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The evolution of the Shiwanghe River valley in response to the Yellow River incision in the Hukou area, Shaanxi, China

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ABSTRACT

Tributary response to mainstream incision is an important landscape evolution process. The objective of this study is to examine tributary valley evolution in response to mainstream incision. The Shiwanghe River, a tributary of the Yellow River in the Hukou area, was chosen for a case study. The terraces and knickpoints of the Shiwanghe River were investigated and correlated to those of the mainstream. Optically stimulated luminescence (OSL) was applied to date fluvial terraces. Longitudinal profiles of river and terraces were used to analyze valley evolution. The terrace sequence of the Shiwanghe River near their confluence is almost identical to the Yellow River terraces at the Hukou area. This suggests that terrace formations of the tributary and the mainstream are synchronous, and influenced by similar factors. But the formation age of the same tributary terrace varies from downstream to the upper reaches of the river valley. For such terraces, their formation should be controlled by knickpoint migration. A sudden drop in base-level caused by the Yellow River incision would trigger the formation of a knickpoint in the tributary. A new terrace would be formed as the knickpoint propagated upstream throughout the tributary valley. Due to the different erodibility of bedrock, a set of interbedded sandstone and shale, the major knickpoint would disassemble into a cluster of small ones during its propagation. The age of terrace formation with various valley segments depends on knickpoint migration rate and distance from the confluence. Vertical incision of the Yellow River results in knickpoint recession of its tributaries. The migration rate of knickpoints was affected by climate, lithologic variation, and, to some extent, structural control.

1. Introduction

Stream incision is an important landscape evolution process, and there has been substantial research on its controlling factors (Schumm, 1977; Knighton, 1984; Morisawa, 1985; Richards, 1987; Bull, 1991; Schumm and Ethridge, 1994). In a drainage basin, stream incision commonly occurs in response to relative base-level lowering, which can be caused by tectonic uplift (Bull and Knuepfer, 1987), changes in sea level or local base level (Schumm, 1993; Menier et al., 2006; Davis et al., 2009; Gomez and Livingston, 2012), and climate changes, all of which alter the erosive power of rivers (Bull, 1991; Schumm and Ethridge, 1994; Reneau, 2000; Gomez and Livingston, 2012). Lithologic and structural character within a watershed, which provides variable resistance to erosion, also affects the incision (e.g., Schumm and Ethridge, 1994; Reneau, 2000). Stream incision can take place either with knickpoint migration (e.g., Loget and Driessche, 2009; Belmont, 2011) or along the entire length of a mainstream with no knickpoints (Gomez and Livingston, 2012).

Channel incision of a mainstream can trigger a base level fall of tributaries and cause tributary adjustment in the form of upstream migration of knickpoints, entrenchment, and evolutionary valley widening (Germanoski and Ritter, 1988; Kesel and Yodis, 1992; Schumm and Ethridge, 1994; Musselman, 2011). Tributary responses to mainstream incision take place mainly near the confluences of tributaries with the mainstream (Musselman, 2011), causing rapid incision in the lower reaches of the tributary channels due to knickpoint migration (Belmont, 2011). If adjacent rock formations are prone to erosion, the base level lowering may result in both channel incision and hill slope adjustment (Gomez and Livingston, 2012). Knickpoints are characterized by polygenesis and multiple causality (Phillips et al., 2010), and are highly varied based on geographical locations. The estimated migration rates of knickpoints range from a few millimeters per year (e.g. Schildgen et al., 2010; Zhang et al., 2011a) up to several meters per year (e.g. Anthony and Granger, 2007). Even for the same knickpoint, the migration rates may change with time. The average recession rate of Niagara Falls had been estimated to be ~1.3 m/a during the Holocene

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(Gilbert, 1907; Ford, 1968), but it has decreased to 0.1–0.01 m/a in recent decades (Tinkler, 1993). Difference of knickpoint migration rates implies that knickpoints and their recession cannot be attributed to any particular cause or history without consideration of local conditions (Phillips et al., 2010).

