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Geochemical composition of the last deglacial lacustrine sediments in East Tibet and implications for provenance, weathering, and earthquake events

Lianji Liang, Hanchao Jiang*

State Key Laboratory of Earthquake Dynamics, Institute of Geology, China Earthquake Administration, Beijing 100029, PR China

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ABSTRACT

Identifying and understanding the respective influence of climate and tectonic processes becomes a frontier topic in tectonically active mountain ranges. In the eastern Tibetan Plateau, earthquake occurred frequently and usually led to formation of many dammed lakes. In this study, a last deglacial section of lacustrine sediments at Xinmocun in eastern Tibet is selected for conventional X-ray fluorescence (XRF) and Scanning XRF (SXRF) elemental analysis. The high correlation of major and trace element abundances between the Xinmocun lacustrine samples and the loess-soil samples from the Chinese Loess Plateau (CLP) supports the previous view of the eolian origin of the Xinmocun lacustrine sediments. Analysis of major element abundances, ratios, and trace element ratios indicates that the dust provenance of the Xinmocun lacustrine sediments is different from that of the CLP, and is similar to that of the loess at Ganzi and Hongyuan nearby the study area. The significant variations of most geochemical elements and their close coupling with grain-size variations cannot be reasonably explained by the changes in transport dynamics of eolian dust, and is possibly caused by the intermittent changes in available dust provenance. Frequent earthquakes triggered abundant landslides and provided large amounts of dust for the study area. Accordingly, in the >16 μm fraction of the Xinmocun grain-size record, many element abundances and their ratios, such as SiO_2/Al_2O_3, TiO_2/Al_2O_3, CaO/Al_2O_3, Sr/Al_2O_3, Rb/Sr, and Na_2O/Al_2O_3, can be regarded as sensitive indicators of earthquake events in the tectonically active regions. SXRF measurements at the U-channel surface can provide some cost-effective indicators of seismic events, such as Si/Al, Ti/Al, Ca/Al, Sr/Al, Zr/Rb, and Rb/Sr. Significant variations in most element abundances and their ratios of the Xinmocun lacustrine sediments correlate closely with those of its grain-size record. They all show no increasing or decreasing trends with time. These suggest that tectonic activities characterized by seismic events possibly had a major role on the landscape erosion in the eastern Tibetan Plateau, while the climatic influence seems minor.

1. Introduction

Climate and tectonic processes are two major factors which exert a significant influence on the landscape evolution in tectonically active mountain ranges. Identifying and understanding the respective influence of these two factors becomes a frontier topic. The central element of the climate–tectonic coupling is denudation.

In the eastern margin of the Tibetan Plateau, thermochronology analysis of zircon and apatite indicated that the denudation rates reached 1–2 mm/y for the Longmen Shan region during the Late Cenozoic (Kirby et al., 2002). Later, long-term denudation rates for the Pengguan Massif and Longmen Shan front measured by low-temperature thermochronology were estimated to be ~0.5–0.7 mm/y (Kirby, 2008; Godard et al., 2009). Recently, short-term denudation rates in the earthquake region were estimated to vary between 0.2 and 0.3 mm/y, which are measured from concentrations of ^{10}Be in quartz extracted from river sand prior to the Wenchuan earthquake (Ouimet et al., 2009; Ouimet, 2010). As for the great discrepancy between the kilo-year and million-year timescale erosion rates, Ouimet (2010) proposed that earthquake-related landslide erosion was a potential explanation. In order to confirm such a hypothesis, a detailed denudation processes needs to be analyzed reasonably in the eastern Tibetan Plateau.

* Corresponding author.
E-mail addresses: hcjiang@ies.ac.cn, hanchaojiang@hotmail.com (H. Jiang).

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Geochemical composition of sediments is strongly influenced by source area composition, transportation and post-depositional weathering. In this study, we measure and compare conventional X-ray fluorescence (CXRF) and scanning XRF (SXRF) elemental signals in the last deglacial Xinmocun lacustrine sediments in the eastern Tibetan Plateau which was preliminarily confirmed to have been transported into the study area by wind (Jiang et al., 2014a). After examining variations in geochemical compositions of the lacustrine sediments, we develop various geochemical indicators to identify the provenance of the Xinmocun lacustrine sediments and to decipher the last deglacial paleoenvironmental changes in the eastern Tibetan Plateau. These will allow us to gain insight into the climate–tectonic coupling in this tectonically active region.

2. Materials and method

The Xinmocun lacustrine section (32°2.7′N, 103°40.1′E, 2188 m a.s.l.), about 11 m thick, is located at Diexi in the upper reaches of the Min River on the eastern margin of the Tibet Plateau (Jiang et al., 2014a). This region is characterized by a windy and semi-arid climate, alpine valleys, and frequent earthquakes (Fig. 1A). The occurrence of strong earthquakes possibly results in rockfalls and landslides from the valley sides (Keller and Pinter, 2002; Xu et al., 2013). Following the 1933 Diexi earthquake ($M = 7.5$), several landslide-dammed lakes formed in the upper reaches of the Min River (Nie et al., 2004; Wang et al., 2011; Xu et al., 2015). The bedrock exposed on the Diexi paleo-dammed lake catchment is dominated by Silurian phyllite, quartz schist, carbonatite and Triassic phyllite, limestone, and metasandstones (Wang et al., 2005; Yang et al., 2008). Recently, the high-resolution grain-size measurements indicate that the Xinmocun lacustrine sediments are dominated by silt (~76.6%) and have abundant clay (~20.3%) (Fig. 2). The powder samples collected in 2011 are selected at an interval of 10 cm for the conventional XRF measurements. Since about 2 m of the lowest section was buried during the recent road repairs, U-channel samples with a length of 8.79 m were collected from the exposed Xinmocun section (Fig. 1B). Each U-channel was cut into about 60–70 cm long and remained overlap at least 5 cm long from one U-channel to the other (Fig. 1C–E). The U-channel samples were scanned on XRF Core Scanner at 0.5 cm intervals.

