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Analysis of the causes of large-scale loess landslides in Baoji, China

J.S. Shi [a,b], L.Z. Wu [c,*], S.R. Wu [a], B. Li [a], T. Wang [a], P. Xin [a]

[a] Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing 100081, PR China
[b] China Geological Survey, M.L.R, Beijing 100037, PR China
[c] State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan, 610059, PR China

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ABSTRACT

Landslide hazards are common in western China. Understanding the mechanism of landslides in loess-covered regions is particularly important for landslide risk assessment. A detailed landslide survey including large-scale slide drilling and geophysical exploration was carried out at the edge of the Loess Plateau on the north side of the Wei River in China. We reconstructed the geomorphological evolution model of the Wei River and analyzed slope structures and lithology. Engineering geologic conditions and active fault properties in the landslide regions were investigated. The results showed that paleogeomorphology of the north slope of the river gradually lowered from south to north. Ancient landforms showed a gradual transition to the south Sanmen Lake Basin from the piedmont alluvial plain during the Pliocene to early Pleistocene. The lake basin in the southern part of the study area gradually retreated, and the Wei River formed in the early Pleistocene. The main river flow shifted northward because of neotectonic movement and periodic climate changes until the Holocene, and then gradually moved southward to produce the current landforms. The active Wei River fault at the edge of the Loess Plateau acted as a route of water infiltration, weakening the structural planes. Erosion and rise of the groundwater table caused old (occurrence during the Late Pleistocene) and ancient (occurrence before the Late Pleistocene) landslides to form on the edge of the plateau along active fractures and interfaces of Pliocene sand, gravel and clay. These were multiple deep-seated rotational slides and/or multiple perched translational landslides. Slope stability analysis indicated that the complex landslides that occurred in the loess areas in recent years were closely related to the distribution of water and Pliocene clay.

1. Introduction

Landslides are of global concern because of their great cost to humans (Dai et al., 2002; Zhou et al., 2002; Van Westen, 2005; Huang, 2009). The frequent occurrence of landslide events in western China has led to much research toward understanding landslide processes and related material properties, and implementing effective strategies for their mitigation (Dijkstra et al., 2014). For example, studies have found that where the water content of loess material is low, there is sufficient shear strength to resist sliding. When wet, however, loess strength decreases significantly (Derbyshire et al., 1994). Thus, loess slopes are very prone to landslides.

Northwest China is tectonically active and strongly affected by uplift. Crustal stress has formed large NNE–SSW and WNW–ESE trending strike-slip and thrust fault zones (e.g., Dijkstra et al., 1993). Loess landslides along the Wei River have been intensively studied during engineering and construction projects and environmental conservation planning (Zhang et al., 1995; Liu et al., 1998; Zhang and Wang, 2007; Wang et al., 2011). Many large-scale landslides occur in the region but their formation mechanism has not been well understood. Hu et al. (1965) noted that landslides along the Wei River at the edge of the Loess Plateau vary according to the occurrence time and corresponding geomorphological conditions. Hence, to better understand the formation mechanism, those loess landslides were classified into four types according to the characteristics of loess covering the mass and relationships of the mass with river terraces. The four types are ancient landslides that occurred before the Late Pleistocene, old landslides (during the Late Pleistocene), new landslides (during the Holocene), and modern landslides. The majority of studies in the region have focused on the morphology and features of landslides, potential hazards, and statistical analyses using causative factors such as topography, lithology, and rainfall (e.g., Zhang and Wang, 2007; Wang et al., 2011). A lack of information on the geological and geomorphological evolution of the landslides and adjacent valleys prevents a complete understanding of the landslide formation mechanism (Zhang and Li, 2011).

Landslides may be induced by rainfall and human factors (Huang, 2009; Peng et al., 2015; Wu et al., 2015). Several catastrophic loess landslides caused by irrigation have been reported (Derbyshire et al., 2000; Dijkstra, 2000; Zhang et al., 2009; Xu et al., 2011; Wen and He, 2012; Kimura et al., 2015). Slides and falls have accounted for over 80% of recent landslides in China, with one third of those having occurred on the

* Corresponding author.
E-mail address: wulizhou07@cdut.cn (L.Z. Wu).

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Loess Plateau (Zhang et al., 2009; Zhang and Li, 2011). The plateau lies along the middle reaches of the Yellow River and includes areas of northern Shanxi Province, Ningxia Province, and northern Gansu Province covered by loess (Zhuang and Peng, 2014). Wang et al. (2014a) indicated that groundwater is present in landslide source areas, and that the loess has high porosity. The stability of loess is sustained if the dry climate prevents ground saturation (Wang et al., 2014b). There have been many studies on loess slope failure mechanisms from the perspective of unsaturated soil mechanics of loess in surrounding regions (Tu et al., 2009; Acharya et al., 2011; Xu et al., 2011).

