Journal of Asian Earth Sciences 60 (2012) 235–245

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Fluvial terrace formation in the eastern Fenwei Basin, China, during the past 1.2 Ma as a combined archive of tectonics and climate change

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ARTICLE INFO

Article history:
Received 21 February 2012
Received in revised form 27 August 2012
Accepted 17 September 2012
Available online 27 September 2012

Keywords:
Yellow River
Fenwei Basin
Emei Platform
Fluvial terrace
Loess

ABSTRACT

The key to understanding the fluvial response to climate change and surface uplift is a thorough distinguishing between their roles in terrace formation. Previous studies have tended to attribute the fluvial behavior of deposit–incision alternation to climate cyclicity. A preliminary explanation is proposed here for terrace formation in the eastern part of the Fenwei Basin, China. The observed fluvial terrace sequence was developed by the Yellow River deeply downcutting into the Emei Platform, which was uplifted within the eastern Fenwei Basin, and therefore it probably records the tectonic history of this platform. On the basis of the magnetostratigraphy and optically stimulated luminescence (OSL) dating, a ca. 1.2 Ma chronology was established for this terrace sequence. Pedostratigraphic analysis of the loess deposits accumulated on each tread reveals that the terrace deposits are overlain immediately by a paleosol bed, suggesting that the abandonment of these terraces due to fluvial incision occurred at the transitions from glacial to interglacial climates. The glacial–interglacial climate cycle probably has a temporal control on the fluvial behavior of deposit–incision alternation, even though the Yellow River develops in the subsiding Fenwei Basin. The terrace generation may be sporadic and in the form of unusual stacked pattern before the Emei Platform was uplifted within the eastern Fenwei Basin. The terrace staircases however, formed in synchrony with glacial–interglacial climate cycles since this platform began to uplift in the late Middle Pleistocene. This result indicates that uplift may be necessary in large terrace staircase genesis. It can force the river system to downcut deeply enough during climatic transitions to separate terrace levels adequately, favoring the generation and subsequent preservation of the terrace treads. The terrace sequence of the Yellow River in the eastern Fenwei Basin therefore can be considered as a combined archive of climate change and local tectonic activity.

1. Introduction

River terraces are generally regarded as an important component of the fluvial archive (Bull, 1990), providing important evidence for landscape evolution and surface uplift (Maddy et al., 2000; Lavé and Avouac, 2001; Cohen et al., 2002; Stokes, 2008; Westaway et al., 2009). Furthermore, long-timescale climatic fluctuation can also be readily recorded by terrace sediments (Bull, 1991; Bridgland, 2000; Veldkamp and Tebbens, 2001). River terraces therefore are often used to evaluate the response of fluvial systems to climate change and surface uplift induced by tectonics or climate (e.g., Harvey and Wells, 1987; Hsieh and Knuepfer, 2001; Westaway, 2002; Pan et al., 2003; Gao et al., 2008), and have long been of great interest to researchers.

Terrace generation is often marked by an alternation between sedimentation and vertical incision (Bull, 1990; Merritts et al., 1994), which is mainly related to allogenic (climate change, surface uplift, and base level change) and autogenic (intrinsic behavior and complex response) controls (Schumm, 1977; Antoine et al., 2000; Vandenberghe, 2003; Bridgland et al., 2004). Numerical simulations further reveal that the response of a river system to these controls is likely to break the competing balance between sediment flux and transportation power by discharge (e.g., Veldkamp and van Dijke, 2000; Bogaart et al., 2003; van Balen et al., 2010), resulting in incision–deposition alternations (Bull, 1979, 1990). However, despite these advances in interpreting the occurrence of fluvial terraces, the timing of fluvial terrace formation with respect to climatic fluctuation, and the function of these allogenic and autogenic controlling factors in river terrace development are still poorly understood (Vandenberghe, 1995; Bridgland and Westaway, 2008; Maddy et al., 2008; Erkens et al., 2009). Previous work correlated terrace sequences with climatic records (e.g., Bull, 1990; Sumbler, 1995), arguing that fluvial deposition and incision probably take place respectively in glacial and interglacial periods or the converse (Penck and Brückner, 1909; Zeuner, 1945; Büdel,

