Prolonged landscape stability sustained the continuous development of ancient civilizations in the Shuangji River valley of China's Central Plains

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Abstract: The continuous development of the Neolithic to Bronze-Age cultures on China's Central Plains is well contested by archaeological and historical research. Environmental factors that sustained such an exceptionally long cultural continuity are, however, poorly understood. The evolution of fluvial landscapes and its relationship with cultural developments are key to disentangle the close interaction between the environment and civilizational discourse on the Central Plains. Here, we present OSL and AMS 14C ages and other environmental data collected from a range of typical geomorphological locations in the Shuangji River valley, which is situated at the heartland of the Central Plains and long considered to be one of the most important regions for the rise of the Chinese civilization. Combining the OSL and 14C dates, results of particle size and soil/sediment micromorphological analyses, and geoarchaeological field observations, we reconstructed the evolution of Holocene geomorphological landscape in the Shuangji River valley. The results show that the Neogene alluvial fan was incised into a wide valley during the early Pleistocene. Subsequent alluvial processes were constrained within this general framework of regional landform. The period of 20 ka BP and 10-8 ka BP saw two episodes of basin-scale alluvial incision, which created two alluvial terraces (i.e., T4 and T3), respectively. Despite the occurrence of episodic floods and some large-scale alluvial siltation during 8-3 ka BP, the alluvial surfaces remained stable for a prolonged

period of time and thus provided optimal living conditions for prehistoric inhabitation. We argue that the geomorphological foundation and prolonged landscape stability were instrumental to the continuous cultural developments on the Central Plains as seen in the Shuangji River valley as a representative of such long-term human-environment interactions. Our geoarchaeological survey for the first time reveals basin-scale evidence on the mechanism responsible for this distinctive relationship between alluvial landscape and cultural development, in which the terrace-surface stability, alongside many other cultural factors, profoundly shaped the celebrated cultural continuity on prehistoric Central Plains.

Keywords: Shuangji River, geomorphology, landscape, Central Plains, cultural continuity

1. Introduction

In alluvial geoarchaeology, basin-scale reconstruction of palaeo-environment and landscape evolution is vital to our understanding of long-term and multi-scalar interactions between cultural successions and environmental fluctuations (Kidder et al，2008, 2012, 2015; Zhuang and Kidder , 2014). Alluvial basins provide essential natural resources for cultural developments. The ways how humans organize their settlements, produce food, and interact with one another are therefore inherently influenced by the altitude, landform, climate, and many other physical properties of alluvial basins (Brown, 1997). Because of this, basin-scale human-environmental dynamics contribute significantly to the shaping of civilizational discourses under different alluvial settings. For instance, Kidder et al. (2008) found that the Upper Tensas Basin of the Lower Mississippi River which is characterized by a prolonged stability of alluvial landscapes but with several episodes of significant river readjustments, as revealed by recent geoarchaeological surveys, is closely associated with prehistoric and historical cultural developments in the basin for the past 10,000 years. Similarly, the recent systematic basin-wide survey and reconstruction of the Holocene alluvial landscape of the Upper Nile have shed fresh insights into the responses of Holocene fluvial environments to climate change and how they affected human adaptations (Macklin et al, 2013, 2015). The importance of demonstrating the long-term development of fluvial landscapes to a more rigorous evaluation of prehistoric cultural adaptations can be also seen in Giosan and colleagues' recent study (2012) which reconsiders the classical issue of the collapse of the Harappan civilization through their robust reconstruction of the late-Holocene fluvial landscape in the region. Some of the findings allowed by these geoarchaeological surveys are significantly different from previous suggestions on societal responses (e.g., succession of the Kerma Kingdom) to climate change, which

88 tend to hold a simplistic, one-sided perspective. Instead, these new studies promote a holistic
89 understanding of the importance of geomorphological condition (e.g., stabile alluvial landscapes) to
90 cultural succession, resilience and adaptation.

91 Large river basins across China, including notably the different catchments of the Yellow River,
92 Yangtze River, and the Western Liao River, sustained the prosperity of multiple prehistoric cultures
93 and civilizations (Yan, 1987; Su, 2009; Liu and Chen, 2017). Compared to other civilizational
94 regions such as the Lower Yangtze River which experienced dramatic rise and fall of early
95 civilizations (Yu et al, 2000; Zheng et al, 2021; He et al, 2021), the Central Plains region in the
96 Middle and Lower Yellow River valleys was one of the few regions where prehistoric cultures
97 developed continuously without an obvious hiatus (Liu and Han, 2016). Such a cultural continuity
98 eventually fostered the emergence of early cities and state-level polities on the Central Plains which
99 is widely considered one of the most important regions for the origin of the Chinese Civilization.
100 Amongst the factors that sustained this unique civilizational discourse on the Central Plains, the
101 physical environment and its characteristics played an instrumental role (Zhou et al, 2005). While
102 long-term climate change has a profound impact on the overall patterns and characteristics of
103 cultural developments (Yu et al, 2020), it is the specific geomorphological conditions that define
104 how humans adapt to different environmental settings and climate regimes (Macklin et al, 2015).
105 Specifically, settlement patterns and subsistence strategies of prehistoric cultures in the region are
106 intrinsically constrained by altitude, topographic undulation, and hydrology of the alluvial
107 environments (Lu et al, 2013a, 2017).

