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The effect of the Wenchuan earthquake on the fluvial morphology in the Longmen Shan, eastern Tibetan Plateau: Discussion and speculation

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ABSTRACT

Although large earthquakes can have significant impacts on the geomorphology of mountain rivers, the consequences of such impacts remain poorly understood. The Ms 8.0 Wenchuan earthquake of 12 May 2008 created knickpoints (waterfalls) in the river systems of the Longmen Shan, eastern Tibet Plateau, in addition to numerous landslides along rivers. In this study, we use high-resolution remote sensing images and field surveys to examine how the Baisha and Jianjiang River channels responded to the Wenchuan earthquake. The morphological response along the Baisha River was a knickpoint, with a height of 4.5 m, which was studied from 2008 to 2012. However, the river did not show rapid incision via knickpoint migration during the post-earthquake period. In fact, post-seismic flooding destroyed the face of the co-seismic knickpoint. The rapid removal of the knickpoint suggests that the abrupt vertical displacement associated with the earthquake did not exceed the adjustment threshold of the fluvial dynamic equilibrium, and so was unable to drive rapid morphological change at the local scale. Along the Jianjiang River, the average meander migration rate of the Beichuan reach was −2.8 m/yr between 2001 and 2008, but increased to 51.1 m/yr during the five years following the 2008 Wenchuan earthquake. This rapid increase in the meander migration rate is attributed to excess sediment supplied to the river as a consequence of the earthquake. These two case studies indicate that the Wenchuan earthquake caused channel aggradation rather than a significant increase in river incision by locally generating relief across the river.

1. Introduction

Active tectonic uplift due to earthquakes is a sporadic process. Abrupt faulting with significant co-seismic vertical displacement across a fluvial channel may initiate rapid morphological changes on a scale of a corresponding reach. Yanites et al. (2010) proposed a conceptual model for fluvial incision processes reacting to large earthquakes, based on a case of the river Pei-Kang responding to the 1999 Chi–Chi earthquake, Taiwan. Similarly, Huang et al. (2013) explained the progressive evolution process of river morphology in response to the same earthquake, choosing the Tachia River as an example in central Taiwan. In addition, co-seismic landslides along a river valley can influence the fluvial processes of sedimentation and erosion (Dadson et al., 2003; Lin et al., 2008a, 2008b; Chen, 2009). Many other researches have also been implemented in Taiwan (Chen, 2010; Cook and Suppe, 2010; Hayakawa et al., 2010; Huang and Montgomery, 2012), which is a region of high uplift rates (Peng et al., 1977; Lundberg and Dorsey, 1990; Chan et al., 2010). However, the links between large earthquakes and river response have rarely been analyzed and documented in regions of low-shortening settings, such as the eastern margin of the Tibet plateau (King et al., 1997; Wang et al., 2001; Zhang et al., 2004; Shen et al., 2005).

The rivers of the Longmen Shan in the Eastern Tibet Plateau are one of the best natural laboratories to study the fluvial morphology changes under the above mentioned tectonic circumstances. The 2008 Wenchuan earthquake, one of largest continental thrust events worldwide (Liu-Zeng et al., 2009; Fu et al., 2011), produced surface ruptures over 300 km long in total (Fig. 1) (Fu et al., 2008, 2011; Li et al., 2008; Zhang et al., 2008;

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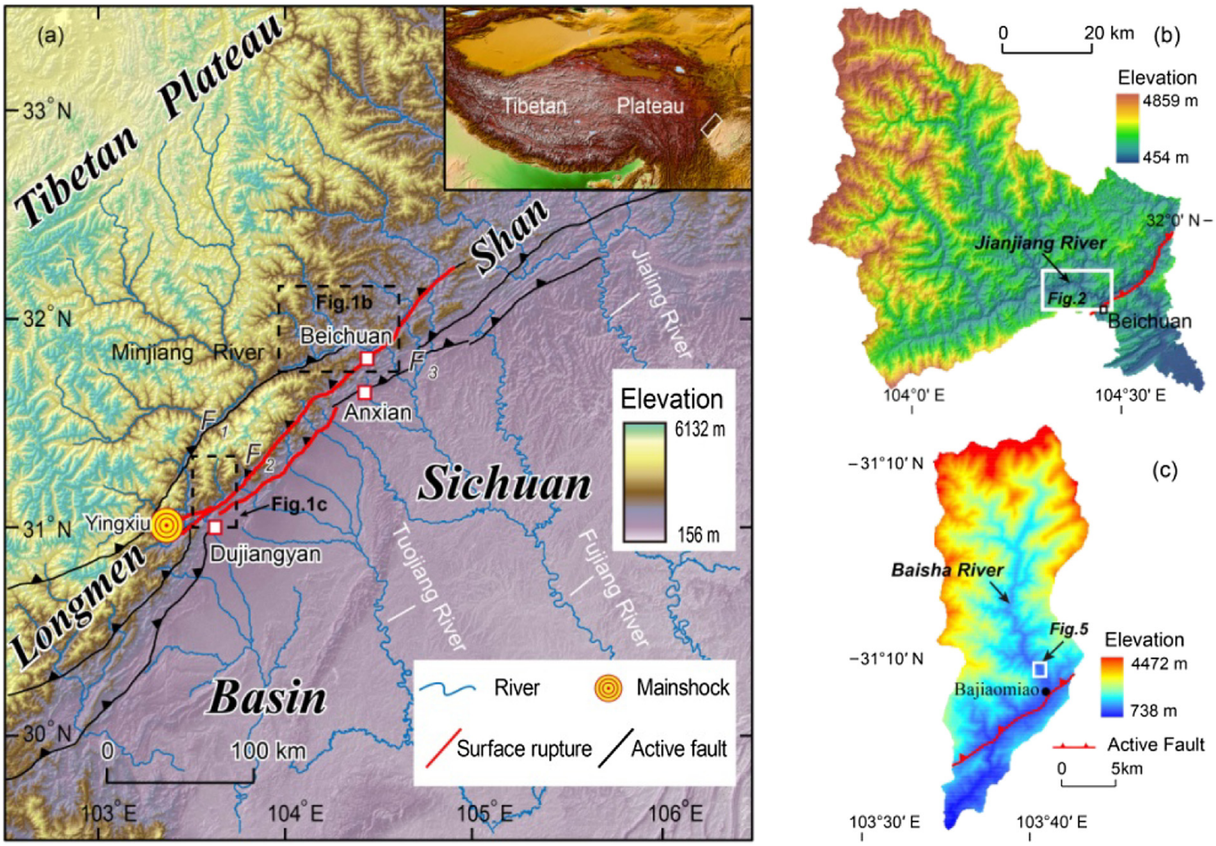

