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Effects from the Wenchuan Earthquake and seismic hazard in the Longmenshan Mountains at the eastern margin of the Tibetan Plateau

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ABSTRACT

Effects from the disastrous Ms 8.0 Wenchuan Earthquake of May 12, 2008 show that the seismic hazard is closely related to the proximity of active faults and elevated areas of unstable rock as well as the recurrence rate of large earthquakes. Dextral-slip thrusting in the Longmenshan Mountains formed large displacement along ~250 km of the Central Longmenshan Fault and smaller offsets along sub-parallel faults. The distribution pattern of the major destruction has a strong northeast–southwest orientation closely related to the ruptured faults and decreases noticeably 3–5 km away from the Central Longmenshan Fault and ~2 km from the other faults. Thousands of landslides, rock falls and debris flows triggered by the earthquake lie chiefly adjacent to the principal fault, and smaller-scale landslides along the other faults as well as in distant areas. Some landslides formed dams whose impounded waters threatened downstream cities. Future landslides, rock falls and debris flows will result from rock loosened by the earthquake during rainy seasons or subsequent earthquakes.

The Central Longmenshan Fault had maximum displacements of 4.6 m dip-slip and 6.1 m dextral-slip and the total dip and dextral-slip displacement for all faults is 5.9 m and 7.0 m, respectively. These faults apparently converge at depth and account for the crustal shortening in the region. Their displacements coupled with convergence rates determined by GPS measurements provide an estimated recurrence interval for an Ms 8.0 earthquake along the Central Longmenshan Fault of between 4600 and 6600 years and that for the entire Longmenshan Mountains between 1000 and 3000 years.

1. Introduction

The devastating Ms 8.0 Wenchuan Earthquake of May 12, 2008 in Longmenshan Mountains at the border of the Tibetan Plateau and the Sichuan Basin dramatically altered the understanding of the seismic hazard in the region and the need for evaluation and planning to mitigate such effects in the future (Figure 1). The Wenchuan Earthquake caused major destruction and casualties from fault displacement and direct shaking, along with triggered secondary geological effects, which greatly added to the disaster. It killed 69,195 and injured 374,177 people, with 18,403 still missing, according to data released by the government on June 30, 2008. Seven Ms 6.0–6.4, 29 Ms 5.0–5.9, and more than 200 Ms 4.0–4.9 aftershocks occurred up to June 30, 2008. One Ms 6.4, an Ms 6.0 and seven Ms 5.0–5.9 aftershocks were concentrated in the northeast section of the Longmenshan seismic zone and the other 24 Ms 5.0–6.1 aftershocks were concentrated in the southwest section of the Longmenshan seismic zone (Figure 1). Fortunately, only several people were injured by the frequent aftershocks due to effective precautions by the government against the aftershocks and their potential danger.

The earthquake resulted from the eastward motion of the Songpan-Ganzi terrain of the eastern Tibetan Plateau over the Sichuan Basin (Figures 1 and 2). This is achieved by dextral-slip thrusting within the northeast-trending Longmenshan Mountains along the plateau's edge. Such movement has uplifted the mountains since Miocene and formed the present eastern margin of the plateau (Tapponnier and Molnar, 1977; Burchfiel et al., 1995, 2008; Yin and Harrison, 2000; Kirby et al., 2002). The displacement causing the 2008 earthquake occurred along the principal northeast-trending longitudinal fault strands controlling the mountains where past movements and erosion created high relief that set the stage for thousands of landslides and rock falls being triggered by the shaking. Many slides dammed rivers to cause local flooding and threatened catastrophic downstream torrents from burst dams, which required emergency cutting of spillways. Weakened rock about the heads of many slides created precarious situations that will cause future collapses.