108 The vast Central Plains region in fact includes a diverse range of landscapes and environments.
109 As one of the regions that has received most intensive archaeological quest for the origin of Chinese

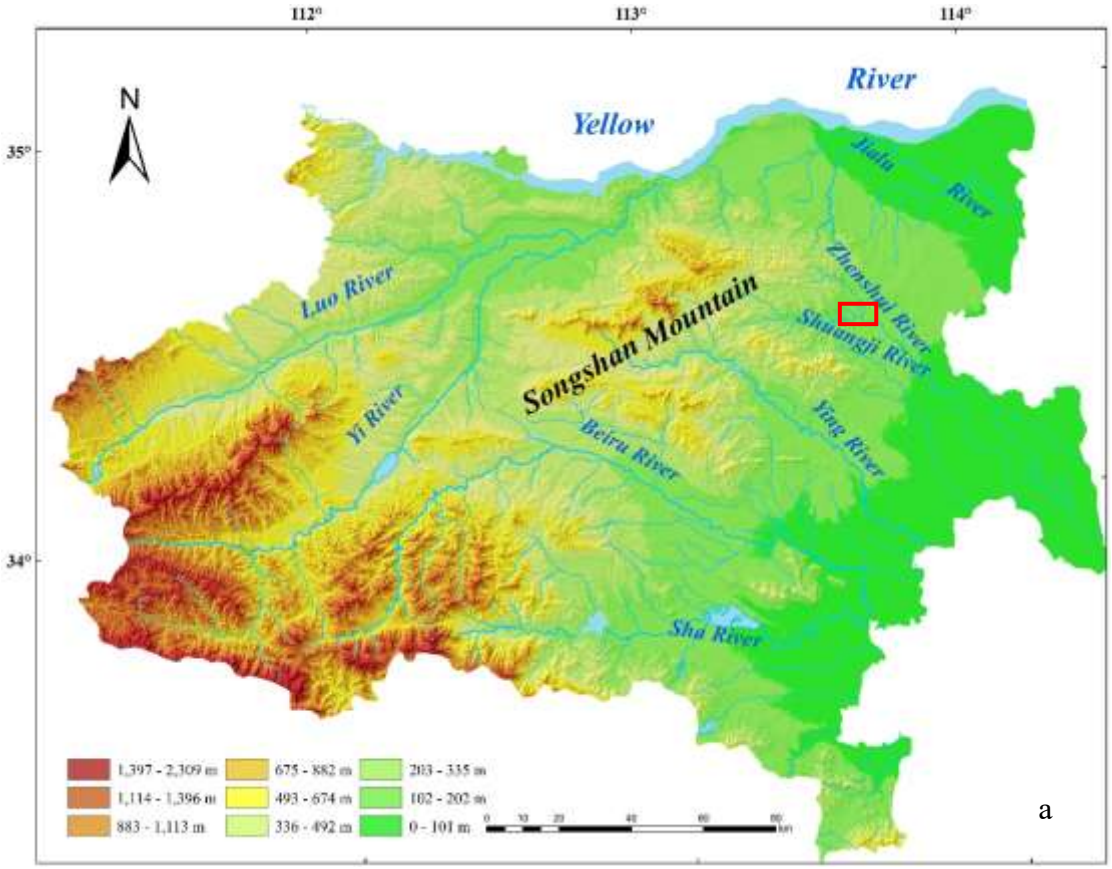
civilization, the Shuangji River valley of the Central Plains provides an ideal case to investigate how the growth and flourishment of prehistoric settlements were intricately related to the evolution of Holocene geomorphological landscapes of the river basin (Zhang ZY, 2007). Recently, several studies have investigated the relationship between the Holocene environment and cultural development in the Shuangji River. Zhang ZY et al. (2007) proposed that, confined by the narrow river valleys on shallow geological outcrops, most Yangshao culture and later Neolithic sites were situated on the alluvial terraces (T2) or further high up on the loess tablelands in the region. Whilst one might assume that, according to Zhang ZY et al.'s suggestion, these Neolithic sites might be free from the impact of floods, Xia et al. (2003) found flood deposits embedded on the oldest and highest-elevation alluvial terraces (T4) and thus suggested that the flood occurred during the 3550-3400 BP. If this was indeed the case, it would mean that these places were once inundated in flood water. According to Wang H (2007, 2019), an event of alluvial aggradation occurred between 5000-2500 BP in Shuangji River. Based on these studies, Lu (2017, 2019b) and colleagues further proposed three episodes of alluvial accretion and incision that took place between 10000-9000 BP, 9000-4000 BP, and 4000-historical times, respectively in the Shuangji River region. More chronological data and a more accurate chronological framework are required to refine these reconstructions on the evolution of the Holocene geomorphological landscape in the Shuangji River valley, especially the duration and mechanism of its prolonged stability. More importantly, synthetic studies are needed to further understand why prehistoric settlements were concentrated on the loess tablelands and alluvial terraces, how such a prolonged landscape stability supported continuous cultural developments in the Shuangji River valley of the Central Plains, and if such human-alluvial landscape dynamics represented a distinctive model of prehistoric cultural adaptation in China.

