Abstract
Holocene geomorphic changes have fundamentally shaped the spatial-temporal distributions of prehistoric and historical settlements in North China. Through intensive field surveys and careful field examination of typical sedimentary sequences, we reconstructed the Late-Pleistocene and Holocene geomorphic history in the two major basins of the mid-lower Fen River, central-south Shanxi, China. Our first-hand data provides crucial information for reconstructing the dynamic relationship between the characteristics of Holocene geomorphic changes and settlement distribution patterns in the two basins from the Neolithic period to the Bronze-Age Xia-Shang Dynasties. In the Taiyuan Basin, due to river downcutting processes from the end of the Late Pleistocene to the Early Holocene, edge of the basin emerged and evolved into tablelands. The elevation of the flat lands atop the tablelands that was significantly above the level of floodwater provided an ideal environment for early settlements. The Holocene geomorphic changes are characterised by continuous fluvio-lacustrine aggradation, and the central basin became void of human settlements due to uninhabitable hydrological and geomorphic conditions and especially due to frequent floods. Instead, most settlements were located along the basin, displaying a unique “around-basin” distribution pattern. In the Linfen Basin, following large-scale incision of the main channels and branches of the Fen River during the Late Pleistocene, platform-type plain with deep incised valleys was formed. Similar to the surrounding loess tableland, the central basin became an optimal environment for human activities and settlement construction, forming a “full-basin” like settlement distribution pattern that is distinctively different from the “around-basin” distribution pattern in the Taiyuan basin.

Keywords
the mid-lower Fen River basins; geomorphic evolution; prehistoric settlement distribution models; regional cultural sequence; Holocene climate events

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Holocene geomorphic evolution and settlement distribution patterns in the mid-
lower Fen River basins, China

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1. Introduction

Characteristics of historic human activities are closely related to local and regional
geomorphic changes. The spatial-temporal distribution pattern of ancient settlements is
particularly influenced by geomorphic changes as demonstrated by many recent studies
(Despriée et al., 2011; Woodward and Huckleberry, 2011; Macklin and Lwin, 2015;
Ollivier et al., 2016). Typically, these new geoarchaeological investigations in different
regions worldwide have revealed rhythms of long-term geomorphic changes and how
they influenced ebb and flow of ancient cultures. During the flood-prone periods of the
Tensas Basin in the lower Mississippi River, the ancient inhabitants were forced out of
the basin and migrated to the higher peripheries of the basin. They only made a return
to the lowlands when the geomorphic process of floods became less active (Kidder,
2006; Kidder et al., 2008). At the Kerma culture region of the Upper Nubia, river valley
bottoms became uninhabitable as active alluvial activities of several branches of the
Nile transformed the alluvial plain into a swampy area before ~7.3 ka BP. The
contemporaneous communities sought other optimal places than river valleys for
occupation and other economic activities (Honegger and Williams, 2015). Perhaps a
more telling and indeed more exciting example comes from recent geological and
geomorphic investigations in the Indus valley, which provide new evidence to the long-
standing debate of what caused the ‘collapse’ of the Indus Civilization. Giosan et al.
provide important geomorphic evidence for the so-called eastern migration of Harappan settlements. Whilst their research is focused on a broad-brush reconstruction of culture-geomorphic dynamics, other recent studies provide complementary, micro-scale evidence on human adaptations to climate changes. For instance, Singh et al. (2017) have shown that stable hydrology and landform enabled the Indus urban settlements to be situated and utilize resources next to a paleochannel located between the Indus River and Ganges-Yamuna River. A particular significant finding in these aforementioned new studies is that geomorphic changes do not necessarily take place simultaneously with climate change. It is thus crucial to investigate geomorphic changes taken place on the ground and reconstruct their diachronic chronological relationship with climate fluctuations in order to better understand the dynamic relationships among climate, environment and society and especially to better understand the robust adaption and resilience of ancient cultures facing climate fluctuations and environmental vagaries. In China, whilst recent studies also seize upon this new scholarly advancement and have demonstrated that geomorphic evolution was indeed of vital importance to understanding cultural developments in the Yangtze River (Liu et al., 2011; Li et al., 2013; Guo et al., 2014) and the Yellow River (Li et al., 2014; Wang et al., 2016; Li et al., 2017; Lu et al., 2017), these studies are mainly focused on long-term climate fluctuations and there is a lack of a longue durée perspective towards the reconstruction of geomorphic evolution and its changing relationships with ancient societies.

