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Tectonic controls for transverse drainage and timing of the Xin-Ding paleolake breach in the upper reach of the Hutuo River, north China

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ABSTRACT

The upper reach of the Hutuo River flows along the Xin-Ding basin and cuts a transverse drainage through the Xizhou Mountain and the Taihang Range into the North China Plain. Previous studies showed that the Xin-Ding basin was occupied by a lake during the early-middle Pleistocene. However, the timing of the paleolake breach and the mechanism for the creation of the transverse drainage are unknown. We constructed the fluvial terrace sequence in the upper reach of the Hutuo drainage combined with thermoluminescence (TL) and optically stimulated luminescence (OSL) dating, as well as the timescale of the overlying loess–paleosol sequence. Our results reveal that (1) five terraces (T5–T1) developed along the upper reach of the Hutuo River, amongst which terraces T4–T1 were formed synchronously at ~600, ~120–130, ~20–26 and ~6–7 ka, respectively; (2) the creation of the transverse drainage and breach of the Xin-Ding paleolake occurred between ~600 and ~130 ka; and (3) the mechanism for the creation of the transverse drainage is via river piracy of paleostreams on both sides of the drainage divide. Localized differential uplift and associated tilting of the Xizhou Mountain block during the middle Pleistocene result in the formation of the transverse drainage and breach of the Xin-Ding paleolake.

1. Introduction

Drainage reorganization in late Cenozoic has been widely recognized in many of the world's large river systems and extensively studied by geomorphologists (e.g., Blackwelder, 1934; Harvey and Wells, 1987; Bull, 1991; Bishop, 1995; Stokes and Mather, 2003; Clark et al., 2004; Cordier et al., 2006; Stokes, 2008; Stokes et al., 2008; Bridgland et al., 2012). Since at least the nineteenth century, numerous researchers have noticed the role of transverse drainage and discussed its causes (e.g., Lane, 1899; Twidale, 1966; Hunt, 1971; Lucchitta, 1972). Transverse drainages are streams that cut across tectonically controlled geological structures such as faults, folds, and orogenic highlands (Oberlander, 1985; Stokes et al., 2008). They are generally characterized by distinctive but narrow and deeply dissected gorges or canyons that cut through obstructing mountains. In the past decade interest has increased on the mechanism of transverse drainage (Mayer et al., 2003; Stokes and Mather, 2003; Clark et al., 2004; Douglass and Schmeeckle, 2007; Stokes et al., 2008; Douglass et al., 2009).

The creation of transverse drainage can be interpreted by numerous factors (e.g., Twidale, 2004; Stokes et al., 2008; Douglass et al., 2009), but it is generally associated with the mechanisms of (i) antecedence (fluvial incision keeps pace with tectonic uplift and growing structures) (e.g., Hasbargen and Paola, 2000; Simpson, 2004); (ii) superimposition (a concordant river erosionally removes an overlying sedimentary cover to become discordant with an underlying, different bedrock/structure) (e.g., Oberlander, 1985; Douglass and Schmeeckle, 2007); (iii) overflow (a lake, ponded behind a resistant sill, finally overspills the lower divide because of climate-related lake level rise) (Meek and Douglass, 2001); and (iv) stream piracy (an increasing headward erosion across an uplifted surface results in the capture and rerouting of a less active stream) (e.g., Harvey and Wells, 1987; Stokes and Mather, 2003). These mechanisms are themselves driven by factors that are internal (e.g., bedrock lithology and geologic structure) or external (climate change, tectonism, and eustacy) to the fluvial system (Stokes and Mather, 2003). Thus, knowledge of the origin of transverse drainage provides insights in the rearrangement of fluvial system and long-term landscape development.