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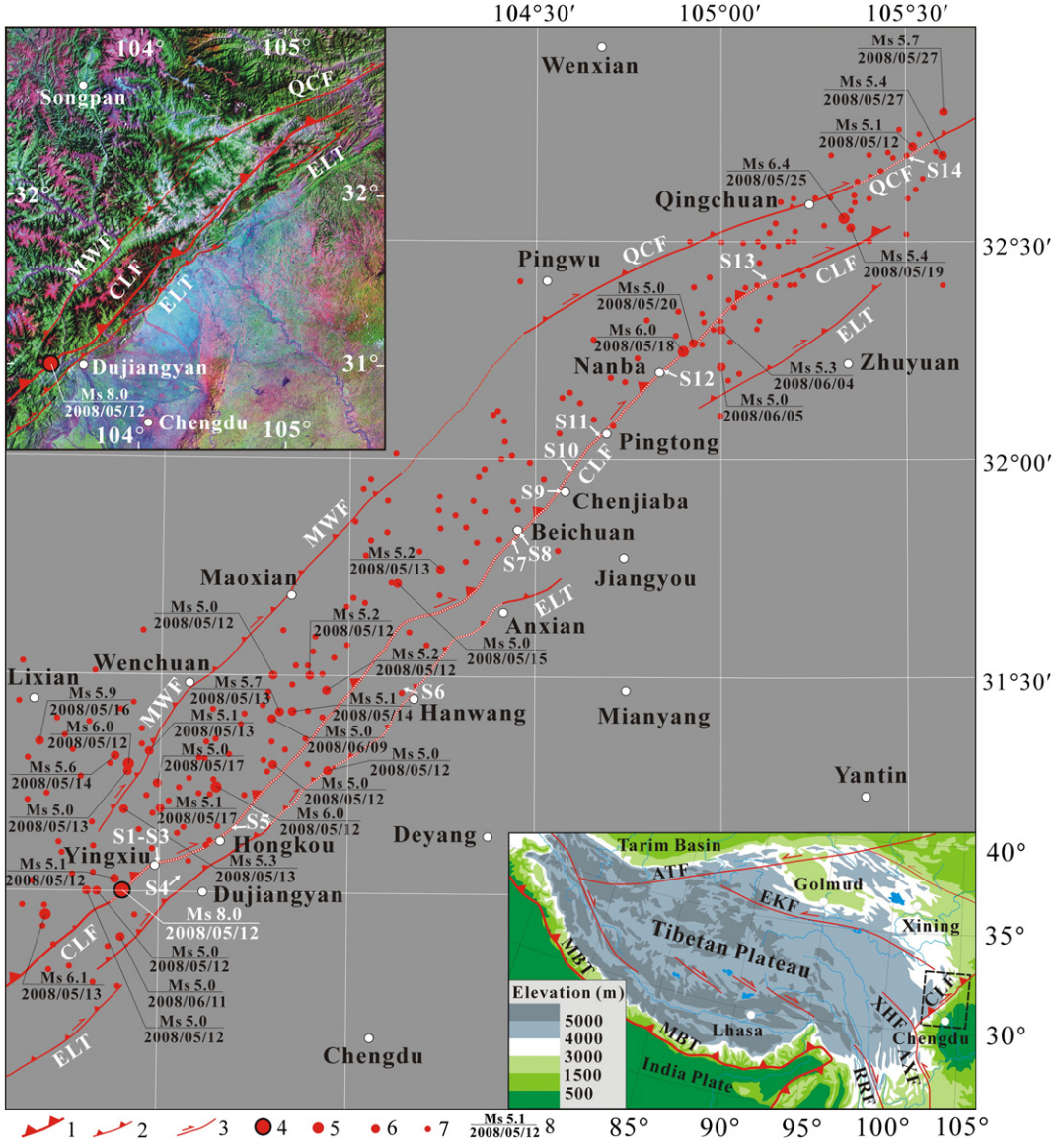

Fig. 1. Map of the Longmenshan Mountains showing fault ruptures and seismicity of the Wenchuan Earthquake and aftershocks. The upper left inset map is a satellite image of the Longmenshan Mountains with superimposed active faults. The lower right inset map shows the tectonic setting of the studied area and location of the image and major active faults. The Tibetan Plateau lies to the northwest and Sichuan Basin to the southeast. Explanation: 1, major thrust fault; 2, minor seismic fault; 3, strike-slip fault; 4, Ms 8.0 Wenchuan Earthquake epicenter; 5, Ms 6.0–6.9 aftershock epicenter; 6, Ms 5.0–5.9 aftershock epicenter; 7, Ms 4.0–4.9 aftershock epicenter; 8, magnitude (upper) and date (lower) of earthquake; S1, sites mentioned in text; CLF, Central Longmenshan Fault; ELT, East Longmenshan Thrust; MWF, Maoxian–Wenchuan Fault; QCF, Qingchuan Fault; XHF, Xianshui He Fault; AXF, Anninghe–Xiaojiang Fault; RRF, Red River Fault; ATF, Altyn Tagh Fault; MBT, Main Boundary Thrust. S1–S14 mark locations mentioned in text.

An understanding and delineation of these direct fault displacements and related seismic effects, the secondary geologic effects, and the delayed geologic effects is needed in the immediate planning for reconstruction and land use in the region. Such a seismic microzonation coupled with estimates of return-times for large earthquakes, the risk, can provide the basis for an evaluation of the overall seismic hazard for the region. The fault deformation and seismic effects of the Wenchuan Earthquake along the Longmenshan seismic zone were studied soon after the earthquake during May 16 to June 26, 2008, before the field evidence was destroyed by aftershocks, rainfall and rescue activities and several months later Wang (2010) made additional careful surveys along the faults under quieter conditions. The results are valuable for both delineating the zone of deformation along the faults and for a more precise understanding seismic tectonic movement characteristic of an earthquake of this size in the region and its return-time. Details and photographs of the offsets along the various faults involved and the relations of the displacements with phases of the earthquake were presented by Wu et al. (2009). These are briefly summarized below along with an overview of the secondary and delayed landslides, rock falls and mud flows. Delineation of the seismic hazard is found to involve direct displacement along fault zones, broader deformation zones that extend some distance from the faults, and more distant local areas of potential landslides, which may occur both during and after an earthquake. A consideration of all the fault offsets indicates that they can be considered a single zone that coupled with a new analysis of GPS measurements leads to an estimate of the risk. The purpose of this paper is to show this complexity in evaluating the seismic hazard, based on the effects of the 2008 earthquake and how the related fault displacements provide a new assessment of the recurrence interval of a similar great earthquake.

2. Fault displacement and deformation

Seismic faulting occurred chiefly along the Central Longmenshan Fault (CLF) where dextral-slip thrusting resulted in right-lateral slip