The mid-lower Fen River basins (Fig.1) experienced pronounced geomorphic changes since the Late Pleistocene period due to a combination of tectonic and climate factors. The fertile soils and rich natural resources fostered economic production and cultural flourishment from the Neolithic to Bronze-Age times. The Taosi City, for instance, was one of the largest urban centers in late-Neolithic North China. The mid-lower Fen River basins present an ideal case to examine long-term dynamic relationships between geomorphic changes and societal development in different sub-regions. We conducted intensive geomorphic surveys in the mid-lower Fen River basins and reconstructed the spatial-temporal distribution patterns of Neolithic and Bronze-
Age settlements and their relations with Holocene geomorphic changes. We identified two contrasting settlement distribution patterns, the so-called “around-basin” distribution model in the Taiyuan Basin (TYB) and the “full-basin” distribution model in the Linfen Basin (LFB), respectively, which were both fundamentally constrained by Holocene geomorphic changes. We present how our geomorphic survey was conducted and how the data was collected, and discuss possible reasons responsible for shaping the two contrasting settlement distribution models and their significance to our understanding of regional culture-environmental dynamics.

2. Regional geological settings and cultural backgrounds

Fen River is the second largest tributary in the middle Yellow River. Its midstream flows through the TYB in central Shanxi, and the lower reaches runs through the LFB in south Shanxi (Fig.1). TYB and LFB, divided by the Lingshi Uplift, are surrounded by the Lüliang Mountains, Taihang Mountains and Emei Platform. Moreover, the Chaizhuang Uplift further divides the LFB into south and north sectors.

TYB and LFB are parts of the Shanxi Graben System. The initial subsidence phase of the two basins took place in the Pliocene (Wang et al., 1996). During the Early-Middle Pleistocene, large lakes developed in the basins. However, the extensive lakes gradually shrunk and eventually disappeared toward the Late Pleistocene (Li et al., 1998). In the LFB, several fluvio-lacustrine terraces were formed by the Fen River incisions during the Late Quaternary (Hu et al., 2005, 2017).

In the TYB, small branches of the Fen River, including the Wenyu River, the Fangshan River, the Wuma River, and the Longfeng River, are originated in the mountain areas on both sides of the basin, before flowing down through the central plain. These small branches and the mainstream of the Fen River form a well-connected water network. In contrast, in the LFB, the mainstream of the Fen River and its tributary branches such as the Honganjian River, the Quting River, the Lao River, the Ju River, the Fu River, and the Kuai River are characterized by downcutting activities, forming deep incised valleys. Situated in the eastern Loess Plateau, the mid-lower Fen River basins have a warm temperate climate. The average annual temperature is 10-13°C, and
The average annual precipitation is 410-520 mm (Wang et al., 2009). Precipitation is primarily brought in by warm-moist summer monsoon.

The mid-lower Fen River connects the Central Plains and the Loess Plateau of China and has played a key role in fostering Neolithic and Bronze-Age cultural developments and prehistoric regional interactions (Li and Hwang, 2013; Lin and Xiang, 2017). To date, the earliest Neolithic culture discovered in the TYB and LFB is the Early Yangshao culture (ca. 7.0-6.0 ka BP). By the 6.0-5.5 ka BP period, the Middle Yangshao culture witnessed remarkable development in both basins, characterized by highly developed painted pottery industry and considerable expansion of Middle Yangshao settlements. The basins were continuously occupied during the succeeding Late Yangshao (5.5-5.0 ka BP) and Early Longshan period (5.0-4.5 ka BP). At around 4.5-4.0 ka BP, the Late Longshan culture in the region is marked by widespread use of the pottery \textit{li} tripod and emergence of early urban centers. The Taosi City (ca. 4.3-3.9 ka BP) (He, 2013) rose to an important regional center after a prolonged period of continuous cultural development during the Yangshao period in the region (Department of Archaeology, National Museum of China, 2007). Several decades of excavations at the Taosi City have revealed elite tombs buried with extravagant grave goods, large-sized palatial foundations, and a possible observatory, as well as other important archaeological features (He, 2013). The city was surrounded by a large number of settlements, including some which were specialized in economic production such as stone quarry and stone tool production (Liu et al., 2013). By the Bronze Age Xia (4.0-3.6 ka BP) and Shang (3.6-3.1 ka BP) periods, even though the regional center had shifted to other region, the Fen River basins continued be a vital region for regional cultural development and the exploitation of natural resources by the central state located further south (Liu, 2009).

