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# Late Pleistocene paleolake evolution in the Hetao Basin, Inner Mongolia, China

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A B S T R A C T

The paleolake that once existed in the Hetao Basin, China, represents an important stage of the Yellow River drainage system evolution in the region, but it has not been studied in detail to date. In particular, the formation and driving forces of the paleolake evolution since the late Pleistocene is still poorly understood. In this study, optically stimulated luminescence and radiocarbon dating were combined with multiproxy analysis of lacustrine sediments in the central Hetao Basin to reconstruct the paleolake evolution. Proxies included carbonate $^{18}O$ and $^{13}C$ isotopes, grain size, magnetic susceptibility, and color. In combination with stratigraphic records, the proxies indicated the existence of a lake environment in the Hetao Basin between ~150 and ~18 ka BP. The paleolake between 150 and 130 ka BP was an open system. Between 130 and 54 ka BP, the paleolake basin closed, with high lake levels at the beginning of the period and then a gradual decrease. After 54 ka BP, the paleolake began to outflow and gradually shrank in size, and after 18 ka BP an alluvial fan covered the region, and the paleolake disappeared. We propose a combination of tectonic uplift and climate changes as the main drivers of paleolake formation and evolution since the late Pleistocene.



## 1. Introduction

The Hetao Basin, characterized by floodplain and desert, is a key part of the Yellow River drainage system and one of the dust sources in arid western China that can influence regional (Chinese Loess Plateau), and even global climate change (Nie et al., 2015). Modern dust is derived from surface sediments, mostly related to lacustrine deposition, within a paleo-drainage system in the basin (Geological and Mineral Bureau, 1991; Chen et al., 2008, 2013; Jiang et al., 2012; Li et al., 2015). Thus, lacustrine deposits in the basin can provide important evidences for the evolution of the paleo-drainage system and the timing and location of dust sources.

Previous studies have proposed that a huge, unified paleolake once existed in the Hetao Basin during the late Pleistocene (Chen et al., 2008; Fan et al., 2010; Li et al., 2015); however, the exact timing of the formation and disappearance of the paleolake has remained elusive. Chen et al. (2008) suggested that the paleolake formed between ~60 and 50 ka BP in Hetao Basin. In an analysis of lacustrine sediments of the Togtoh Platform in the east of the Hetao Basin, Jiang et al. (2012) suggested that the paleolake started to outflow after 100 ka BP. Recently, Li et al. (2015) inferred the paleolake covered both the Ulan Buh Desert and the adjacent Hetao Basin, formed at 155 ka BP, and existed until 87 ka BP. Lacustrine sedimentation on the platform of the northern Hetao Basin suggest that the paleolake disappeared until 20 ka BP (Gong et al., 2013). Moreover, the degree of openness of the lake system and the driving forces also remain debated. Some researchers have suggested that the paleolake was enclosed (Jiang et al., 2012; Li et al., 2015), while others consider that the Hetao paleolake was a large lake connected to the Yellow River (Jia et al., 2016). In terms of drivers, Wei et al. (2016) concluded that long-term climatic factors controlled paleolake evolution, while Jiang et al. (2012) considered

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that tectonic events induced lake disappearance. Most previous studies have focused on lacustrine sediments at the inlet and outlet of the Hetao Basin (Chen et al., 2008; Jiang et al., 2012). The lack of records from lacustrine sediments in the interior of Hetao Basin means that the existing reconstructions of paleolake evolution may be inaccurate (Fig. 1). Thus, using a multiproxy approach combining lithology, optically stimulated luminescence and $^{14}C$ dating results, and other proxies (carbon and oxygen isotopes, magnetic susceptibility, grain size, and color), we report here on the evolution of the paleolake that once covered the Hetao Basin and its possible driving factors.

## 2. Regional setting

The Hetao Basin, China, is a Cenozoic fault basin surrounded by the Ordos Plateau to the south, the Helan Mountains to the west, and the Yinshan Mountains to the north. At present, the Yellow River flows eastward along the southeast margin of the basin to the Jinshaan canyon via Togtoh County (Fig. 1). Regional geological investigations have revealed that late Quaternary lacustrine sediments are widely distributed in the Hetao Basin, extending in an east–west direction along the northern margin (Jia et al., 2001; Ma et al., 2004; Li, 2006; Jiang et al., 2012). Normal faults along the southern piedmont of the Yinshan Mountains are associated with rapid uplift of the Yinshan massif, and buried faults occur along the southern margin of the Hetao Plain (Cao, 2001). The Hetao Basin is located in a continental semiarid-arid zone, with a mean annual temperature 5.6–7.8 °C (Guo et al., 2008), mean annual rainfall 130–215 mm, and mean evaporation rates approximately 1810–3005 mm. Precipitation is mostly associated with the East Asian summer monsoon (Wang, 2003; Ye et al., 2010). The arid climate results in two deserts in the region, the Ulan Buh Desert to the southwest and the Hobq Desert to the south (Fig. 1). This study focused on the analysis of a large lacustrine outcrop at Bingfanggou which is located on the central position within the basin and exposes a detailed stratigraphic sequence (Fig. 1).