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http://dx.doi.org/10.1016/j.jseaes.2012.09.016

1982; Molnar et al., 1994; Formento-Trigilio et al., 2003). Compared with these past works, recent studies suggest that river downcutting may occur during short warming or cooling transitions (e.g., Vandenberghe, 1995, 2008; Pan et al., 2003; Maddy et al., 2005; Antoine et al., 2007; Bridgland and Westaway, 2008). In addition, although climate change seems to be responsible for fluvial behavior of deposition–incision alternation (Bridgland and Westaway, 2008), it has no bearing on whether terrace staircases are formed (Bull, 1990; Bridgland, 2000; Westaway et al., 2002). The degree of fluvial incision, which can probably be amplified by surface uplift (Maddy, 1997; Lavé and Avouac, 2001), has important influence on the generation and subsequent preservation of catchment-scale terrace flights (Maddy et al., 2000; Westaway et al., 2009). Abundant evidence from fluvial records in tectonically active mountains, therefore, has increasingly led to interpretation of terrace genesis as a combined result of climate change and surface uplift (e.g., Starkel, 2003; Hetzel et al., 2006; Maddy et al., 2008; Wang et al., 2009; Vandenberghe et al., 2011). However, distinction between fluvial responses to climate change and surface uplift using terrace archive requires a thorough evaluation of the specific roles of both factors in the development of fluvial sequences (Li et al., 1997; Gibbard and Lewin, 2009).

Of potential value in addressing these issues would be the precise chronology of a complete fluvial terrace sequence. The Yellow River (Huanghe), one of the largest rivers in the world, runs across numerous tectonic zones and major active faults in China, offering a favorable setting where the fluvial response to climate change and surface uplift can be evaluated individually (Pan et al., 2009; Craddock et al., 2010). Moreover, most fluvial terraces occurring along the Yellow River are mantled directly by thick aeolian loess, which can provide an excellent age constraint on underlying terrace levels (Liu, 1985; Pan et al., 2010). In recent decades, the history of fluvial terraces by the Yellow River has served as a core theme within geomorphology (e.g., Li et al., 1996; Cheng et al., 2002; Pan et al., 2005, 2007). Much attention has been paid to the landscape evolution that is related to the dramatic uplift of the Tibetan Plateau during the Neogene and Quaternary (Li, 1991; Li et al., 1997; Harkins et al., 2007; Perrineau et al., 2011). A geochronological framework for the fluvial terrace sequences of the Yellow River has also been reliably established using the multiple approaches of magnetostratigraphy, pedostratigraphy, electron spin resonance (ESR) dating, luminescence dating, and cosmogenic radionuclide dating (e.g., Cheng et al., 2002; Pan et al., 2009; Zhang et al., 2010; Perrineau et al., 2011). In contrast, the fluvial response to climate and surface uplift in the middle reach of the Yellow River is less well known.

The specific objective of this paper is to define the response of the fluvial landscape of the Yellow River to tectonic movement (uplift or subsidence) and climate change in the eastern Fenwei Basin, China. A well-preserved fluvial terrace sequence was formed by the Yellow River in the Emei Platform that developed within the east part of that Basin. It may have been shaped in a complete tectonic context of uplift and subsidence (Research Group AFSOM, 1988). This fluvial sequence is covered by thick aeolian loess, enabling relative dating of the underlying terraces (Pan et al., 2003), thus providing new insight into the geomorphic response of the Yellow River to tectonic and climatic changes.

In this study, a new geochronology for the terrace sequence of the Yellow River is constructed using a combined approach of magnetostratigraphy and optically stimulated luminescence (OSL).