3. Research methods

3.1. Characterizing Late Pleistocene-Holocene geomorphic changes

Well-designed, intensive geomorphic surveys were carried out in 2016 and 2017 in the mid-lower Fen River basins. We examined typical strata and sedimentary
sequences from a diverse range of geomorphic units. The depositional processes-related
natures of these sediments and the geomorphic events they represent were carefully
examined during the field surveys. This provides crucial information for stratigraphic
correlation and characterization of major geomorphic events in the Fen River and some
of its tributaries. We draw schematic plans of Late Pleistocene-Holocene geomorphic
changes and their relationships with settlement occupations (Fig. 2). Samples were
collected from several key sedimentary sequences for OSL (optically stimulated
luminescence) dating.

3.2. OSL Dating

OSL dating was applied to determine the absolute chronologies of some key
sedimentary sequences representative of typical geomorphic events. Standard single-
 aliquot regenerative-dose procedure (Murray and Wintle, 2000, 2003) was performed
to measure the equivalent dose ($D_e$) at the Ministry of Education Laboratory for Earth
Surface Processes, Peking University and the Institute of Geographical Sciences, Henan
Academy of Sciences. The uranium, thorium and potassium contents of the samples
were measured by neutron-activation-analysis (NAA) at the China Institute of Atomic
Energy.

3.3. Modelling prehistoric settlement distributions

We obtained geographic locations and related details of around 990 Neolithic and
Bronze-Age sites based on published information from the “Atlas of Chinese Cultural
Relics: Shanxi Volume” (Bureau of Chinese Cultural Relics, 2006) and many other
published archaeological reports. These sites were plotted onto a GIS map using
ArcGIS10.3 software. In accordance with cultural characteristics and chronological
sequences, the historical evolution and spatial distributions of these sites were analyzed
and discussed below.

4. Results and discussion

4.1. Dating results

Table 1 shows the dating results of the 16 OSL samples collected from the FSH,
the WMH, the KS, the LF, the GX and the HM profiles. These dates confirm our field
observations that the Late Pleistocene was a crucial period when major geomorphic
units or landforms were formed (e.g., the LF, GX and HM locations) and that some of
the locations were subjected to further geomorphic changes during the Holocene (e.g.,
the FSH, WMH, and KS locations). The age and depth relationships at the WMH and
LF locations are of particular significance. The OSL samples were taken from almost
the same depth at the two locations, while their chronological results are consistently
far apart from each other. This indicates that the two locations experienced different
rhythms of geomorphic changes and landscape dynamics since the Late Pleistocene.
This difference and its implications to understanding settlement distribution patterns
are further discussed below.

4.2. Reconstructing geomorphic histories

4.2.1. Taiyuan Basin (TYB)

In the western TYB, between the eastern piedmont of the Lüliang Mountains and
the fluvial plain in the central basin, the tableland is mainly composed of alluvially-
reworked loess. Rivers originated in the mountains run through the tableland before
joining the Fen River in the plain. At the Fangshan River and the FSH profile (Fig. 3a,
b), for instance, the lower part of the tableland consists of alluvial sands and gravels,
the middle part is a typical Late Pleistocene loess layer embedded with sandy and gravel
lenses, and the upper part is another layer of wind-blown loess of the Holocene age.
This sedimentary sequence indicates that the Fangshan River plain experienced
continuous upward accretion of alluvial sediments during the Late Pleistocene when
alluvial fans were formed simultaneously. From the end of the Late Pleistocene to the
Early Holocene, the river began a rapid downcutting process and the previous alluvial
fans evolved into tablelands. The tablelands were covered by aeolian loess. After
continuous downcutting of the Fangshan River in the Early Holocene, alluvial
aggradation resumed in the Middle Holocene, resulting in the formation of a fill terrace
(T1). The terrace surface is 4 m above the present river channel. The lower part of the
terrace consists of sand and gravels, while the middle part is a brownish-reddish silty
clay layer, with an OSL date of ~4.16±0.28 ka BP. The upper part is a thin Late
Holocene loess layer.
Compared to the western TYB, the eastern TYB that is situated between the mountains and the Fen River fluvial plain in the central basin is a higher and wider tableland primarily comprised of reworked loess. Typical sedimentary sequences can be seen at the Wuma River and the WMH profile (Fig.3c, d). The Middle Pleistocene loess and the paleosol (paleosol no.S1 in previous studies, Feng et al., 2004) developed during the last interglacial are preserved at the bottom of the tableland at this location. The middle part of the tableland is a Late Pleistocene loess layer containing sandy and gravel lenses as well as thin silty, reworked loess, and the upper part is a layer of Holocene loess. This sequence suggests that from the end of the Late Pleistocene, the Wuma River began the downcutting process, incising the landscape to up to 20 m deep. After this massive incision process, a fill terrace (T1) emerged during the Middle Holocene. The OSL dating results show that the beginning of the alluvial aggradation took place prior to 5.0 ka BP, followed by river incision at approximate 4.0 ka BP (Table 1).

