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Optical dating of landslide-dammed lake deposits in the upper Yellow River, Qinghai-Tibetan Plateau, China

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ABSTRACT

Two large landslides, Dehenglong and Suozi, blocked the upper Yellow River from Longyang Gorge to Liujia Gorge on the Qinghai-Tibetan Plateau. This research is significant because no relevant chronologies for this landslide-dammed lake had been reported. Twelve OSL samples were collected from the lacustrine sediments of the landslide-dammed lake deposited on both banks of the upper Yellow River. Samples yielded similar ages of ca. 80 ka. The Dehenglong landslide and Suozi landslide are thus inferred to be triggered by ca. 80 ka tectonic movements.

1. Introduction

In recent years, researches on landslide-dammed lake deposits have received wide attention (Costa and Schuster, 1988; Korup, 2005), as the ephemeral damming of water by landslides across a river poses serious threats to people and property. A landslide-dammed lake may cause downstream flooding due to dam breach and rapid release of the impounding water or potential upstream flooding as the impounding lake water level rises. Landslide-dammed lakes can arrest the incision rates of bedrock when alluvial fills inhibit headward erosion, whereas catastrophic dam failures may cause the orders of magnitude of sediment yields greater than 'normal' sedimentation rates (Korup et al., 2007; Ouimet et al., 2007). Conversely, lacustrine sediments may record the timing and duration of the landslide dams in the fluvial sediment cascade (Korup and Clague, 2009). Therefore, it is vital to evaluate the role of landslide-dammed lakes in the fluvial sediment cascade (Korup, 2012).

In China, most research on landslide-dammed lakes was conducted in the southeast margin of the Tibetan Plateau (Dai et al., 2005; Korup and Montomery, 2008; Chen et al., 2013). Field evidence of a sequence of lake deposits indicates that two large landslides dammed the upper Yellow River on the northeastern Qinghai Tibetan Plateau. Landslide-dammed lakes could be triggered by torrential rainfall (Phartiayal et al., 2009), or by earthquakes (Chen et al., 2013; Higgitt et al., 2014). An improved chronology on the timing of landslide-dammed lakes in the Late Pleistocene may help differentiate between climate and tectonic factors. ^{14}C dating method is infeasible in our study due to frequently lack of terrestrial organic materials and low total organic carbon contents, as well as severe age underestimation for ^{14}C ages older than 25 ka for samples from arid areas in north China (Lai et al., 2014). Optically stimulated luminescence (OSL) dating, addressing the last light-exposure event, has been widely applied in dating landslide-dammed lakes around the world and some reliable chronologies have been obtained (Chen et al., 2008; Wang et al., 2014; Phartiayal et al., 2009). In this study, age control of the lake sediments from Longyang Gorge to Liujia Gorge were provided by twelve OSL samples from the lacustrine sediments and potential landslides that caused this lake sediments were also investigated.

2. Geological background

The Longyang Gorge-Liujia Gorge segment of the upper Yellow River (35°20′ – 36°20′ N; 100°15′–103°25 E Fig. 1) is located at the transitional belt between the Qinghai-Tibetan Plateau and the

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Loess Plateau (Li, 1991). The Yellow River originates in the northeastern Qinghai-Tibetan Plateau with an average altitude of ~4000 m above sea level (a.s.l.) and descends through a series of Cenozoic basins in northeastern Tibet. Since the Mid-Quaternary, the Qinghai-Tibetan Plateau has experienced substantial tectonic upheaval, and the upper Yellow River is incised deeply (>600 m) into a series of intermontainous basins and bedrock ranges (Craddock et al., 2010), from west to east including Gonghe, Guide, Jianzha-Qunke and Xunhua Basins. The incision of the Yellow River Movement at ~1.0 Ma with the formation of the Jishi Gorge, formed the VI terrace which is 900 m above the river level in Xunhua Basin (Li, 1991). At the beginning of the late Pleistocene, the degradation of the Yellow River cut the Longyang Gorge 800–1000 m deep (Li, 1991). There are about 12 faults (Fig. 1) between Longyang Gorge and Liujia Gorge in the upper Yellow River. These faults trend NW to SE, with northernmost fault segments oriented NNW to SSE. The Yiheilong, Jianzhadong and Duolonggou faults bound the Qilian Shan-Xi Qinling block, and may be epicenters of past earthquakes. Dehenglong, Suozi, Gelongbu and Ninqiu landslides are also in proximity to these three faults. Recent seismic data indicate that these faults are still active, generating >5 magnitude earthquakes (Li et al., 2011; Q.E.A, 1989). Deep landscape dissection by the Yellow River on the northeastern margin of the Tibetan Plateau has resulted in high-relief, narrow river gorges that frequently experience large landslides.

The lithology of the exposed profiles along the gorge sides are mainly Neogene red mudstone and Quaternary loess. The climate in the study area is semi-arid, with an average precipitation of ~342 mm/year but an average evaporation of ~1689 mm/year. And the temperature ranges between −28 °C and 25 °C.