The Hutuo River originates northeast of Wutai Mountain, the highest mountain in north China, and flows along the northern part of the Xin-Ding basin, a graben in the northeastern part of the Shanxi rift system (Figs. 1 and 2A). In the southern part of the basin, the river turns eastward to flow along the Dingxiang and Dongye subbasins and cuts a gorge through Xizhou Mountain and the Taihang Range into the North China Plain (Fig. 1). The ancestral Hutuo drainage was proposed to flow southward into the Taiyuan basin by the way of the Shilingguan or Taiheling Col and joined the Fenhe River during the Pliocene (Fig. 1) (Willis and Blackwelder, 1907; Wang, 1926; Zhang, 1959; Lou and Du, 1960; Li and Liang, 1965; Wang et al., 1996). Subsequent uplift of the Xizhou Mountain in the early Pleistocene (Wang et al., 1996)

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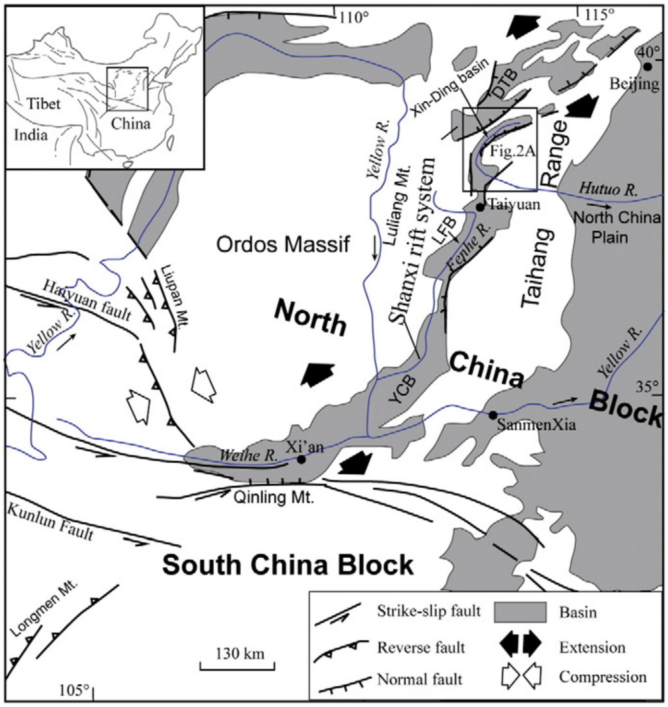

Fig. 1. General tectonic setting of the Shanxi rift system and its adjacent regions (modified after Zhang et al., 1998). Inset map showing major faults in China. Abbreviations: DTB, Datong basin; LFB, Linfen basin; YCB, Yuncheng basin; Mt, mountain; R, river. Triangles (reverse faults) and tick marks (normal faults) on hanging wall side.

forced the ancestral Hutuo drainage to abandon its southward-flowing channel. Drilling data (Hydrogeological Team of Geological Bureau of Shanxi Province, 1977) revealed that the Xin-Ding basin was dominated by a paleolake during the early-middle Pleistocene. However, the timing of the paleolake breach and its mechanism are poorly understood. From the drainage features, the breach of the Xin-Ding paleolake is related to the creation of the transverse drainage where the paleolake links across the Xizhou Mountain to the present Hutuo drainage in the Taihang Range area (hereinafter referred to as the Shihouping–Pingshang transverse drainage) (Fig. 2A). Thus, the mechanism of this transverse drainage is the key to the paleolake breach.

The drainage incision process may be documented by river terrace development along the ancestral and present valleys (Stokes and Mather, 2003). Thus, in this paper we first map and reconstruct fluvial terrace sequence in the basin and gorge segments of the Hutuo River in combination with field investigations, thermoluminescence (TL) and optically stimulated luminescence (OSL) dating, and the loess–paleosol timescale to determine the timing of the breach of the Xin-Ding paleolake. We then rebuild the long-term drainage evolution of the upper reach of the Hutuo River system. Lastly, we explore the mechanism of the development of the Shihouping–Pingshang transverse drainage and its controlling factors. This study provides a meaningful understanding of the effects of localized differential uplift and related tilting on rivers in a graben setting.

2. Regional setting

The Shanxi rift system is bordered by the Ordos Massif to the west and the Taihang Range to the east and is characterized by an S-shaped string of asymmetric intermontane basins over 1200 km from north to south (Fig. 1) (Xu and Ma, 1992; Zhang et al., 1998). The extension of this rift system was thought to have been driven by large-scale strike–slip faults associated with the collisional interaction of the Indian and Eurasian plates and eastward motion of the Tibetan Plateau (Peltzer et al., 1985; Xu and Ma, 1992; Zhang et al., 1998). This process may have started in the Miocene (Zhang et al., 1998), but the formation of the present grabens occurred mainly since the Pliocene (Xu et al., 1993).