The central TYB is a recent fluvial plain. As shown by the sedimentary sequence at a 25 m-deep pit exposed by sand quarrying in the west of the central plain (Fig.4), the sediments here are mainly composed of fluvial gravels embedded with reworked loess. Based on the lithological properties of different layers, this sequence can be divided into six sedimentary units. According to the OSL dating results and the stratigraphic correlation with other profiles in the same basin, layers 1-5 were deposited during the Middle-Late Holocene and layer 6 was deposited during the Late Pleistocene. These results also suggest that alluvial accumulation took place during both the Late Pleistocene and the Middle-Late Holocene, while the transition from the terminal Pleistocene to the Early Holocene was an episode of erosion. As the sediment core no. XD (Fig.1) in northern basin indicates, the change of sedimentation regime from erosion to alluvial aggradation occurred around 6.0 ka BP. The aggradation of the alluvial plain also witnessed the formation of alternating fluvio-lacustrine geomorphic units, which continued to the historical period (Wang, 1997). To sum up, since the Early Holocene, the central basin has been a river-lake fluvial plain, while the piedmont area around the basin edges is a tableland cut through by rivers (Fig. 2a, Fig. 5a).
4.2.2. Linfen Basin (LFB)

LFB is located in the lower Fen River. Although the central part of the basin is very flat and open, deep incised valleys were formed along the Fen River and its tributaries during the Holocene. The basin as a whole exhibits a platform-type plain landscape. Near the Chaizhuang location of the middle basin is a tectonic uplift area. This tectonic uplift resulted in a raised loess tableland. The lower Fen River basin is partitioned into two parts by the Chaizhuang Uplift. The northern LFB is trending towards north-east direction, while the southern LFB is trending towards east-west direction.

The LF profile (Fig. 6a) in the northern LFB shows that lacustrine deposits consisting of laminated greyish-green clay were widely distributed in the basin before 60.0 ka BP. At about 60.0 ka BP, the downcutting process of the Fen River began, forming a lacustrine fill terrace (T3), which was subsequently mantled by paleosol-loess sequences in the middle-late Late Pleistocene. The rapid downcutting reached the position of terrace T2, which was similarly covered with aeolian sediments including paleosol and loess of the middle-late Late Pleistocene age. The incision gradually reached the bottom of the modern valley. During the Late Holocene, a fill terrace (T1) was formed. The LF profile confirms that the Fen River incision has reached a remarkable depth of around 30 m since 60.0 ka BP, especially during the Late Pleistocene.

The GX profile (Fig. 6b) is located on the south side of the Chaizhuang Uplift and at the confluence point of the Fu River and the eastern Fen River. Influenced by the Chaizhuang Uplift, from the lacustrine deposits formed in the early Late Pleistocene on the top to the bottom of modern riverbed, the cumulative depth of the downcutting process of the Fen River is over 40 m. During the river incision, a base terrace (T2) and a fill terrace (T1) were developed in the middle Late Pleistocene and the Late Holocene, respectively. The ages of the terrace T2 (Fig. 6b) suggest, again, the remarkable depth of the Fen River incision of up to 35 m during the early-middle Late Pleistocene.

The sedimentary characteristics of the HM profile (Fig. 6c) located in the center of the southern LFB are similar to the two profiles just described. But because it lies in
the depression center of the central basin, the incision range of the Fen River at this location is relatively small. In this profile, the height of the terrace T2 is roughly the same as those at the two aforementioned profiles, while the height difference between the terrace T2 and terrace T3 is significantly smaller than that at the GX profile. This confirms that, relative to the basin, the differential uplift of the Chaizhuang Uplift primarily took place in the early-middle Late Pleistocene. During the Late Pleistocene in the lower Fen River, the large scale river incision was related to the regional tectonic uplift.

Our examination of the geomorphic changes and chronological patterns at these profiles clearly suggest that, during the rapid downcutting of the Fen River and its tributaries in the LFB in the early-middle Late Pleistocene, the platform-type plain with deep incised valleys were already formed at that time (Fig. 2b, Fig. 5b).

