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Assessing tectonic and climatic controls for Late Quaternary fluvial terraces in Guide, Jianzha, and Xunhua Basins along the Yellow River on the northeastern Tibetan Plateau

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ABSTRACT

This study focused on well-preserved fluvial terrace sequences that span the past 100 ka in the Guide, Jianzha, and Xunhua basins along the Yellow River that drained the northeastern Tibetan Plateau. New geomorphic, stratigraphic, sedimentologic and chronologic data from twelve depositional sequences within terraces yielded better constraints on rates of incision, degradational and aggradational phases for the Yellow River. Age control was established by sixteen OSL ages on quartz grains from fluvial sediments. Three fluvial aggradational phases were identified between 100 and 80 ka, 53 and 40 ka and 21 and 12 ka associated with terrace levels respectively at 120 to 95, 61 to 45 and 25 to 15 m above river level. These aggradational phases reflect multiple processes including enhanced fluvial discharge, sediment availability with glaciation, deglaciation and increased monsoonal precipitation. The initiation of fluvial degradation was linked to mega-floods released from landslide-dammed lakes at ca. 76, 38, and 16 ka, though these changes may also reflect variations in sediment-load discharge relations with climate change. The apparent net incision rate is 1.13 ± 0.11 mm/yr for the past 100 ka and is consistent with late Cenozoic tectonic uplift rates >0.5–2 mm/yr and recent GPS-based rates. The fluvial dynamics of the upper reach of the Yellow River was variably controlled by climate-induced changes in discharge sediment-load relations on stadial to interstadial timescales, episodic mega-floods from the breach of landslide dams, and with net incision in the past 100 ka in response to tectonic uplift of the Tibetan Plateau.

1. Introduction

The past hydrodynamic states of the Yellow River, which spans much of the breadth of China, reflect complex interactions amongst allogeneic factors such as sea level, tectonics, and climate change and autogenic forces including lithology, fluvial dynamics, and flooding (Vandenberghe, 2003; Limaye and Lamb, 2016). Fluvial stratigraphic sequences and associated loess deposits for terraces have provided valuable insights on aggradational and degradational history of the Yellow River within the context of late Cenozoic uplift of the Tibetan Plateau (Li, 1991; Li et al., 1996, 1997; Harkins et al., 2007; Pan et al., 2009; Wang et al., 2010; Hu et al., 2016). The formation of the Yellow River drainage along the margin of the Tibetan Plateau, near Lanzhou initiated about 1.8 Ma with fluvial incision propagating steadily westward for the Late Pleistocene (Fig. 1) (Li et al., 1997; Fang et al., 2005; Craddock et al., 2010). This incision appears to be in response to a cooling climate with expansion of lakes across the eastern Tibetan Plateau, spillover, erosion and drainage integration, leading to the entrenchment of the Yellow River (Craddock et al., 2010). The Yellow River incised into Guide Basin ca. 1.7 Ma (Fang et al., 2005) and deeply into the Jianzha Basin (Fig. 1) ca. 1.1 Ma (Pan et al., 1996). Fluvial degradation formed the 700–900 m deep Jishi and Longyang bedrock gorges (Fig. 1) at least by 1.1 and 0.125 Ma, respectively. Initial incision in the Tongde Basin, ~100 km to the south of Gonghe Basin, was apparently recent at ca. 0.5 Ma based on ^{10}Be and ^{26}Al burial ages for quartz-rich fluvial sands, possibly reflecting local base-level controlled by a bedrock sill (Craddock et al., 2010). The

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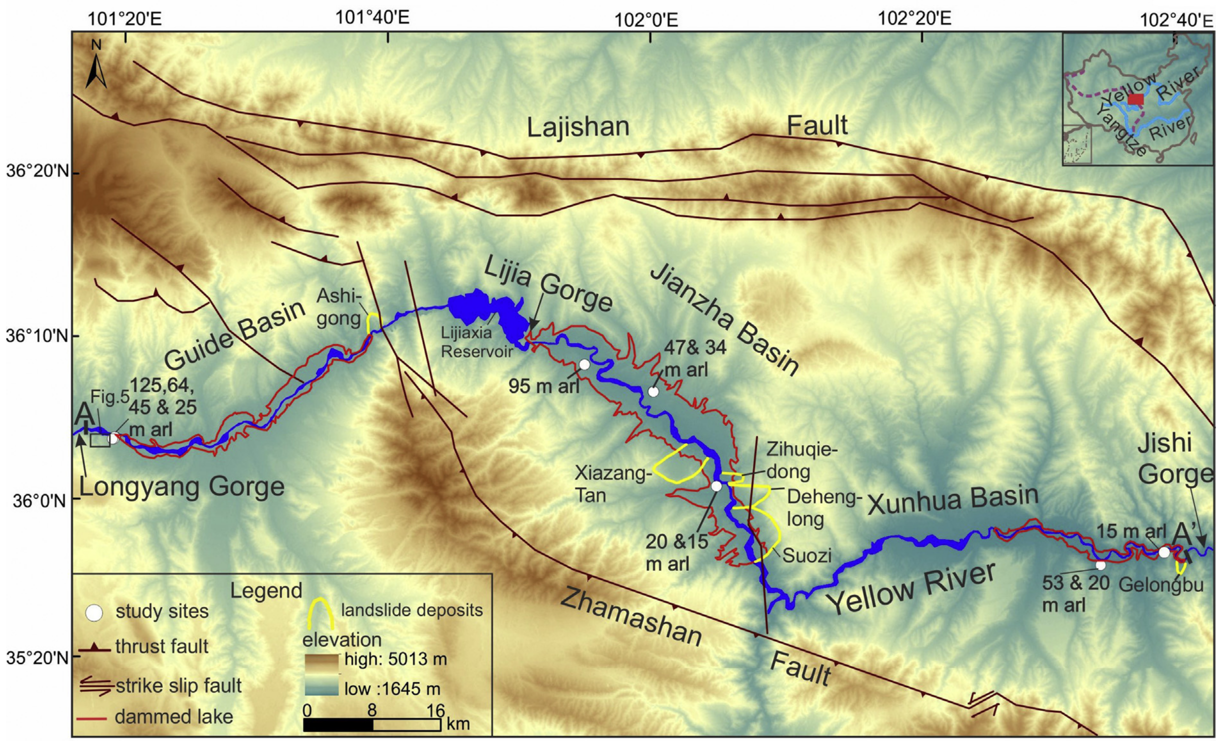