The Xin-Ding graben northeast of the rift system is bounded by Yunzhong Mountain to the west, Heng Mountain to the north, and

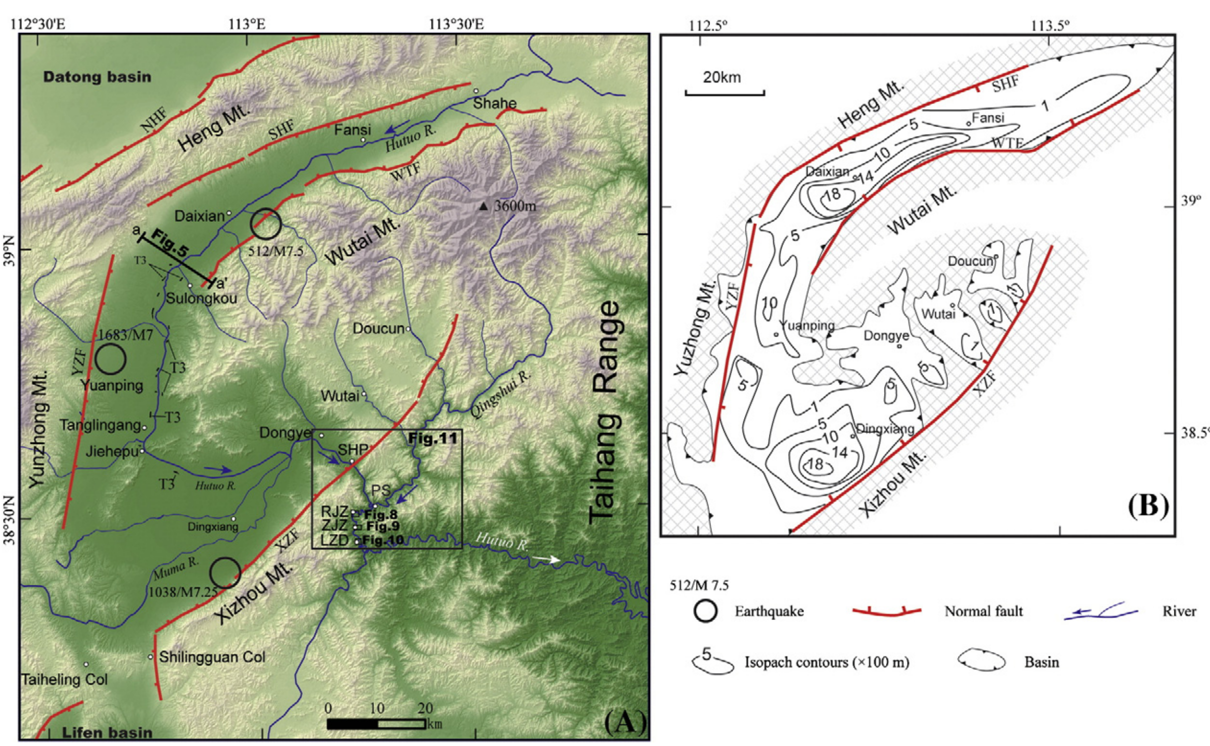

Fig. 2. (A) Active faults and drainage characteristics of the upper reach of the Hutuo drainage system. The shade relief is from the Shuttle Radar Topographic Mission (SRTM). Small regions in the basin show the sparsely preserved T3. See location in Fig. 1. (B) Isopachs of late Cenozoic sediments in the Xin-Ding basin modified from Wang et al. (1996). The Xin-Ding basin consists of Daixian, Yuanping, Dingxiang, and Dongye subbasins. Towns and villages: LZD, Lingzidi; PS, Pingshang; RJZ, Rongjiazhuang; SHP, Shihouping; ZJZ, Zhaojiazhuang. Active faults: NHF, northern Hengshan fault; SHF, southern Hengshan fault; WTF, Wutai fault; XZF, Xizhou fault; YZF, Yunzhong fault. R, river; Mt, mountain.