4.3. Regional cultural sequence and settlement distributions from Neolithic to Bronze-Age

The Early Yangshao culture (7.0-6.0 ka BP) is the earliest Neolithic culture discovered in the TYB and LFB to date. There were two and nine Early-Yangshao settlements, in the two basins, respectively (Fig.7). People resided in semi-subterranean houses during this period. The Early Yangshao communities were primarily reliant on dryland farming (Han, 2010). Typical pottery vessels of this period included the bo bowl, pen basin, ping bottle, guan jar, and so on. Ground stone production tools were dominant, such as axe, adze, chisel, spade, knife, grinding slab and grinding handstone. The pottery vessel sets and stone tools used by the Early Yangshao communities were different in the two basins. The round-bottomed hu jar with folding mouth and the red-topped bo bowl were the most representative types of pottery in the TYB (Tian, 1996). By comparison, the jujube-core-shaped, flat-bottomed ping bottle with small mouth, and the long point-bottomed ping bottle with small mouth became the characteristic pottery types in the LFB (Wei, 2018). By the 6.0-5.5 ka BP period, the Middle Yangshao culture settlements increased significantly in both basins, with the numbers reaching 17 and 143 in the TYB and LFB, respectively. Features of pottery vessels and stone tools tended to be consistent between the two basins. Painted pottery was very
prevalent in the archaeological assemblages at local sites. The point-bottomed ping bottle with small overlapping mouth was the most representative type of pottery. By the Late Yangshao phase (5.5-5.0 ka BP), the settlements in TYB saw a small increase, increasing to 35 in number. In the LFB, although there were still 53 settlements, the number evidently smaller compared to the previous phase. Between the two basins, many differences in pottery and stone tools became apparent. In the TYB, the flat-bottomed hu jar with bell-mouth and double-ears became the most representative type of pottery whilst the painted pottery industry was still flourishing. However, the industry suffered a sharp decline in the LFB at the same time, even though some types of pottery similar to those in the previous phase were continuously used (Tian, 1996). During the Early Longshan period (5.0-4.5 ka BP), the settlements number in the TYB decreased slightly to 28, contrary to a sharp increase to 175 in the LFB. The characteristics of the archaeological assemblages in the two basins became consistent again. Distinctive pottery vessels were ding tripods, fu cauldron, dou dish and jia tripods (Tian, 1996). At around 4.5-4.0 ka BP, numbers of the Late Longshan culture settlements reached 82 and 229 in the TYB and LFB, respectively, the highest numbers since the Early Yangshao period in the region. The dryland farming became more developed and intensified (Zhao and He, 2006), and domestic animals (e.g., sheep and cattle.) were also raised at some sites (Brunson et al., 2016). Besides the semi-subterranean houses, above-ground houses and cave buildings also began to be constructed and occupied (Bureau of Chinese Cultural Relics, 2006). More importantly, the Taosi City (He, 2018) in the LFB expanded to an area over 280 ha. It was enclosed by a massive rammed-earth enclosure, inside which were palaces, altar and observatory, as well as many other archaeological features. Some elaborate objects, such as stone chime bells, crocodile-skin drums, jade objects and a few bronze vessels, were also unearthed from the site. These discoveries suggested the formation of a regional state-like entity around the Taosi City. After 4.0 ka BP, during the Bronze-Age Xia-Shang periods, economic industry and agriculture further developed, and the use of bronze vessels became increasingly popular. However, in both basins, settlement numbers decreased, and the regional population as well as the level of social prosperity declined.
In the Neolithic and the early historic periods, regional population and settlement numbers grew simultaneously together with social development, cultural exchange and technical innovation. During the Late Longshan period (Fig.7a, b, c), the rapid growth in settlement numbers in both the TYB and LFB might have been related to the emerging trans-Eurasia culture exchange since the late fifth millennium BP (Spengler et al., 2014; Dong et al., 2017). The Fen River basins was a key area of this increasingly connected transcontinental network. Domesticated sheep, arriving into central China via the steppe corridor, for instance, had occurred at the Taosi site (Brunson et al., 2016). This supplementary subsistence strategy of sheep husbandry might have facilitated humans to better adapt in their expanding catchments and territories, especially to mountainous areas. Fig.7a also shows that two episodes of decreases in regional settlements occurred during the Late Yangshao period after 5.5 ka BP and in the Bronze-Age Xia-Shang Dynasties after 4.0 ka BP, although the inconsistent changes of the settlement numbers in the TYB and LFB were also observed from the previous phase (Fig.7b, c). Our surveys show no clear alterations in the regional geomorphic process in this regions during these two periods. However, on a broader scale, these two episodes of settlement reduction coincided with two Holocene climatic events when climates were deteriorating- the “Holocene Event 4” and the “Holocene Event 3” (Bond et al., 1997; Wang et al., 2005), which might have caused or linked to the drier and cooler climate in the mid-lower Fen River after 5.5 ka BP (Lü and Zhang, 2008; Chen et al., 2015; Goldsmith et al., 2017) and 4.0 ka BP (Liu and Feng, 2012; Dong et al., 2013a; Sun and Feng, 2013; Dong et al., 2018). Specifically, the declining land carrying capacity would have led to the population outflow from the LFB beginning from the Late Yangshao period. This demographic and social changes from the Middle Yangshao to Late Yangshao in the LFB are similar to the contemporary transition in the Central Plains (Jia et al., 2008; Drennan and Dai, 2010). In contrast, the TYB may have become a more attractive area for population migration due to its improved landform and ecological conditions. This improvement is evidenced by the slight growth of settlements number in the basin, a situation similar to the contemporary changes observed in the south-central Inner Mongolia (Xu, 2010; Liu et al., 2016) and
the Gansu-Qinghai District regions (Dong et al., 2013b).

