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Late Quaternary climatic and tectonic mechanisms driving river terrace development in an area of mountain uplift: A case study in the Langshan area, Inner Mongolia, northern China

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ABSTRACT

The Langshan Range is located in the western Yin Mountain orogenic belts and the western Hetao fault-depression zone in Inner Mongolia, northern China. This area is on the northwestern margin of the East Asian monsoon region. The fluvial terraces in the transverse drainage of the Langshan Range represent a primary geomorphic response to local tectonic uplift and climatic changes. The terrace evolution was reconstructed using a combination of optically stimulated luminescence (OSL) dating and terrace tread measurements. The terraces, designated T4 through T1, were abandoned at about 58.00, 46.25, 32.19, and 15.79 ka BP, respectively. Their aggradation occurred primarily during cold periods of the last glacial stage, and incision occurred primarily during shifts from cold to warm climate stages. Geomorphic analysis showed the terrace heights were controlled by the tectonic uplift in the area. Differences in river incision rates and terrace geomorphic features indicate that the uplift of the Langshan Range included a component of tilting north to south during the period of 58.00–41.28 ka BP, whereas the uplift of the Langshan area tended to be equal on a regional scale after 32.19 ka BP.

1. Introduction

Fluvial terraces preserve excellent records of geologic processes in the form of geomorphologic features and fluvial deposition as a result of intrinsic and external actions (Schumm, 1977). Intrinsic changes tend to occur on relatively short time scales (10–1000 a) and produce small landforms (on a scale of 10–1000 m) resulting from adjustments along individual river reaches. (Maddy et al., 2001a, 2008; Vandenberghe, 2002). The primary factors affecting river terrace evolution on greater spatiotemporal scales consist of external processes, i.e., tectonic activity, climatic variations and base level changes. (e.g., Bridgland, 2000; Vandenberghe and Maddy, 2001; Vandenberghe, 2002, 2003). Climatic changes result in alternating incision and deposition caused by changes in the ratio of stream flow to sediment flux. Such processes may explain terrace development in areas of minor tectonic activity but cannot explain the development of multistage terraces (Bull, 1979, 1990; Xu and Zhou, 2007). Sustained tectonic uplift plays an important role in terrace development by providing the dynamics for river incision (incision is also controlled by sea level changes in low-elevation coastal zones).

General understanding of the forces driving fluvial terrace development in areas of mountain uplift has evolved. During the nineteenth and twentieth centuries, the pangeosyncline theory was the basis for models of crustal uplift and its control over fluvial terrace development (e.g., Chambers, 1848; Home, 1875; Whitaker, 1875). Presently, most geologists agree that fluvial terrace development in areas of mountain uplift is driven by the combined effects of tectonic uplift and climatic change (e.g., Maddy et al., 2000; Bridgland et al., 2004; Bridgland and Westaway, 2008; Westaway et al., 2009; Wang et al., 2010; Herfried et al., 2012; Hu et al., 2012; Viveen et al., 2013; Ren et al., 2014) or by downcutting because of tectonic activity and aggradation for climatic cyclicity (Starkel, 2003; Westaway, 2009). Others have concluded that the primary factor controlling terrace development is tectonic uplift and that climate change can be ignored in areas of rapid uplift (e.g., Cheng et al., 2002; Sun, 2005; Zhang et al., 2014a). In fact, the climate and the geologic setting both count for a great deal as leading factors driving terrace formation.

The Langshan area is located in the western Yin Mountain orogenic belts and in the western Hetao fault-depression zone in Inner Mongolia, northern China. Earthquakes occur frequently in this area as a result of intense tectonic activity that began in the late Cenozoic (Wang et al., 1984; Sun et al., 1990; Deng et al., 2002; Cheng et al., 2006; Li, 2006). In addition, this area is located on the northwestern margin of the East Asian monsoon region. Large-scale normal faulting affecting the piedmont zone (Research group of Active fault system around Ordos Massif, 1988; Chen, 2002; Ran et al., 2003) has created the fault-block depression of the Hetao basin and has led to uplift of

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the Langshan Range and development of a transverse drainage network associated with further uplift of the Langshan Range. A system of river terrace sequences developed along these transverse drainages, and the terrace surface geomorphology and the underlying fluvial sediments reflect not only the tectonic uplift but also are very sensitive to climatic changes and thus provide good records for the study of this area.

In this study, four to five river terraces along one transverse drainage of the Langshan Range were identified during field investigations of 25 representative river valleys. These terraces were designated T5 through T1. Their evolution was reconstructed using a combination of optically stimulated luminescence (OSL) dating and mapping of the terrace treads. The climatic and tectonic mechanisms driving the river terrace development and the relationships between the terraces and a palaeolake were studied. In addition, a model of the spatial relationships generated during uplift was developed based on an analysis of the rates of river incision and the geomorphic features of the terraces.