We present results from our geomorphological and geoarchaeological surveys in the Shuangji River valley and reconstruct evolution of Holocene geomorphological environments using high-resolution chronological and environmental data. Our results highlight the close relationship between the cultural continuity and landscape stability in the basin and shed new lights to understand how long-term geomorphological evolution facilitated the unparalleled cultural continuity on prehistoric Central Plains and evaluate the environmental foundation to this unique discourse to the rise of early civilizations in China.

2. Geographical setting and archaeological backgrounds

The Shuangji River valley is situated in the middle part of the Central Plains. The river originates from the low mountainous area to the northeast of the Songshan Mountain range. It flows through a diverse range of terrains from northwest to southeast, including mountains, loess tablelands and alluvial plains. The entire length of the river channel is around 171km, and the whole catchment covers an area of > 1800km^2 (Figure 1). The region belongs to the temperate continental climate zone with an average annual temperature of around 15°C and an average annual precipitation of around 600mm. Controlled by the Songshan Uplift, the regional topography is high on the northwest and low on the southeast, with the altitude undulating between 110-180 m above sea-level. The sediments in the valley mainly consist of wind-blown loess accumulated during the Quaternary era. Loess deposited during the Late Pleistocene is most widespread, whilst loess of the middle Pleistocene age can be also seen in some areas. Tertiary red clay is exposed on some higher-altitude locations of the region. The Shuangji River channel cuts out a deep (15-30 m) and wide (200 m) northwest-southeast running valley on flat loess tablelands. Similarly, some other small tributaries such as the Zhenshui River and the Huangshui River also create deeply (10-20 m) incised

valleys on the loess landscape.



