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Provenance and earthquake signature of the last deglacial Xinmocun lacustrine sediments at Diexi, East Tibet

Hanchao Jiang [a,*], Xue Mao [a,b], Hongyan Xu [a], Huili Yang [a], Xiaolin Ma [a,b], Ning Zhong [a,c], Yanhao Li [a,c]

[a] State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, Beijing 100029, PR China
[b] College of Geosciences and Resources, China University of Geosciences, Beijing, 100083, PR China
[c] University of Chinese Academy of Sciences, Beijing 100049, PR China

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ABSTRACT

Well-preserved lacustrine sediments are found in some areas in East Tibet. This region is characterized by a windy and semi-arid climate, alpine valleys, and frequent earthquakes. Measurements of rare earth elements, observations from a scanning electron microscope and a high-resolution record of grain-size measurements allowed us to compare fine sediments from the Xinmocun section in the Diexi Lake, with loess from the Chinese Loess Plateau and South China. Results indicate that fine grains of the Xinmocun lacustrine sediments were transported by wind and trapped in the lake, whereas the >16 μm fraction was likely from local sources. The grain-size changes within the section repeatedly show abrupt coarsening and upward fining, probably due to palaeoearthquake events. Large earthquakes in the study area often caused rockfalls and landslides, exposing fine sediments that had accumulated on mountains' slopes. The fine grains were then retransported by wind to the Diexi Lake. Optically stimulated luminescence dating of the Xinmocun section indicates continuous deposition from 18.65 to 10.63 ka. These results indicate that palaeoearthquakes in the study area had a mean recurrence interval of ~0.32 ka. Therefore, we propose that lacustrine sediments in a tectonically active region have the potential to record a continuous history of palaeoearthquakes. Palaeoearthquakes probably produced numerous rockfalls and landslides in alpine valleys and provided significant sources of regional eolian dust.

1. Introduction

The Longmen Shan mountain range lies along the eastern margin of the Tibetan Plateau. The 1933 Diexi ($M = 7.5$) and 2008 Wenchuan ($M = 8.0$) earthquakes caused tens of thousands of fatalities and widespread damage to the properties. As a result, numerous recent studies explored tectonic movements in the mountain range and discussed their possible links with the India–Eurasia collision (e.g. He and Oguchi, 2008; Parsons et al., 2008; Xu et al., 2008; Zhang, 2008; Zhang et al., 2008; Hubbard and Shaw, 2009; Liu-Zeng et al., 2009; Wang et al., 2009; Xu et al., 2009; Zhang et al., 2009a, 2010; Fu et al., 2011). In constrast, only a few studies focused on the palaeoearthquake history of the Longmen Shan region, which is pivotal to understanding the evolution of fluvial geomorphology regionally (Oguchi et al., 2001).

Recently, Wang et al. (2005) found a suite of dammed lacustrine sediments that are several tens of meters thick in the Diexi Lake located in the upper reaches of the Minjiang River, northwestern Sichuan Province and the eastern margin of the Tibetan Plateau. Radiocarbon dates indicated that these sediments were deposited between 22–10 ka (Wang et al., 2005); however, new AMS ^{14}C dates show the base of the section may be 40.5 ka (Zhang et al., 2009b). Thus, the age of these sediments remains uncertain. Moreover, previous work has not focused on the provenance of the sediments in the Diexi Lake. Furthermore, soft-sediment deformation, interpreted as evidence of palaeoearthquakes, was discovered at Shawan, beside the Diexi Lake (Wang et al., 2011), posing a challenge for the extraction of environment information directly from the dammed lacustrine sediments at Diexi.

In recent years, eolian dust accumulation on the Tibetan Plateau has attracted wide attention. Whether the Tibetan Plateau is a significant dust source is an important environmental issue (e.g. Fang, 1995; Fang et al., 2003, 2004; Lu et al., 2004; Sun et al., 2007; Kaiser et al., 2009a, b; Lai et al., 2009) in the Sichuan Basin (Han et al., 2010; Yang et al., 2010a,b), South China (Qiao et al., 2003; Hao et al., 2010) and even the Far Eastern Pacific regions (Hovan et al., 1989, 1991). Synoptic dynamics and remote sensing tracing of a dust storm from 3 to 5 March, 2003 in Lhasa, South Tibet, demonstrate that the Tibetan Plateau possesses all the necessary factors and conditions to generate dust storms (Fang et al., 2004). Currently, there are several different ideas on the generation of loess on the Tibetan Plateau. Loess in southern Tibet is believed to have a glacial origin, resulting from eolian sorting of glaciofluvial outwash deposits of braided river channels or alluvial fans, due to local near-surface winds (Sun et al., 2007). On the other hand, widespread tectonic activity in the region could produce large amounts of silty loess (Smalley, 1995). Optically stimulated luminescence (OSL) dating

* Corresponding author. Tel./fax: +86 10 62009082.
E-mail addresses: hcjiang@ies.ac.cn, hanchaojiang@hotmail.com (H. Jiang).

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suggests that eolian dust accumulation is episodic in the southern Tibetan Plateau (Lai et al., 2009). Typically, a large amount of silt-size material has to be produced and transported to provide a loess deposit. Given that loess formation depends strongly on specific geomorphological conditions and associated processes, different regions possibly have different mechanisms of loess generation.