2. Geologic and geomorphic setting

The Langshan Range is located in the western Yin Mountains, northwest of the Hetao basin, through which the Yellow River flows. The Langshan Range is elongated in the NE–SW direction, is 370 km wide at its base, and rises 1500–2200 m above sea level (Fig. 1A). It is bordered on the south by the Hetao basin, which lies at an elevation of 500–1200 m lower than the mountain crest (Fig. 1C); this elevation difference is marked by several fault scarps (Fig. 1B). The mountain's northern flank slopes gently down to the Inner Mongolian plateau, and to the west lie the Boketai and Yamalek deserts (Fig. 1A).

The basement rocks in this area primarily consist of an Archaean group and the Proterozoic Langshan (Cha'ertaishan) group. Jurassic breccia and Cretaceous brick-red gravel strata overlie these older rocks along an angular unconformity. Palaeogene, Neogene, and Quaternary deposits are distributed in the valleys and piedmont of the Langshan Range. A Quaternary upper Pleistocene series (Qp^3) is exposed primarily along the Langshan piedmont and consists of diluvial, alluvial, and lacustrine sediments. Due to the Yanshan movement during the Mesozoic, the crust in the Langshan area thickened and underwent lateral shearing, and a NE-trending orogenic belt formed owing to northsouth extension and thrust nappes. Meanwhile, a set of small NE-trending faults developed. During the Eocene (E^2), for deformation of the Himalaya, large-scale normal faults developed, the Hetao fault-block basin began to form, and the uplift of the Langshan Range block began. The Quaternary was a period of extensive vertical offset in the area when relative movement between the uplifted Langshan Range block and the down thrown piedmont basin block was measured at a maximum of 1.00 mm/a (Research group of Active fault system around Ordos Massif, 1988), and the transverse drainage network developed on the Langshan Range (Fig. 1C).

3. Methods

3.1. Measurement

The river terrace elevations were measured using a high-resolution global positioning system (differential GPS), and the thicknesses of the alluvial deposits were measured by tape. Not all of the alluvial deposit thicknesses could be measured because of human modification of the deposits.

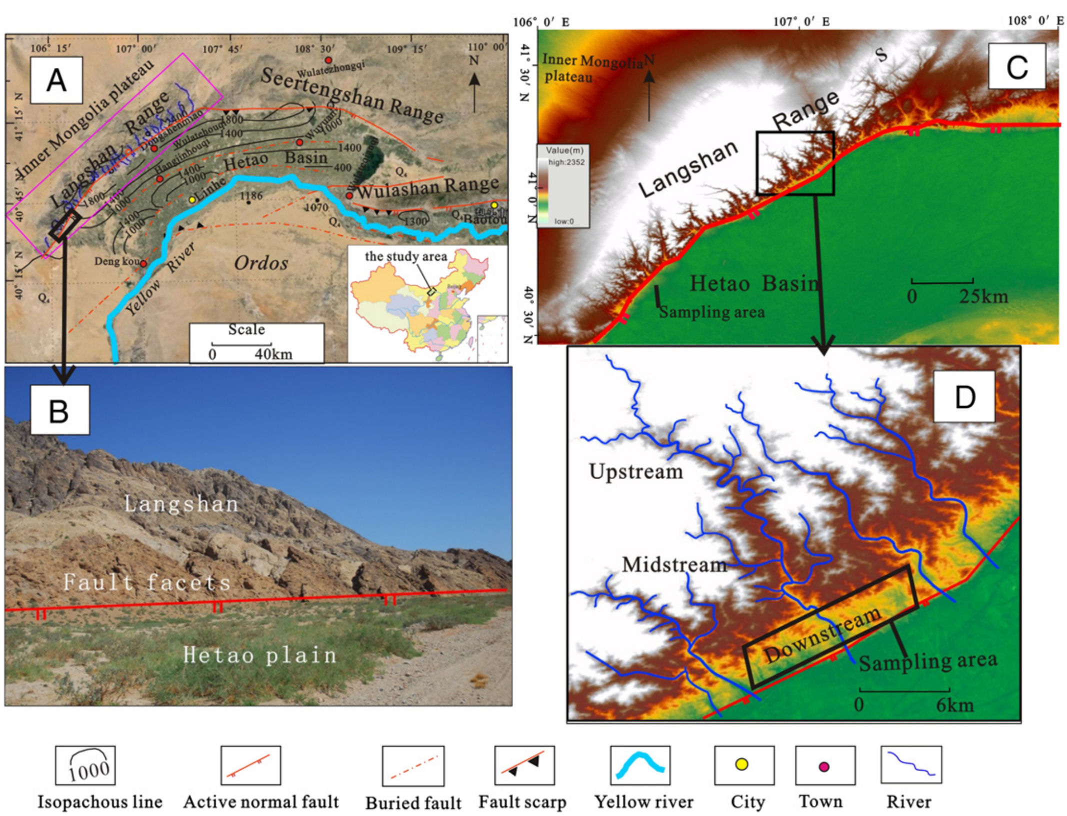

Fig. 1. (A) General tectonic setting of the Hetao rift system and adjacent areas. (B) Faults at base of Langshan Mountain (C) DEM map of the drainage in the Langshan area (D) Location of sampling area in the drainage area. The location of the study area in (A) and (C) is denoted by the box.