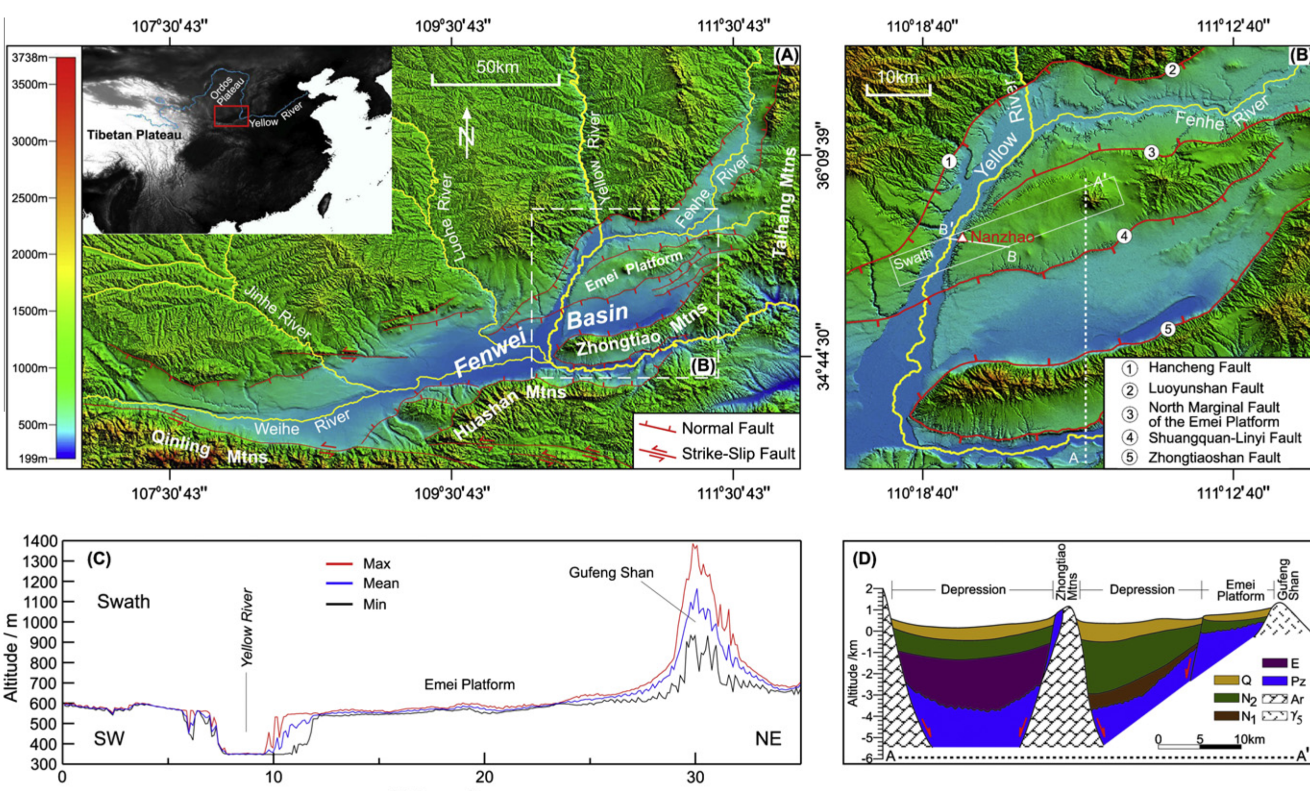

Fig. 1. Topographic map of the Fenwei Basin. (A) Major faults, rivers, and mountains around the Fenwei Basin. The Yellow River cuts through the eastern Fenwei Basin and flows eastward out of the basin along the southern front of the Zhongtiao Mountains. The inset map displays the location within China. (B) The study area of the eastern Fenwei Basin with the sampling site of the Nanzhao area and normal fault list. The Emei Platform was uplifted within this study area. (C) Maximum, mean, and minimum topography along a 5-kam-wide swath window (oriented perpendicular to swath transect). On this swath plot, the extent of major topographic features across the Emei Platform is displayed. (D) A lithostratigraphic section revised from Research Group AFSOM (1988) across the eastern Fenwei Basin. Its position is coincident with the dashed line (A′–A) in Fig. 1B.