3. Landslide-dammed lakes and relevant landslides

Combining geomorphologic investigation and satellite image analysis, a set of lacustrine sediments and terrace deposits from Longyang Gorge to Liujia Gorge in the upper Yellow River have been identified. We checked all the possible locations of the landslides by satellite image and conducted a walkover survey from Longyang Gorge to Liujia Gorge. Although a large number of small-scale landslides could readily be observed on both banks of the river, two adjoining landslides are the only sizable landslides that could dam the upper Yellow River, and the head scarps of both landslides were mainly controlled by Dehenglong Fault and their frontal edges by Jianzhadong Fault (Li et al., 2011). These two giant paleo-landslides are Dehenglong landslide (Fig. 2) with an estimated volume of 14.35×10^8 m^3 and Suozi landslide (Fig. 2) with an estimated volume of 21.45×10^8 m^3. They are located on the left bank of the Yellow River in Jianzha County, contiguous to each other. The basement rock, from which both Dehenglong landslide and Suozi landslide rotate, is a Neogene red mudstone which is overlain by Triassic gneiss. At some places in the upper Yellow River, the landslide mass deposited on to the clayey silt of the IV terrace (Li et al., 2011). On the other bank of the Yellow River, opposite Dehenglong landslide and Suozi landslide, a multitude of Triassic gneiss, the same material as the main body of Dehenglong landslide and Suozi landslide, were found, overlying on a Neogene red mudstone. Because these two landslides are in proximity to each other and their lateral boundaries are hard to be distinguished, we define them as Dehenglong-suozi landslides to understand the formation of the landslide-dammed lake.

The lacustrine deposits are on the terraces of the river much higher than the current river bed, and are not in the basin or depression locations. They are distributed in both banks of the river along the upper stream from the damming location. The landslide-dammed lake sediments intermittently extended for ~46 km upstream from Dehenglong-Suozi landslides to Liujia Gorge at both banks of the upper Yellow River, and no lacustrine sediments were found downstream of Dehenglong-Suozi landslides. The thickness of the sediments varies from several meters to ~146 m, thinning upper stream onward. The lacustrine sediments also overlay on different geomorphological units, e.g. the landslide deposits and fluvial terraces (Fig. 3c). For the lacustrine sediments at Lijia Gorge and Jianzha County, their top and bottom are at the same elevations of 2200 m a.s.l. and 2135 m a.s.l., respectively.

4. OSL dating for two typical sections of the landslide-dammed lake

4.1. Qunke section

The lacustrine sediments consist mainly of silt, clay, fine sand with clear laminar bedding. Qunke section is exposed at Qunke

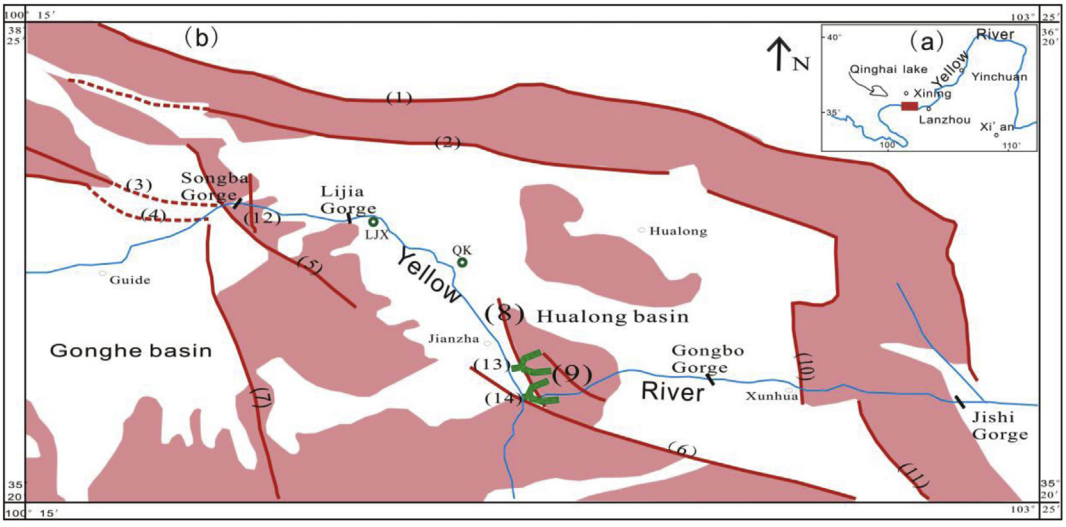

Fig. 1. Map showing the geographical location of the study area in the whole Yellow River, China.(a) Square denotes study area. (b) Distribution of lacustrine sediments sections, landslides and faults (1) Lajishanbeiyuan Fault (2) Lajishannanyuan Fault (3)Yeniushan Fault (4) Deqiansi-Ashengong Fault (5) Zhamashan Fault (6) Wendudasi Fault (7) Gangcasi Fault (8) Jianzhadong Fault (9) Dehenglong Fault (10) Xunhuadong Fault (11) Wulonggou Fault (12) Songba Fault (13) Suozi landslide (14) Dehenglong landslide. Lijiaxia and Qunke sections are abbreviated as LJX and QK.