The drought triggered by dramatic climatic transition at ~4.0 ka BP might have severely affected the dryland farming in North China (An et al., 2003; Wu and Liu, 2004) with dramatic demographic and social consequences. Our survey and data synthesis thus provide solid evidence to show that, whilst geomorphic characteristics might remain stable, the Holocene climate might experience more frequent fluctuations, causing significant impact on regional settlement distributions.

4.4. Relationships between the settlements distribution models and the geomorphic histories

In the TYB and LFB, the spatial distributions of Neolithic and Bronze-Age settlements were evidently different from each other. The distribution densities also vary on different landforms. In the TYB, most ancient settlements were located on the loess tablelands between the piedmont and the central plain, and a few settlements also situated on the river valleys of low mountains area. No settlements can be found in the central plain. These show a distinctive “around-basin” distribution model (Fig.2a and Fig.7a). In the LFB, a large number of settlements were distributed on the loess tablelands in front of the mountains as well as the platform-type plain in the central basin. Only a minority of settlements were found in the river valleys of low mountains. These two distributional characteristics show a “full-basin” distribution model. These two contrasting spatial distribution models of ancient settlements in the TYB and LFB reconstructed by our geomorphic evidence are closely related to the differences in the geomorphic histories and characteristics of the two basins.

In the TYB, during the Late Pleistocene, large-scale alluvial aggradation in the peripheral piedmont of the basin led to deposition of thick reworked loess with embedded sand and gravels. From the terminal Pleistocene to the beginning of the Holocene, following the massive incisions of the Fen River and its tributaries, the piedmont zone evolved into an alluvial tableland, which was capped by several meters of Holocene aeolian loess. During the Holocene, the tableland surface was constantly above flood levels, which was advantageous for economic production and settlement occupation to take place on it. The plain in the central basin was low and flat, and the
Fen River and its tributaries migrated frequently. Since 6.0 ka BP, the plain experienced an aggradation of alluvial sediments and floods became more frequent consequently. In the central basin, it was therefore not suitable for habitation for a long period of time.

In the LFB, the Fen River and its tributaries had begun to incise as early as before 60.0 ka BP. Most areas in the central basin, formerly occupied by lakes, evolved into the platform-type plain that was mantled by aeolian deposits accumulated since the middle Late Pleistocene. During the Late Pleistocene, the incision range of the Fen River reached at least 22 m. Throughout the Holocene, in the central basin, the flood levels of the Fen River and its tributaries were much lower than the surface of the platform-type plain. This elevation difference became a conducive factor, encouraging human occupation and intensive economic activities during the Neolithic and Bronze-Age periods.

From the Late Pleistocene onwards, between the TYB and LFB, there was over 40 km long Lingshi Uplift, which was characterized by a bedrock-gorge landscape in the north. This makes the Fen River course resistant to erosion, blocking the retrogressive erosion process commencing from the LFB. In addition, the long-term intermittent uplift of the Lingshi region might have led to the aggradation of the TYB as the elevation of the local base-level. These were two major reasons for the different evolutionary patterns of regional geomorphic processes between the TYB and LFB sections of the Fen River (Wang et al., 1996).