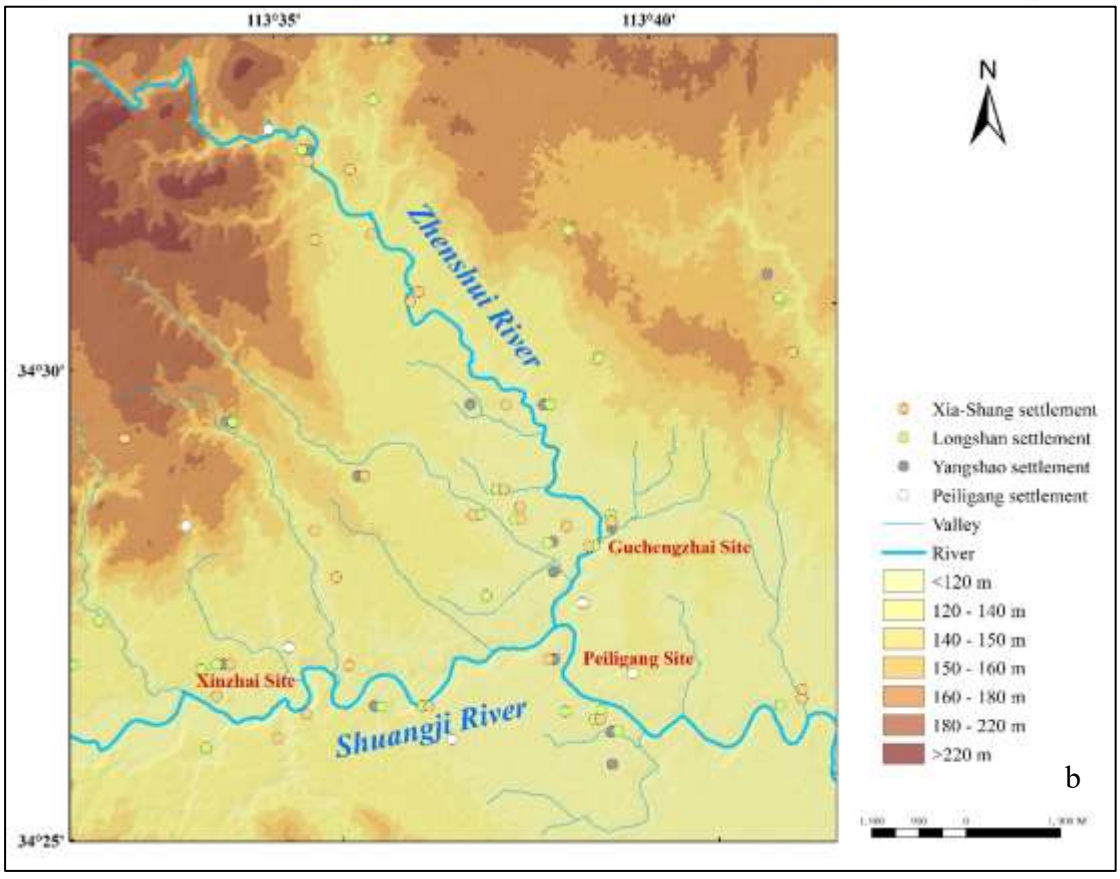


Figure 1. Geographic location of the studied region. a. Location of the Shuangji River valley (red rectangular) in the Songshan Mountain Region. b. The terrain, water system and distributions of prehistoric settlements of the Shuangji River valley.

Despite of a relatively small river, the Shuangji River valley has sustained continuous development of prehistoric cultures. This continuity is parallel with the prosperous prehistoric cultural sequence on the broad Central Plains region (Figure 2). As early as the Palaeolithic period, human activities were already active in the region and from the early Neolithic period, sedentary settlements began to emerge (Wang YP, 2013). The earliest Neolithic culture on the Central Plains, the Lijiagou site (ca.10500-8600 BP), was located in the Shuangji River valley (Wang YP et al, 2011). Since the Peiligang culture period (ca. 9000-7000 BP), settlements began to mushroom across the region, making it a region with the highest population density in the contemporary Central Plains. The settlements were, however, of small scale and there was no clear hierarchical difference between them (Lu et al, 2013b, 2019a; Li YQ et al, 2020). The settlement growth further accelerated during the Yangshao culture period (ca. 7000-5000 BP) and by the late Yangshao culture period (ca. 5500-5000 BP), settlements in the region began to display some hierarchical difference. The number of Longshan culture settlements (about 5000-4000 BP) further increased, with the emergence of many walled towns such as the Guchengzhai (Cai and Ma, 2002) and Xinzhai (SACRCPU and ZICH. 2008) walled towns. Whilst the Xia-Shang civilization in the following period (ca. 4000-3000 BP) saw a slight decrease in settlement number compared to the Longshan period, the difference in scale and rank of the Xia-Shang settlements was pronounced. Despite the absence of a capital center, some sites such as Xinzhai (SACRCPU and ZICH. 2008) and Wangjinglou (Gu,

2016) were of an enormous scale, and were accompanied with high-rank architecture and artefacts, indicative of their rank status amongst contemporary sites. This culture sequence in Neolithic and Bronze-Age Shuangji River valley is similar to that of the Songshan region also on the Central Plains. Additionally, such a similarity also lies in settlement distribution patterns of the Shuangji River and Songshan regions. Because prehistoric settlements were concentrated on the loess tablelands between the low mountains and plains of the Shuangji River valley, we focused in particular on the loess tablelands in our survey, which covered an area of around 140km^2 (Figure 1b).