The Jin-Shaan Canyon in the Loess Plateau (Fig. 1a) provides a most illustrative context for studying the evolution of the Yellow River. Previous investigations on terraces are mainly focused on studying early stages of the relationship between the Yellow River and the plateaus (Willis et al., 1907; Wang, 1925; Teilhard and Young, 1930; Barbour, 1933; Zhang, 1957, 1988; Zhu, 1989; Li, 1993; Yue et al., 1997; Lin et al., 2001; Cheng et al., 2002; Fu, 2002; Wang et al., 2002; Shi, 2008; Zhang et al., 2009; Pan et al., 2011). Few studies have been conducted on tributary response to the Jin-Shaan Canyon incision. In the canyon area, there are many knickpoints in the landscape, as seen by waterfalls in both mainstream and tributary valleys. The famous Hukou Falls is one example of them (Guo et al., 2012). These knickpoints indicate headward erosion of the rivers due to lower base levels downstream, and also result in the formation of new fluvial terraces. The incision of the Yellow River lowers the base level of erosion for its tributaries in the region. The Jin-Shaan Canyon, therefore, provides an outstanding case study to tributary response to mainstream incisions, especially at Hukou, since extensive research has been done on Yellow River incisions in this area (Cheng et al., 2002; Zhang et al., 2010, 2011b; Guo et al., 2012), and there is a confluence of the Yellow River and a tributary (Shiwanghe River) (Fig. 1).

The objective of this study is to examine tributary valley evolution in response to mainstream incision. The Shiwanghe River was chosen for a case study. The terraces and knickpoints of the Shiwanghe River were investigated and correlated to those of the mainstream. The optically stimulated luminescence (OSL) technique was applied to date fluvial terraces.

2. Geological and geomorphologic settings

2.1. Ordos plateau and its loess deposits

The study area is located in the southeastern part of the central Chinese Loess Plateau (CLP) (Fig. 1a). Bedrock exposed in this area is characterized by Triassic sandstone interbedded with mudstone or shale. This bedrock is covered by a thick mantle of Neogene red clay and Quaternary loess deposits (Liu, 1985; Wang et al., 1985; BGMRSP, 1989). Geologically, both the CLP and the Ordos Plateau (Fig. 1a) are parts of a huge structural unit named the Ordos Basin (Zhang et al., 2006) or Ordos Block (Bi et al., 2012). The geologic evolution of the Ordos Block can be summarized into four stages (Fig. 2) (Wang et al., 1985).

(1) Highland stage (Late Cretaceous to Paleogene). During this period, most of the Ordos Basin was uplifted and became the Jin-Shaan Highland where denudation prevailed (Fig. 2a).
(2) New basin stage (Neogene Period). During this time, fault basins or graben systems (Zhang et al., 1998) formed in the areas surrounding the Ordos Block, and a new Ordos Basin was formed (Fig. 2b). Red clay of lacustrine origin (Wang et al., 1985; Pan et al., 2011) and eolian origin (Guo et al., 2001) accumulated in the new basin.
(3) Loess high plain and inland lake stage (Early Pleistocene). The Ordos Block was uplifted, and loess accumulation began. On the uplifted block, lakes formed in local depressions and drained to other inland lakes in fault basins, and the overall denudation resulted in the formation of monadnocks (Fig. 2c).