5. Conclusions

Our survey of the geomorphic histories of the two mid-lower Fen River basins shows that, during the Late Pleistocene, the peripheral piedmont in the TYB formed a thick reworked loess layer with embedded sandy and gravel lens. From the end of the Late Pleistocene to the Early Holocene, mainly because of the impact of rapid climate change, the region evolved into a tableland following the incision of the Fen River tributaries. After slight downcutting from the terminal Late Pleistocene to the Early Holocene, the plain in the central TYB experienced a long period of fluvial aggradation since the Middle Holocene. In the LFB, because of regional tectonic uplift, large-scale
retrogressive erosions occurred in the Fen River and its tributaries just before 80.0 ka BP. The platform-type plain developed in the central of the basin, with deep incised valleys and comprised of thick lacustrine deposits which were subsequently mantled by aeolian loess.

Although the regional settlements might have been influenced by the Holocene climate fluctuations, such as the “Holocene Event 4” and the “Holocene Event 3”, the different geomorphic histories and characteristics of the two basins were the main reasons for two contrasting settlements distribution models. During the Holocene, around the TYB, the loess tableland surface was always above the flood levels of the Fen River and its tributaries. It was a habitable environment for settlement construction and economic activities. The fluvial plain in central basin witnessed fluvio-lacustrine aggradational dynamics during the Middle-Late Holocene and frequently-occurred floods were disadvantageous for long-term human occupation, resulting in the formation of the so-called “around-basin” distribution model. The central LFB developed the platform-type plain with deep incised valleys throughout the Holocene and flood threat was minimal there, leading to the formation of a “full-basin” distribution model.

Acknowledgements

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References


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Figures and captions

Fig.1. Map showing the mid-lower Fen River and the locations of profiles, core and regional cross-sections mentioned in the text. 1-FSH, 2-WMH, 3-KS, 4-LF, 5-GX and 6-HM. The data of the background map is provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences. (http://www.gscloud.cn).

Fig.2. a. Distributions of ancient settlements in the Taiyuan basin in different periods; b. Distributions of ancient settlements in Linfen basin in different periods.

Fig.3. a. Geomorphic-sedimentary cross-section of the Fangshan River (see Fig.1), b. The profile of FSH (see Fig.1); c. Geomorphic-sedimentary cross-section of the Wuma River (see Fig.1), d. The profile of WMH (see Fig.1).

Fig.4. The profile of KS (see Fig.1).

Fig.5. a. Geomorphic-sedimentary cross-section of the A-A’ in the Taiyuan Basin (see Fig.1); b. Geomorphic-sedimentary cross-section of the B-B’ in the Linfen Basin (see Fig.1; the paleosols older than S5 are not included here; revised from Hu et al. (2005)).

Fig.6. Typical profiles in the Linfen Basin. a-LF, b-GX and c-HM (see Fig.1).

Fig.7. a. Total settlement numbers in the Taiyuan Basin and Linfen Basin. Settlement numbers (densities) on different landforms in (b) the Taiyuan Basin and (c) Linfen Basin.
Pliocene Red clay  Early Pleistocene loess  Middle Pleistocene loess  Late Pleistocene loess  Holocene loess  Paleosol

Bedrock  Gravel  Sand  Silt  Clay  Normal fault

1: Fluvial plain  2: Platform-type plain  3: Loess tableland  4: Mountain
(a) [Graph showing total settlement numbers over time]

(b) [Graph showing settlement numbers grouped by age (ka BP)]

(c) [Graph showing settlement numbers by region]

EY: Early Yangshao
MY: Middle Yangshao
LY: Late Yangshao
EL: Early Longshan
LL: Late Longshan
X: Xia
S: Shang