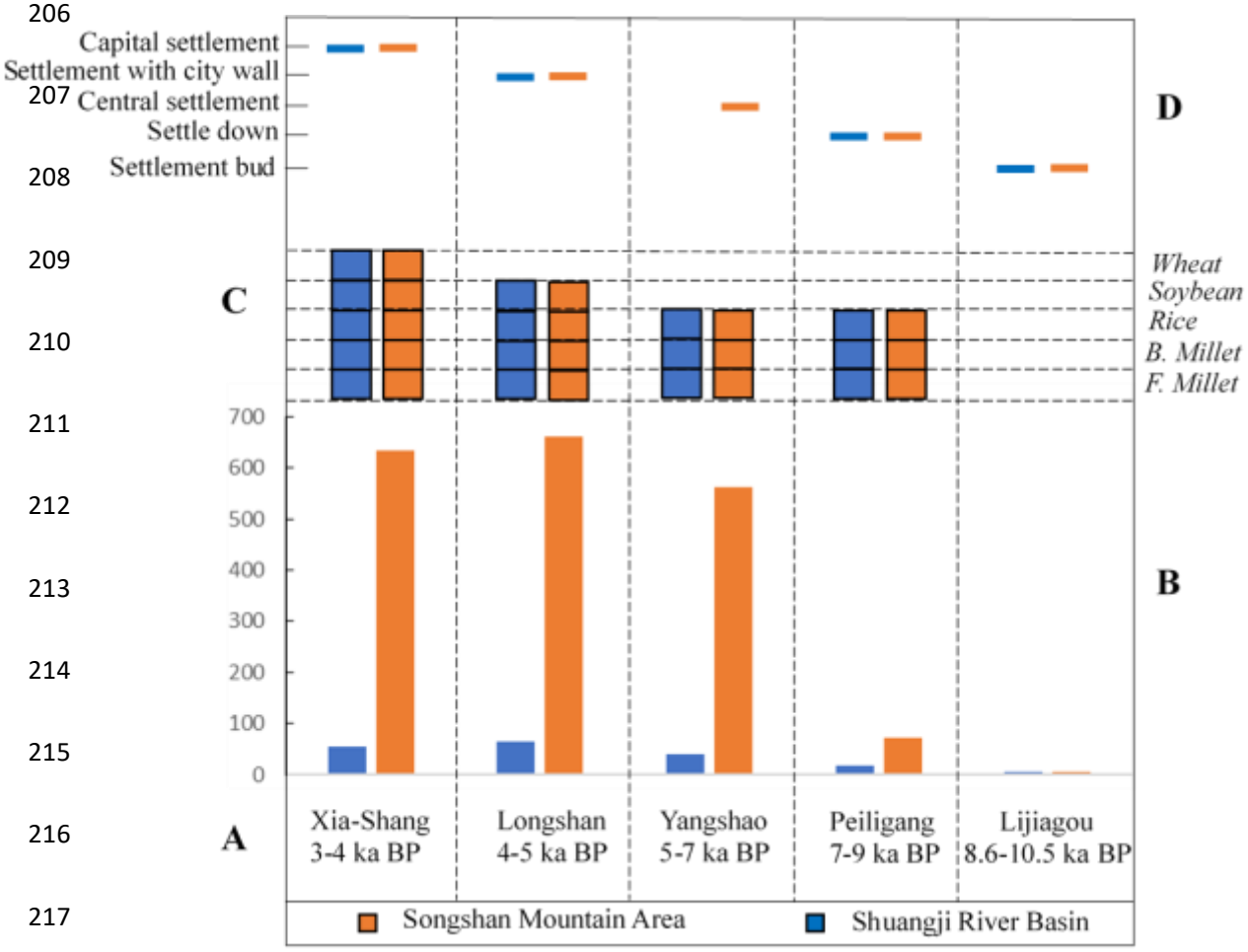


Figure 2. Developmental sequences and cultural characteristics of the prehistoric Central Plains and

Shuangji River valley. Orange represents the Songshan Mountain region as one of the typical regions with continuous cultural developments on the Central Plains. Blue represents the Shuangji River valley. A. Cultural types and chronologies; B. Settlement numbers. There is a similar growth trend of settlements between the Songshan Mountain region and Shuangji River Basin; C. Farming regimes (Liao et al, 2019). B. Millet = Broomcorn Millet. F. Millet = Foxtail Millet; D. Social complexity and organizational structure as represented by settlement patterns. "Budding Settlement" means there were some signs of long-term habitation, but no houses were found.

The Palaeolithic populations and the Lijiagou culture in the Shuangji River were subsisted by hunting, gathering and fishing (Qu et al，2018; Wang C，2016; Wang YP et al, 2018). Agriculture occurred during the Peiligang culture period when foxtail and broomcorn millets began to be cultivated. Rice remains were also found at some Peiligang culture sites (Wang C, 2017a). Agricultural production remained, however, at a low level during this time, whilst hunting, gathering and fishing were still the main sources of food production (Zhao, 2011). This situation changed drastically during the Yangshao culture period. Dryland farming of foxtail and broomcorn millets became predominant in local subsistence packages and at some sites, the scale of rice farming might have also increased, although it is important to note that hunting, gathering and fishing still contributed significantly to food procurement (Wang C，2017b). Agriculture further developed during the Longshan culture period, as marked by the introduction of wheat to the region (Deng et al，2019). In addition to foxtail and broomcorn millets and rice, soybean also began to be cultivated during the Longshan period (Liao et al，2019). Similarly, gathering, hunting and fishing continued to provide supplementary food to the local populations. By the Xia-Shang period, with the addition

of wheat as a crop in the region, the importance of agriculture was further enhanced, although non-agricultural food production still existed (Yao et al，2007). Overall, subsistence economies in the Neolithic times of the region had been dominated by dryland farming of millets, with the gradual formation of a mixed farming system of rice and millets with later additions of wheat and soybean (Zhang JP et al，2012；Bestel et al，2017), whilst gathering, hunting and fishing had been an important supplement to food production. The steady development of prehistoric agriculture in the region benefited from optimal soil and hydrological conditions on stable alluvial and loess landscapes and was foundational to the continuous growth of prehistoric settlements just mentioned.