## 3. Materials and methods

### 3.1. Lithologic description and sampling

The 17 + m thick stratigraphic section of Bingfanggou (BFG), located in the north of the Hetao Basin (41°17′22.80″ N, 107°47′14.42″ E), at an altitude of 1090 m a.s.l., consists of layers of lacustrine silty clay and clay, pebbles, coarse sand, and fluvial gravel. Five main units have been identified in the BFG sequence based on the lithologic description (Fig. 2 and Table 1).

Samples for OSL dating were taken from sandy horizons at depths of 7.82, 8.69, 10.38, and 13.89 m. Those for $^{14}C$ dating were taken from organic-rich horizons at 4.25 and 5.40 m. In addition, bulk samples were taken at 5-cm intervals in Unit 3 for environmental proxy analysis.

### 3.2. Optically stimulated luminescence and radiocarbon dating

Four OSL samples were analyzed using an automatic Risø DA-20–TL/OSL instrument (Denmark) in the Crustal Dynamics Key Laboratory of the Institute of Crustal Dynamics, China Earthquake Administration. The preparation process of raw OSL samples was according to Roberts (2007). The 90–125 mm grains of BFG-OSL-1 and BFG-OSL-2 and the 4–11 mm grains of BFG-OSL-3 and BFG-OSL-4 were separated by dry sieving. The separated grains were then extract the pure quartz to measure (He et al., 2010). Sample equivalent doses (De) were determined using the SMAR dating protocol (Wang et al., 2005). Uranium, thorium, and potassium content were determined by neutron activation analysis. All results

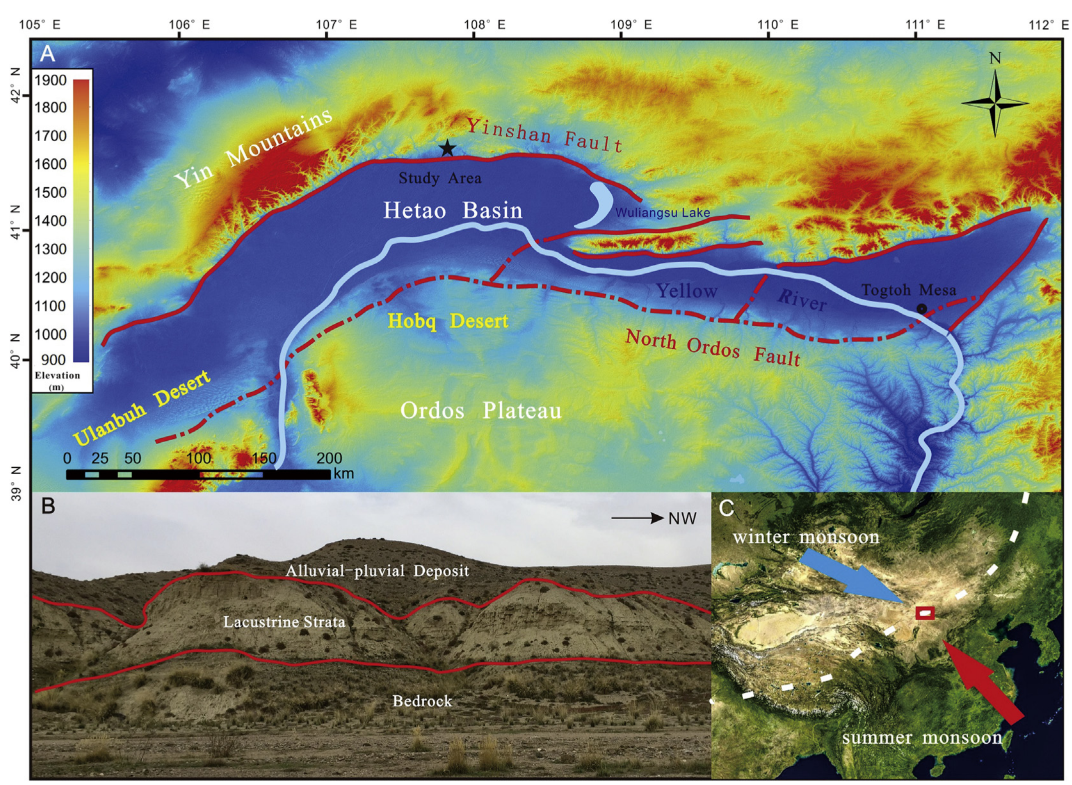


**Fig. 1.** Location of the study area. (A) DEM of the Hetao Basin and study site (The fault patterns revised from Chen, 2002); (B) Bingfanggou lacustrine sedimentation section (Total thickness of the section is about 24 m); (C) map showing the location of Hetao Basin (The dotted white line is the boundary of the East Asian summer monsoon).