Fig. 1. Location of terraces, landslides and extent of landslide-dammed lakes along the Yellow River for the Guide, Jianzhua and Xunhua basins. Faults system shown is from the Qinghai Geological Survey (1971), Zhang et al. (2007) and Li et al. (2013).

latest period of incision in the Gonghe Basin occurred soon after ca. 0.5 Ma, based on ^{10}Be and ^{26}Al burial ages for quartz-rich fluvial sands from the highest terrace at the Daotanghe Divide (Zhang et al., 2014).

Fluvial terraces along the Yellow River are conspicuous and form a sequence of at least twelve elevationally-distinct levels spanning the middle to the late Quaternary (Li et al., 1997; Zhao and Liu, 2003; Pan et al., 2009; Zhang et al., 2009; Wang et al., 2010; Guo et al., 2012; Hu et al., 2017). These terraces have been identified by enumeration (T1, T2, T3 etc.) from the lowest to the highest elevation and were often dated by the overlying stratigraphic succession of loess units and paleosols (Li et al., 1997; Zhao and Liu, 2003; Pan et al., 2009; Hu et al., 2017). Nine conspicuous terraces (T1-T9) were identified in the Guide Basin that occurred from ~5 to 220 meters above the current river level (m arl) (Zhao and Liu, 2003). The age of the nine terraces was constrained by thermoluminescence (TL) ages on quartz grains from overbank deposits for the lowest (T1) to the highest (T9) terraces at ca. 9, 18, 43, 53, 88, 105, 140, 187 and > 187 ka (Zhao and Liu, 2003). Subsequently, electron spin resonance dating of quartz grains yielded respective mean ages for T1, T2, T4 and T5 of ca. 8, 16, 40 and 81 ka, consistent with the TL ages, though errors in the ages are 10–20% (Miao et al., 2012).

The formation of depositional terraces along the Yellow River is often associated with a prolonged period of lateral accretion and aggradation followed by incision forming the terrace scarp. The processes of aggradation and incision may be variable spatially and temporally with significant lateral planation, erosion, truncation and cut and fill depositional sequences. Landslides in mountainous, tectonically-active areas, like the upper reaches of the Yellow River are important factors for the fluvial evolution of this large river system (e.g. Korup and Montgomery, 2008; Egholm et al., 2013; Croissant et al., 2017). The associated damming effect of landslides and subsequent rapid release of impounded water has immediate and lasting effects on fluvial dynamics and can trigger net aggradation, lateral erosion, channel narrowing and rapid incision (e.g. Korup et al., 2010; Croissant et al., 2017). Thus, rapid down-cutting of some reaches of the Yellow River may have been paced by mega-floods with discharge on the order of 10^6–10^7 m^3/s derived from breaches of landslide-dammed lakes at ca. 76, 38, 24 and 16 ka (Ma et al., 2014; Yin, 2014; Guo et al., 2016; Wu et al., 2016). Recent results from a two-dimensional hydro-sedimentary model indicated that about 50% of the coarse-sediment volume of a large landslide is eroded in 5–25 years post landslide emplacement which resulted in a breach of the dammed lake with a mega-flood release (Croissant et al., 2017).

The preservation of terrace sequences along the Yellow River indicates a persistent process to lower base level on 10^4 year timescales to facilitate net fluvial incision, within the context of Pleistocene climate variability (e.g. Church and Ryder, 1972; Hancock and Anderson, 2002; Bridgland and Westaway, 2008a). Base level lowering in continental interiors can reflect differential uplift with tectonic activity, isostatic response to denudation, and from far-field vertical motion associated with subduction, faulting, and deformation of strata (Westaway et al., 2003; Westaway and Bridgland, 2014; Bridgland et al., 2017). In the absence of these mechanisms, reoccupation of terrace treads by a fluvial system may erode the geomorphic and stratigraphic records of fluvial processes. Model simulations of terrace formation suggested that the preservation of multiple terraces can be influenced by uplift rates. These simulations indicate that interpreting terrace records may be difficult in regions where climate variations were superimposed on spatial and temporal variations in tectonically-driven uplift. Uplift rates for the eastern Tibetan Plateau during the late Cenozoic are between 0.5 and 2 mm/year (Clark et al., 2005; Deng et al., 2013; Zhang and Jin, 2013; Pan et al., 2016) which serve to isolate elevationally terrace sequences above flood erosion on 10^4-year timescales. Thus, the terrace sequence of the Yellow River provides