3. Materials and methods

3.1 Regional geoarchaeological surveys and sediment lithology analysis

We conducted field surveys in multiple seasons between 2005-2020. These surveys consulted published geological maps (RGSTHGB, 1987) and ascertained general geological and sedimentary characteristics within the Shuangji River region. According to these geological maps, we first divided the area into different geomorphological types. Then the landforms, sedimentary sequences and gully systems at different geomorphological locations were surveyed in greater detail. Based on these works, we drew a regional geomorphological map and schematic vertical and horizontal sections to show topographic variations at the surveyed locations. The regional prehistoric settlements were superimposed on the geomorphological map in order to understand the spatial relationship between the settlement distribution and landform. We also investigated some important and typical archaeological sites during the field surveys. The age, size, distribution of archaeological remains, geomorphological characteristic, sedimentary sequence and hydrologic condition of these sites were recorded.

In particular, we examined a series of sedimentary sequences along these river valleys and other alluvial landforms and carefully recorded the sediment logs of these sequences. This information provides direct evidence for regional stratigraphical correlation and reveals intra-regional variation on sedimentary histories that were caused by changes in hydrology and other environmental parameters. Furthermore, this regional stratigraphical correlation also helped to situate the archaeological stratigraphy within their wider geomorphological contexts and therefore understand prehistoric adaptations to diverse landforms and environments in the Shuangji River region.

3.2 OSL and radiocarbon dating

We collected samples for OSL and 14C dating from sedimentary sequences that are representative of diverse alluvial processes to determine chronologies of them. These sequences have continuous deposition and thus contain rich palaeo-environment information according to our field observation. A total of 51 OSL and nine 14C dating samples were collected from 12 profiles (Figure 3). OSL dating was completed at the Institute of Geography of Henan Academy of Sciences, whilst 14C dating was conducted at Peking University and Beta Analytic.

The OSL dating adopted the following procedures. 10% mol/HCl was added to the sample to dissolve calcium and carbonate; 30% H_2O_2 was added to remove organic matter. The sediments were then sieved to obtain coarse grained (90－125 μm) and fine (4-11 μm) grained quartz using the method developed and described by Zhang et al. (2010). The purity of quartz was then tested by IR simulation. All measurement was performed on a lexsyg research luminescence reader. Single aliquot regeneration (SAR) protocols (Murray and Wintle, 2003) were used to determine the De (equivalent dose) of coarse and fine grained quartz. 25-30 aliquots were measured for each OSL

286 samples. U, TH, and K were measured using neutron-activation-analysis (NAA). The dose rates and
287 OSL ages were determined by the Dose Rate and Age Calculator ('DRAC') (Durcan et al., 2015).
288 Some 14C dates were obtained from several profiles from a previous study (Lu et al 2019b),
289 which provide a good reference for our present study. The 14C samples from the SY and NYH
290 profiles were processed by the Accelerator Mass Spectrometer (AMS) at Peking University and Beta
291 Analytic Inc. The AMS 14C dates were calibrated using the OxCal 4.4.1 software (Ramsey Bronk,
292 1995) and the IntCal 20 calibration curve（Reimer PJ et al, 2020a, 2020b）.
293
294 **3.3 Grain size and soil/sediment micromorphological analyses**
295 Bulk sediment samples were collected from three examined profiles at the PLG, DJ and SY
296 locations (No. 1, 3, 4 in Figure 3a). These profiles are adjacent to the prehistoric settlements and
297 contain characteristic alluvial strata. Samples at the PLG and DJ profiles were collected every 5cm
298 whilst those at the SY profile were collected at an interval of 2cm. A total of 372 bulk samples were
299 collected and analyzed for particle size distribution. The 71 samples from the DJ profile and the 211
300 samples from the SY profiles were processed at the Sedimentary Laboratory of Peking University
301 whilst the 90 samples from the PLG profile were processed at the Institute of Geography of Henan
302 Academy of Sciences, following same procedures described briefly as follows. Diluted HCl and
303 H_2O_2 were added to the samples to remove organic and inorganic carbon, respectively. The sample
304 was then mixed with 10mL 5% sodium hexametaphosphate ($(NaPO_3)_6$) before being heated on a
305 crucible. This was to fully disperse the particles before they were measured on Malvern Masternsizer
306 2000.
307 Additionally, six soil blocks were collected from the well-preserved and dated palaeosols at