Fig. 1. (a) Topography, active faults (F1–F3), and surface ruptures in the Longmen Shan. F1: Wenchuan-Maoxian Fault; F2: Yingxiu-Beichuan Fault; F3: Guanxian-Anxian Fault. The red line indicates the surface rupture associated with the Wenchuan earthquake (Fu et al., 2008; Zhang et al., 2008; Xu et al., 2009). (b) and (c) are the topography of the Jianjiang River and Baisha River respectively.

Xu et al., 2009) and induced tens of thousands of landslides along the river valleys in the Longmen Shan range (Huang and Li, 2009; Dai et al., 2011; Gorum et al., 2011; Parker et al., 2011). The surface ruptures produced knickpoints (waterfalls) across the river. For example, a knickpoint was produced by the co-seismic deformation in Hongkou Town, Dujiangyan City with a height of 4.5 m (Fu et al., 2009). At Pingtong town and Bailu town, knickpoints were formed along the surface rupture with heights of 2.3 m and 2.4 m respectively (Xu et al., 2008; Yang et al., 2009). Hillslope deposits were released into the rivers, which resulted in a very large increase in the fluvial sediment flux (Wang and Meng, 2009; Tang et al., 2011). Thus, by combining the interpretation of high resolution satellite images and field topographic measurements, we investigate the short-term changes in the fluvial morphology at typical sites from the Baisha River and Jianjiang River to document the effect of such perturbations on the evolution of river morphology in regions of low convergence rate. The implications for the long-term response of the river to the disturbance associated with repeated large earthquakes will be discussed.

2. Regional setting

The Longmen Shan fold-and-thrust belt is approximately 500 km long and 30–50 km wide, and consists of three main sub-parallel faults (Deng et al., 1994; Burchfiel et al., 1995), with thrust and dextral deformation being accomplished along the major fault systems (Burchfiel et al., 1995, 2008; Kirby et al., 2002). The three main faults are from northwest to southeast, the Wenchuan-Maoxian fault (F1), the Yingxiu-Beichuan fault (F2), which is the primary structure responsible for the 2008 Wenchuan earthquake (Xu et al., 2009; Zhang et al., 2010), and the Guanxian-Anxian fault (F3) (Fig. 1). The surface deformation was characterized by oblique thrust/dextral slip with a maximum vertical displacement of 9–10 m (Fu et al., 2008, 2011; Li et al., 2008; Xu et al., 2009; Ran et al., 2010).

The Longmen Shan is characterized by a steep topography which typifies the eastern border of the Tibetan Plateau where several major rivers have deeply dissected. These are from north to south, the Jialingjiang River, Fujiang River, Tuojiang River, and Minjiang River (Fig. 1). Originating in the eastern margin of the Tibetan Plateau, the North–South-trending Minjiang River flows along the Wenchuan-Maoxian fault (F1), passes through the Longmen Shan where it cuts gorges more than 1–3 km deep (Burchfiel et al., 1995) and then reaches the Sichuan Basin at Dujiangyan city.

The Baisha River is a tributary of the Minjiang River (Fig. 1), and the Wenchuan earthquake produced a surface rupture over 14 km long along this river (He et al., 2008a). The Jianjiang River is a tributary of the Fujiang River (Fig. 1). At Beichuan, it is diverted and from there flows northeast, parallel to the Yingxiu-Beichuan Fault, before turning southwest to cross the Guanxian-Anxian Fault (Fig. 2). The Jianjiang flows across various rock units, mainly Silurian slate and phyllite, Devonian limestone and dolomite, Carboniferous limestone and shale, Permian limestone, and Triassic sandstone and shale (Fig. 2). The fluvial evolution of this river has been