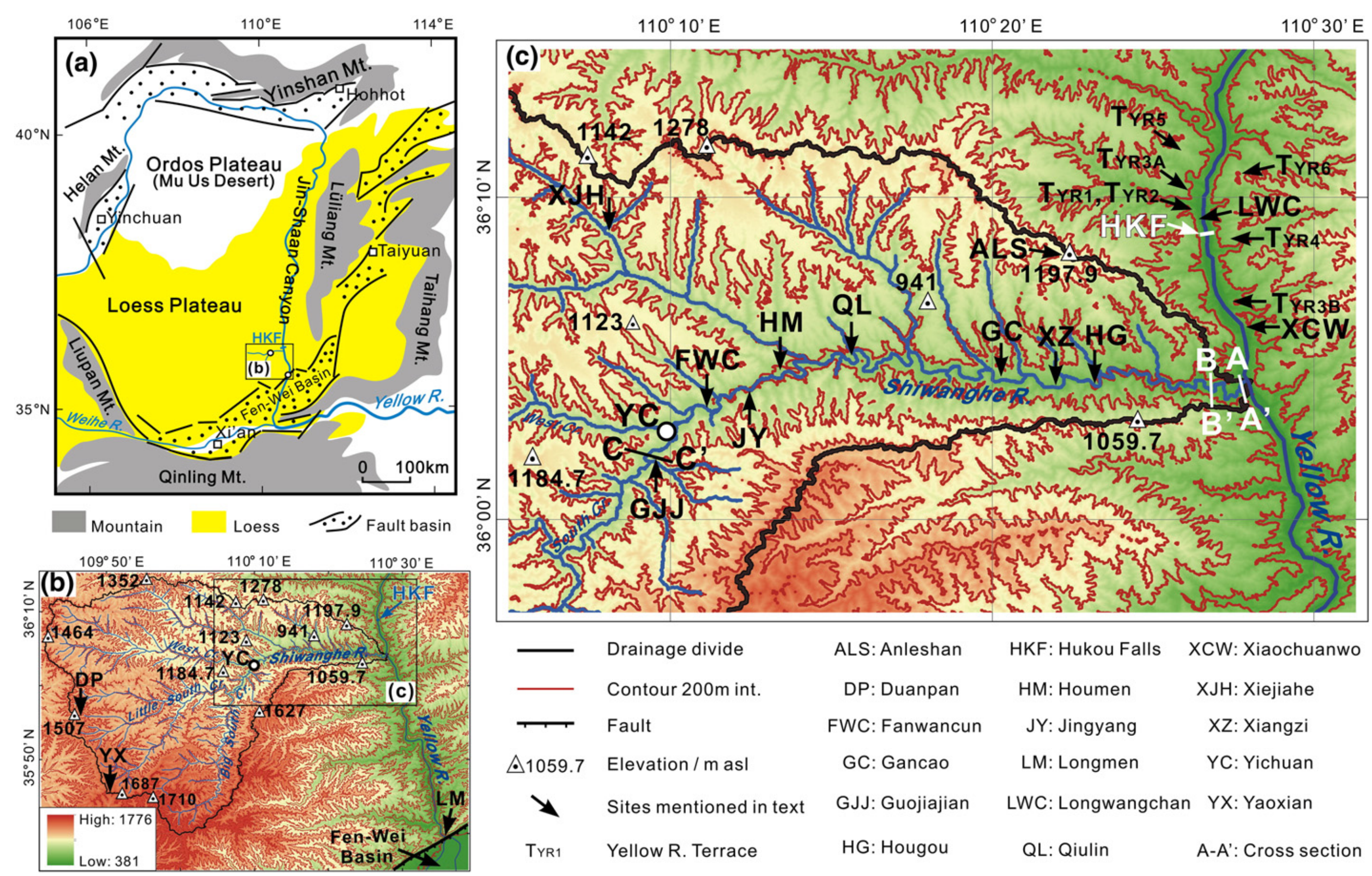

Fig. 1. Maps of the study area. (a) The Chinese Loess Plateau is part of the Ordos Block, the Yellow River flows through the eastern part of the Loess Plateau; (b) DEM showing topographic features of the study area; (c) A close-up of the lower reaches of the Shiwanghe River. The abbreviations refer to locations mentioned in text. This figure is available in color online at www.sciencedirect.com.