Legend:
- Platform-type plain
- Loess tableland
- Mountain
### Table 1

Results of OSL dating from different locations

<table>
<thead>
<tr>
<th>Lab Code (profile)</th>
<th>Depth (m)</th>
<th>U (ppm)</th>
<th>Th (ppm)</th>
<th>K (%)</th>
<th>Dose rate (Gy/ka)</th>
<th>Equivalent dose (Gy)</th>
<th>Age (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L058 (KS)</td>
<td>25.30</td>
<td>1.60±0.07</td>
<td>13.30±0.36</td>
<td>2.98±0.07</td>
<td>3.74±0.15</td>
<td>117.17±12.94</td>
<td>31.34±3.68</td>
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<tr>
<td>L059 (KS)</td>
<td>11.00</td>
<td>2.35±0.09</td>
<td>15.40±0.40</td>
<td>2.27±0.06</td>
<td>4.07±0.23</td>
<td>7.22±0.06</td>
<td>1.77±0.10</td>
</tr>
<tr>
<td>L060 (KS)</td>
<td>0.40</td>
<td>3.00±0.10</td>
<td>16.80±0.44</td>
<td>1.93±0.06</td>
<td>4.54±0.28</td>
<td>4.55±0.13</td>
<td>1.00±0.07</td>
</tr>
<tr>
<td>L061 (FSH)</td>
<td>2.00</td>
<td>2.39±0.10</td>
<td>11.70±0.33</td>
<td>1.51±0.05</td>
<td>3.18±0.19</td>
<td>13.21±0.39</td>
<td>4.16±0.28</td>
</tr>
<tr>
<td>L063 (WMH)</td>
<td>5.80</td>
<td>2.05±0.09</td>
<td>9.35±0.27</td>
<td>1.92±0.06</td>
<td>2.73±0.11</td>
<td>14.72±1.64</td>
<td>5.39±0.64</td>
</tr>
<tr>
<td>L064 (WMH)</td>
<td>0.90</td>
<td>2.11±0.09</td>
<td>7.92±0.25</td>
<td>1.94±0.06</td>
<td>2.76±0.11</td>
<td>10.86±1.81</td>
<td>3.93±0.67</td>
</tr>
<tr>
<td>L3518 (HM)</td>
<td>3.45</td>
<td>2.71±0.11</td>
<td>10.70±0.31</td>
<td>1.74±0.06</td>
<td>4.13±0.22</td>
<td>350.00±14.80</td>
<td>84.83±5.79</td>
</tr>
<tr>
<td>L3519 (HM)</td>
<td>8.85</td>
<td>2.76±0.11</td>
<td>11.10±0.31</td>
<td>1.64±0.05</td>
<td>3.83±0.21</td>
<td>388.10±23.30</td>
<td>101.44±8.17</td>
</tr>
<tr>
<td>L2833 (GX)</td>
<td>7.10</td>
<td>2.78±0.11</td>
<td>11.30±0.32</td>
<td>1.74±0.06</td>
<td>3.07±0.20</td>
<td>136.62±7.25</td>
<td>44.50±3.70*</td>
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<tr>
<td>L2834 (GX)</td>
<td>7.20</td>
<td>2.40±0.10</td>
<td>9.71±0.28</td>
<td>1.60±0.05</td>
<td>2.74±0.17</td>
<td>154.96±6.90</td>
<td>56.50±4.40*</td>
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<tr>
<td>L2835 (GX)</td>
<td>7.20</td>
<td>2.07±0.09</td>
<td>9.78±0.28</td>
<td>1.52±0.05</td>
<td>2.60±0.16</td>
<td>344.67±15.05</td>
<td>132.80±10.20*</td>
</tr>
<tr>
<td>L3520 (GX)</td>
<td>2.20</td>
<td>3.79±0.14</td>
<td>13.30±0.37</td>
<td>2.26±0.07</td>
<td>5.10±0.27</td>
<td>291.40±9.20</td>
<td>57.11±3.49</td>
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<tr>
<td>L3521 (GX)</td>
<td>4.45</td>
<td>3.07±0.12</td>
<td>12.30±0.34</td>
<td>2.03±0.06</td>
<td>4.47±0.23</td>
<td>163.50±5.80</td>
<td>36.62±2.31</td>
</tr>
<tr>
<td>L3522 (GX)</td>
<td>5.25</td>
<td>2.64±0.10</td>
<td>14.70±0.40</td>
<td>1.91±0.06</td>
<td>4.45±0.24</td>
<td>423.50±11.50</td>
<td>95.23±5.71</td>
</tr>
<tr>
<td>L3523 (LF)</td>
<td>8.05</td>
<td>3.09±0.12</td>
<td>12.10±0.34</td>
<td>2.17±0.07</td>
<td>4.54±0.23</td>
<td>299.80±15.50</td>
<td>66.03±4.82</td>
</tr>
<tr>
<td>L3524 (LF)</td>
<td>6.00</td>
<td>2.78±0.11</td>
<td>11.40±0.32</td>
<td>1.90±0.06</td>
<td>4.12±0.21</td>
<td>281.90±5.60</td>
<td>68.48±3.81</td>
</tr>
</tbody>
</table>

* Three ages were published by one of the authors of this article (Feng, 2016).
Conflict of interest statement

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Sincerely,

Jiangqing Liu

Jiaqi Jiang

Yinan Liao

Peng Lu

Xiaolin Ren

Jun Feng
Quaternary International

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