slip faults, potentially allowing for exceptional larger earthquakes, and implying that the area is not experiencing pure ~NS extension but rather NW–SE left-lateral transtension.

1. Introduction

Eastern Tibet, while located farther away from the collision front between India and Asia than the Himalayan range, nevertheless displays a major step in the topography, representing the greatest relief on the plateau. The highest peak of the Longmen Shan thrust belt (7556 m, Gongga Shan, 'GS' in Fig. 1B) is adjacent to the ~500 m-high Sichuan basin, over a distance of just ~50 km. This step in the topography more or less marks the boundary between the seismically active Tibetan Plateau (>4000 m a.s.l., >60 km thick crust, numerous active faults) and the tectonically stable plains of eastern China (Ordos basin, Sichuan basin, Fig. 1A, and South China block) (<1000 m a.s.l., <45 km thick crust, fewer active faults). This transition has been referred to as the "NS-trending tectonic zone" or "NS seismic belt" (green box in Fig. 1A) due to the fact that more than one third of all historical M > 7 earthquakes in continental China have occurred in that zone (e.g., Deng et al., 2003; Zhang, 2013), including the devastating 2008 Mw7.9 Wenchuan earthquake. Such great relief related to high seismic activity makes SE Tibet a key region to decipher the different models of the Tibetan Plateau's deformation. While GPS data (Fig. 1B) reveal that eastern Tibet is rotating clockwise relative to Eurasia around the eastern Himalayan syntaxis along the Xianshuihe fault (Zhang et al., 2004; Gan et al., 2007; Liang et al., 2013), what drives this eastward motion is highly debated and may be explained by different mechanisms. While the above GPS studies advocate continuous deformation of eastern Tibet, other studies in contrast, interpreted the same GPS data to show that eastern Tibet is made of blocks separated by active faults (block-like model, Meade, 2007; Thatcher, 2007).

From low temperature thermochronology data, Zhang et al. (2015) showed that vertical motion along the left-lateral/normal Litang fault system (hereafter LTFS), which is parallel to the Xianshuihe fault, initiated between 5 and 7 Ma. They interpreted this age as corresponding

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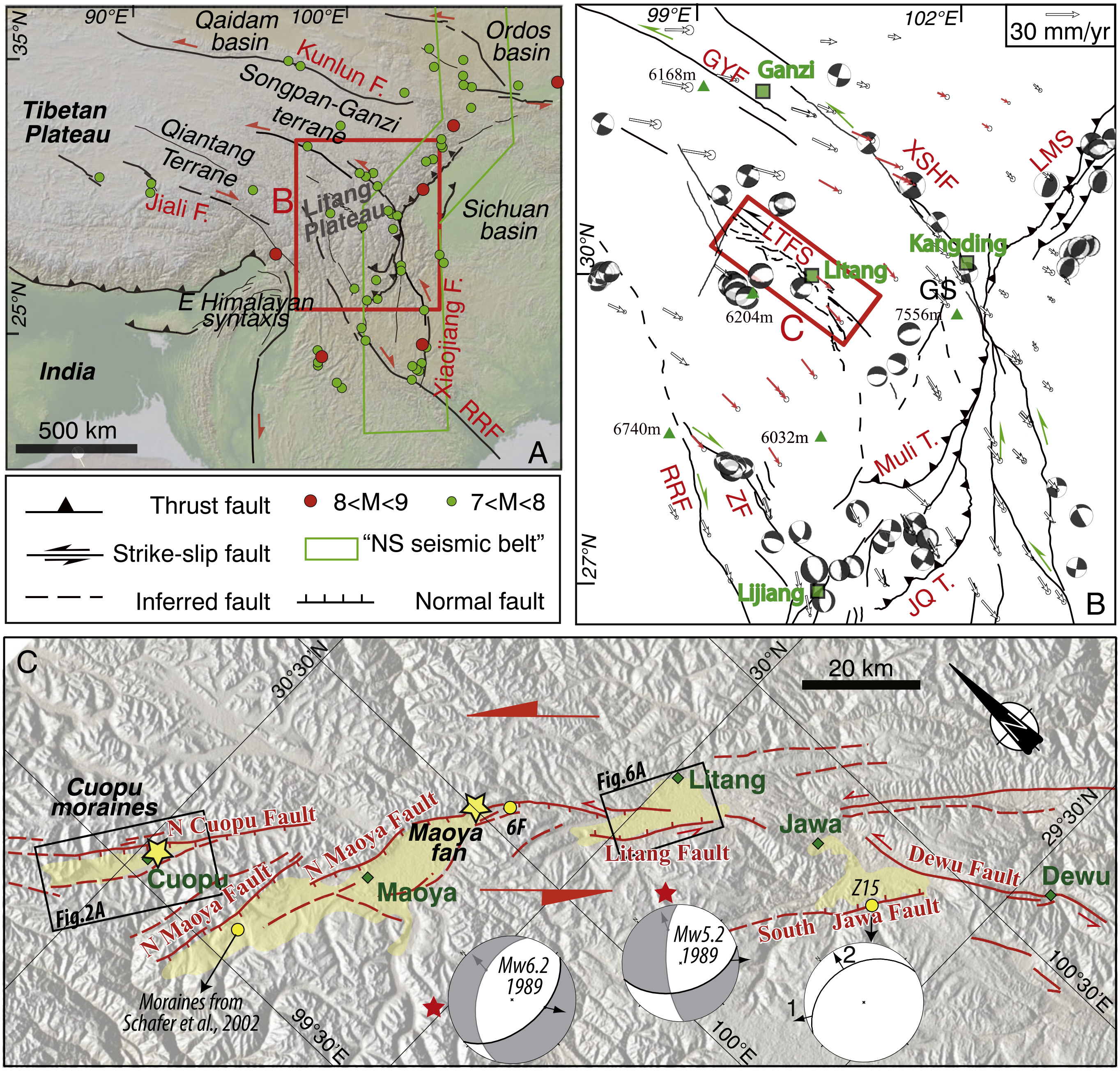