In this paper, we report landslide characteristics in the Baoji area along the Wei River at the northern edge of the Loess Plateau, based on the evolution of the Wei River Valley and its tectonic geomorphology. Slope types, engineering geological characteristics of Pliocene clay,

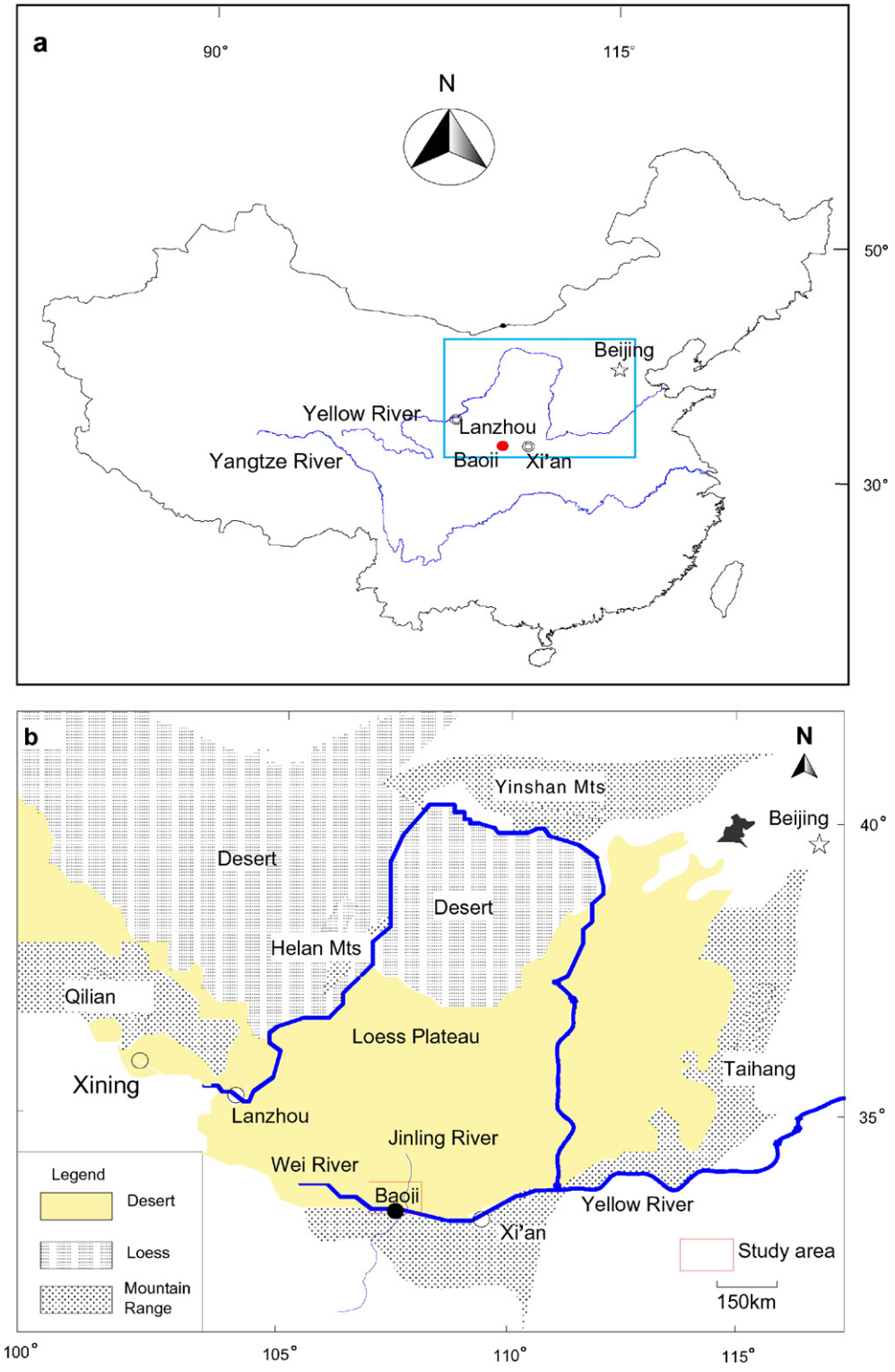

Fig. 1. Maps showing physiographic features in and around study area. (a) Location in China. (b) Study area.