Major and trace elemental concentrations of the Xinmocun powder samples were measured on the Philips PW2404 X-ray Fluorescence Spectrometer and the Finnigan MAT HR-ICP-MS (Element I) instrument, respectively, at Analytical Laboratory of Beijing Research Institute of Uranium Geology, China. Powder samples were dried at 40 °C and ground to 200 mesh size (about <75 μm). About 0.6 g of dry-ground samples were mixed with 6 g of $Li_2B_4O_7$–Li_2CO_3 fusion reagent in Platinum crucibles, heated to 1100 °C in a furnace and finally cooled down to form a glass disc for the major element analysis. Analytical uncertainties for the major elements (SiO_2, Al_2O_3, CaO, $Fe_2O_{3(Totle)}$, K_2O, TiO_2, MnO, Na_2O and P_2O_5) are less than 3%. Loss on ignition (LOI) was obtained by weighing after combustion 1 h at 1000 °C.

The dry-ground samples of 0.05 g for trace element analysis were placed in airtight Teflon vessels. The samples were wetted and shaken lightly to disperse them completely. Five ml of HNO_3 were added, and vessels heated on a hot plate (200 °C) for dissolution. After the solution was dried, 3–5 ml of HNO_3 was added and the vessels were covered for sufficient dissolution. The solution was diluted by 1% HNO_3 and transferred into 50 ml volumetric flasks for elemental measurements. Replicate analyses show good reproducibility and analytical uncertainties less than 10% for most of the trace elements.

SXRF measurements were conducted directly by scanning the U-channel surface on the Avaatech XRF Core Scanner in the State Key Laboratory of Marine Geology, Tongji University in Shanghai,

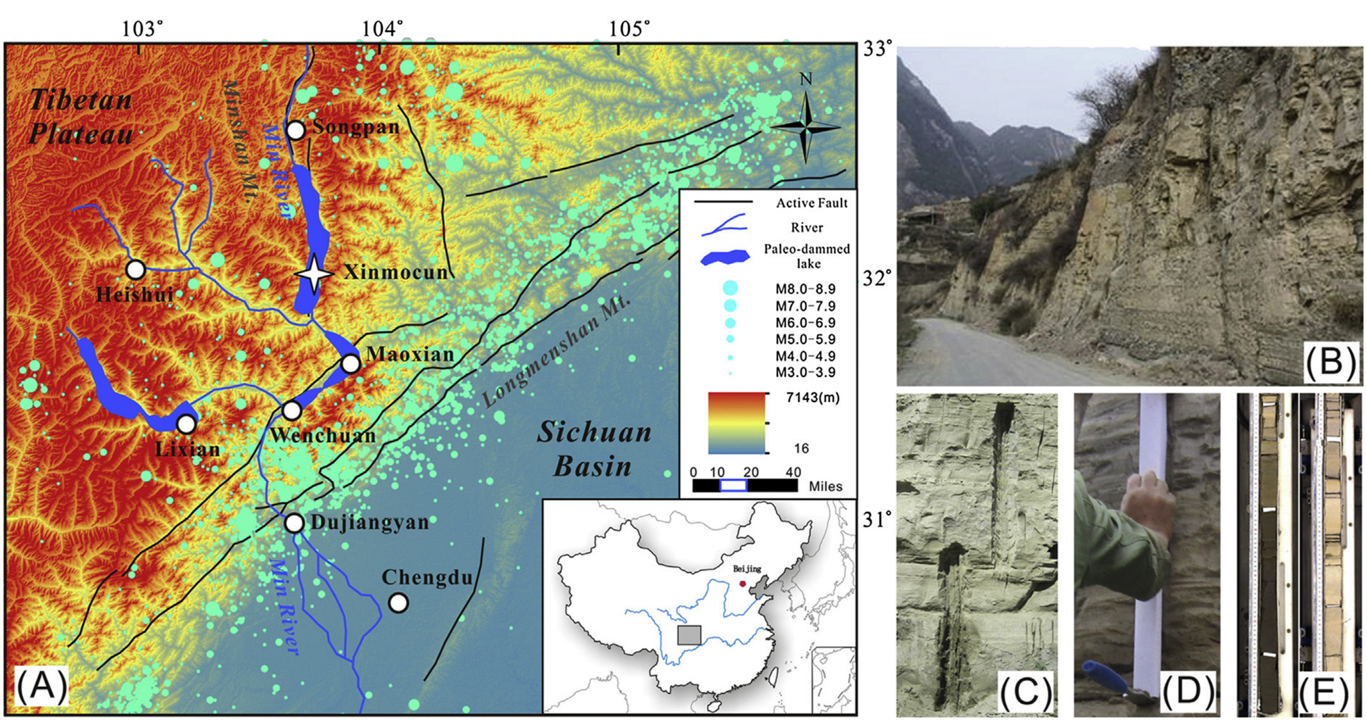

Fig. 1. Map showing the geomorphology, main faults and the drainage system in the study area with the location of the Xinmocun section (star) (A). The light green solid circles show the seismicity from 1900 to 2012. The 1970–2012 seismicity data were from the China Earthquake Data Center (http://data.earthquake.cn/data), and the 1900–1970 seismicity data were from the Department of Earthquake Disaster Prevention of China Earthquake Administration (1995). (B) to (E) denote the lithology of the Xinmocun section in this study and U-channel samples collecting pictures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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