Fig. 1. The Litang fault system (LTFS) in the frame of the India–Asia collision zone. (A) Tectonic map of the eastern Himalayan syntaxis region with DEM in the background. Historical earthquakes of 9 > M > 7 are plotted and the "NS seismic belt" of Deng et al. (2003) highlighted by the green polygon. RRF = Red River fault. (B) SE Tibetan Plateau with horizontal GPS velocities (red arrows are used in the profile of Fig. S3) relative to stable Eurasia (Liang et al., 2013), focal mechanisms of instrumental earthquakes with Mw ≥ 5 (CMT catalogue 1976–2016), as well as main peaks, cities and faults. LTFS = Litang fault system, GYF = Ganzi–Yushu fault, XSHF = Xianshuihe fault, LMS = Longmen Shan, GS = Gongga Shan, ZF = Zhongdian fault, JQ T = Jinhe–Qinghe thrust. (C) DEM of the Litang fault system region with Quaternary basins (in yellow) and active faults (in red). Yellow stars show locations of the two study sites (Maoya fan and Cuopu moraines). Focal mechanisms of earthquakes (lower hemisphere projection) and corresponding slip directions (arrow pointing in the direction of motion of the upper block) are from global CMT catalogue, with the nodal plane assumed to be the fault in black. Brittle fault plane along the South Jawa fault with two generations of striations is plotted with the same convention: "1" = left-lateral striations, "2" = downslip striations (Z15 = Zhang et al., 2015).

to a major fault reorganization in SE Tibet, with the activation of the Lijiang pull-apart basin and Zhongdian fault, as well as the southeastward propagation of the Xianshuihe fault along the Xiaojiang fault system at that time (Fig. 1A,B). Zhang et al. (2015) further suggested that the Xianshuihe and Zhongdian faults allowed eastward sliding of the Litang Plateau during the Pliocene, with the LTFS accommodating differential motion within that block (Fig. 1B). During the Miocene, regional shortening was absorbed by the NNE–SSW-trending Jinhe–Qinghe and Muli thrust systems (Fig. 1B) (Yalong–Yulong thrust belt of Liu-Zeng et al., 2008). Such alternation between thickening and lateral motion along strike-slip faults is in agreement with the "hidden plate-tectonic" model (e.g., Tapponnier et al., 2001) which emphasizes the role of strike-slip faults. Alternatively, present-day normal faults could also be explained by a viscous lower crustal flow originating from the thick central Tibetan Plateau toward its thinner edges around the Sichuan rigid block (e.g., Clark and Royden, 2000; Schoenbohm et al., 2006). For this case, numerical simulations predict that the minimum horizontal stresses (direction of extension) would be parallel to the flow near the plateau margins and perpendicular to the flow out of the high plateau due to divergence of the flow where it spreads out