308 the PLG location and made into thin sections. This was completed at the laboratory of the China
309 University of Geosciences (Beijing). The thin sections were examined using polarized microscope
310 following several reference books (Murphy, 1986; Bullock et al, 1985; Stoops, 2003).
311
312 **4. Results**
313 **4.1 Regional geomorphological systems and sedimentary sequences**
314 Through the surveys, we confirmed that regional landform can be divided into two distinctive
315 systems: the Red Clay Hills system and the Pleistocene Alluvial Valley system (Figure 3). As the
316 remnant landform developed from the Tertiary alluvial fans, the Red Clay Hills are presently situated
317 on places with the highest elevation of the region. Controlled by the underlying topography and
318 tectonic activity, the surface of the hill tilts from northwest to southeast, ranging in altitude between
319 130-300 m. The stratum on the Red Clay Hills is dominated by Tertiary sediments including gravels
320 and clay. Overlying the Tertiary sediments are thin layers of Pleistocene loess. Whilst some
321 Neolithic and Bronze Age settlements were located on the red-clay landforms, these accounted for
322 a small number compared to those settlements located on the alluvial valleys.
323 The Pleistocene alluvial valleys are mainly distributed on both sides of the Shuangji River and
324 along its largest tributary, the Zhenshui River basin. The geomorphological system consists of, in
325 particular, four-ordered river terraces in the valleys. Alluvial terraces T4 are the highest terraces in
326 the region and their elevation is almost the same as the red clay hills. The surfaces of the terraces
327 are generally more than 35 meters above the valley bottom. The terrace sediments are mainly of
328 loose Quaternary sediment clasts. Overall, the distribution of alluvial terraces T4 is scattered, only
329 present at a few locations such as near the Peiligang site (Figure 4). In contrast, alluvial terraces T3

are widely distributed in the Shuangji River and Zhenshui River valleys. The surfaces of them are flat and wide, ca. 20-25 m higher than the valley bottoms. The sediments are dominated by Late Pleistocene and Holocene aeolian loess, but thick layers of Late Pleistocene fluvio-lacustrine sediments with embedded channel deposits can be seen in many examined profiles such as the DTQ and PLGXG sections during our surveys. Many Neolithic-Bronze settlements were densely distributed on top of the alluvial terraces T3, including the large-scale sites at Xinzhai and Guchengzhai. Alluvial terraces T2 are less well-preserved along the main channels of the Shuangji River and Zhenshui River due to river erosion. But a few alluvial terraces T2 are preserved along some small valleys. The surfaces of some alluvial terraces T2 are almost as flat and wide as those of the alluvial terraces T3. The age of alluvial terraces T1 is relatively young, of the late historical period. These terraces are narrower and generally distributed on both sides of the Shuangji River, Zhenshui River and their tributaries.

Because the Neolithic and Bronze-Age settlements were mostly distributed on the alluvial terraces T3 and T4, we paid more attention to these terraces and surrounding landforms along the Shuangji River and its tributaries such as the Zhenshui River. Through the geomorphological and geoarchaeological surveys, we established spatial and temporal variations of alluvial landforms along these rivers and their relationships with prehistoric settlements.