In this paper, we conducted sedimentological analysis on sediments from the Xinmocun section (32º 2.7′ N, 103º 40.1′ E, 2188 m a.s.l.) beside the Diexi Lake (Fig. 1), to explore the provenance and understand their relationship with palaeoearthquake events. We analyzed rare earth elements (REEs) and grain size, conducted scanning electron microscope (SEM) studies of sediments, and compared the results with those of the eolian dust from different regions to explore the provenance of the sediments. Furthermore, sedimentation features observed in the field, material provenance, and high-resolution grain-size and susceptibility (SUS) records were combined to understand the formation of these fine lacustrine sediments in relation to palaeoearthquake events.

2. Geographic and geologic settings

The 2008 Wenchuan earthquake ruptured several strands of the Longmen Shan fault zone, which separates the seismically active Tibetan Plateau from the Sichuan tectonic basin (Fig. 1; Zhang et al., 2003; Zhang, 2008). To its west, elevations reach more than 4000 m above sea level and widespread active faulting attests to continued seismotectonic activity (Wang et al., 2007; Xu et al., 2007; Yao et al., 2008; Liu et al., 2009). East of this belt, however, the elevation of the Sichuan basin lies only ~600 m above sea level and the absence of active faulting suggests relatively weak tectonic activity with a low level of seismicity (Fig. 1).

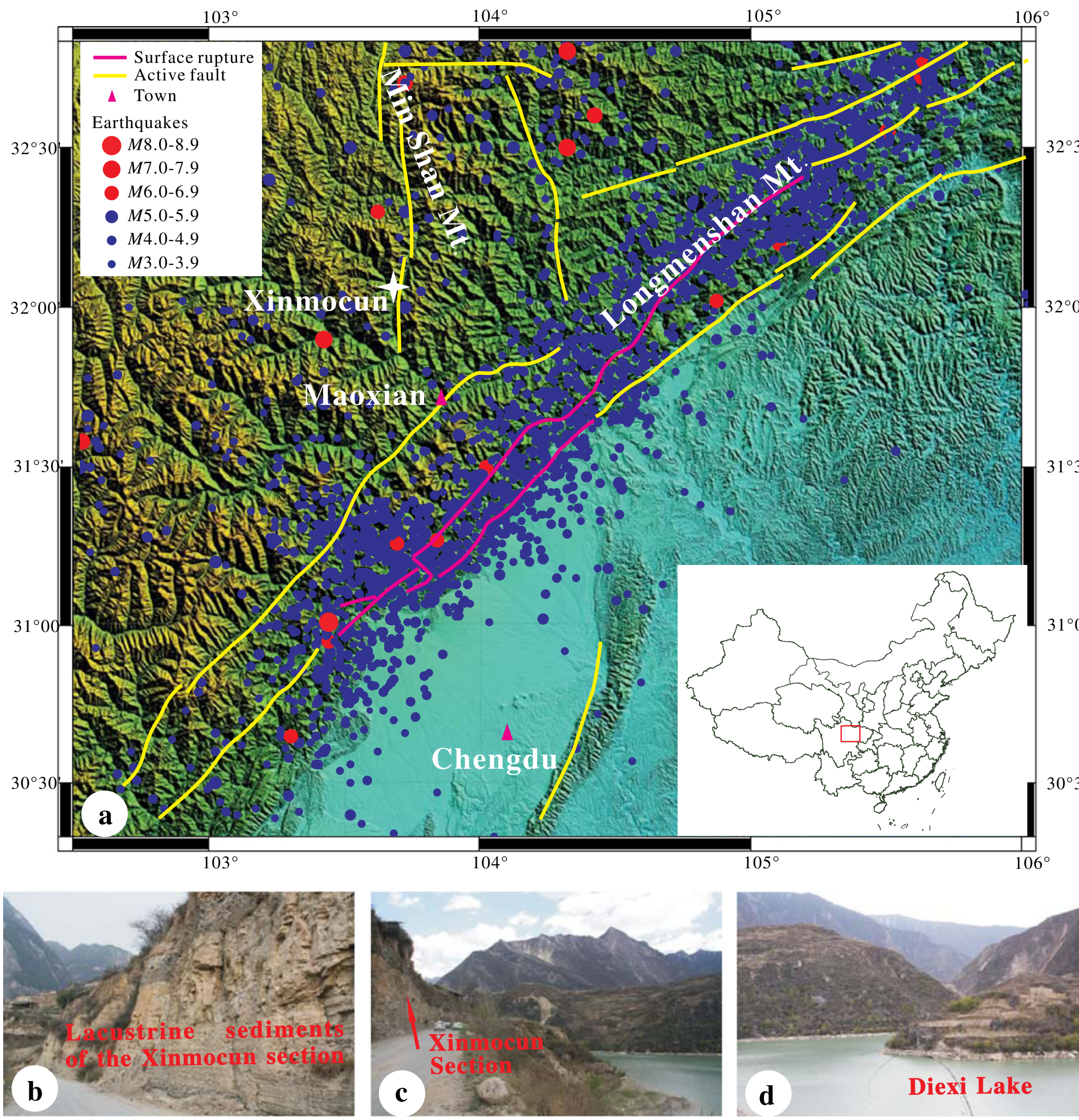

Fig. 1. DEM of the region illustrating the geomorphology and drainage system in the study area (a) with the location of the Xinmocun section (star). The blue and red solid circles show the seismicity between years 1900 and 2012, with red and blue representing large and small magnitude earthquakes, respectively. The 1970–2012 seismicity data were from the China Earthquake Data Center (http://data.earthquake.cn/data). The 1900–1970 seismicity data were from the Department of Earthquake Disaster Prevention of China Earthquake Administration (1995). Surface ruptures and active faults are after Zhang et al. (2010). Inset shows the location of this study area within China. (b) to (d) illustrate lithology of the Xinmocun section and nearby topography.