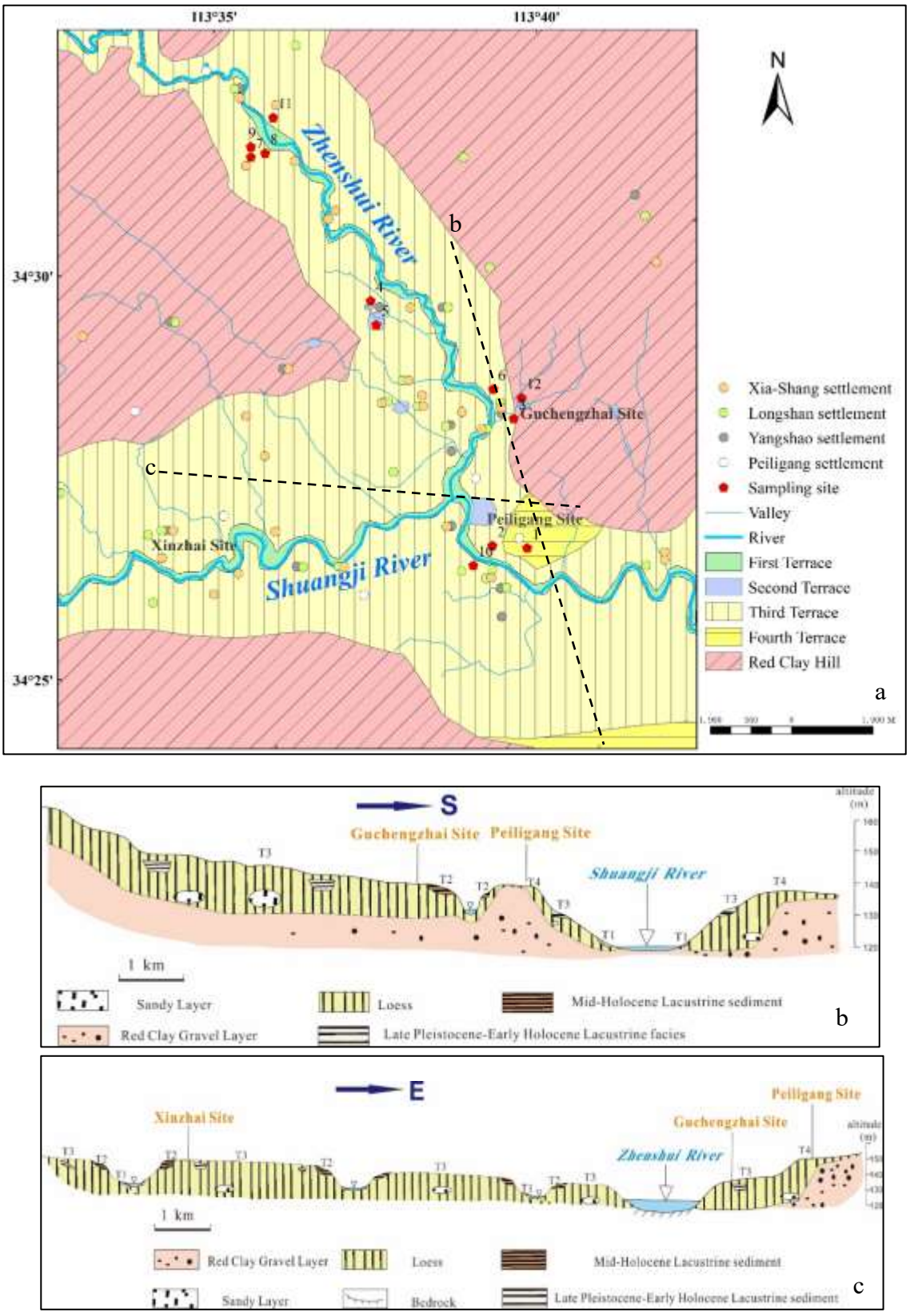


Figure 3. Regional geomorphology and distributions of Neolithic and Bronze-Age settlements. a. The geomorphological types and settlement distributions. The red pentagons indicate the locations

of the stratigraphic sections examined in this paper. 1: PLG. 2. PLGXG. 3. DJ. 4. SY. 5. NYH. 6. GCZ. 7. MSQ. 8. QLN 1. 9. QLN 2. 10. DTQ. 11. QL. 12. XHZ; b. Schematic south-north cross section of the studied region. The locations are marked in Figure 3a; c. Schematic west-east cross section. The locations are marked in Figure 3a.

Figure 4. Satellite image of the Shuangji River valley. a. The satellite image shows that there are four-ordered alluvial terraces in the Shuangji River valley near the Peiligang Site. The vertical

396 distance between the surfaces of alluvial terraces T4, T3, T2 and T1 to the river are about 35m, 25m,
397 15m and 5m, respectively (The data is collected from MAPWORLD); b. Stratigraphy from the
398 excavation at the Peiligang site situated on top of alluvial terrace T4. The top is the cultural layer
399 containing Peiligang Culture (8000 a BP) and Erligang Culture (3500 a BP) remains, note the
400 significant cultural hiatus at the site. The second layer is the Holocene palaeosol. The third layer is
401 the local sheet flow sediments. The bottom is the late Pleistocene loess; c. The alluvial deposits date
402 to the terminal Pleistocene and early Holocene at alluvial terrace T3 from the DW Section, 1km
403 north of the Peiligang site; d. The middle Holocene alluvium on alluvial terrace T2 from the SY
404 Section).
405
406
407 Amongst all the examined stratigraphies, only the PLG section is located on alluvial terraces
408 T4 (Figure 4, 5. Stratigraphic description see the supplementary information document). As shown
409 in the figure, the section is dominated by loess-palaeosol deposits. Whilst alluvial deposits were
410 present at the PLG section, they were only a local phenomenon, such alluvial deposits rarely occur
411 in other excavation trenches at the site. In other words, the local landscape remained stable and was
412 rarely affected by alluvial processes during the Late Pleistocene and early Holocene.
413 Seven of our examined profiles, including PLGXG, DJ, GCZ, MSQ, QLN2, DTQ, QL (No. 2,
414 3, 6, 7, 9, 10, 11 in Figure 3a) belong to alluvial terraces T3 (Figures 4 and 5). These sections
415 generally contain some alluvial strata which are mostly of lacustrine facies that were deposited
416 during the terminal Pleistocene to the early Holocene.
417 The SY, NYH, QLN1, XHZ sections (No. 4, 5, 8, 12 in Figure 3a) are all distributed along the

tributary gullies of the rivers in the region. The presence of lacustrine sediments in some of the profiles also points to high regional water table which was probably induced by climate change. We can also infer that these sections should be parts of the alluvial terraces T2 which formed on tributary gullies during the middle Holocene.

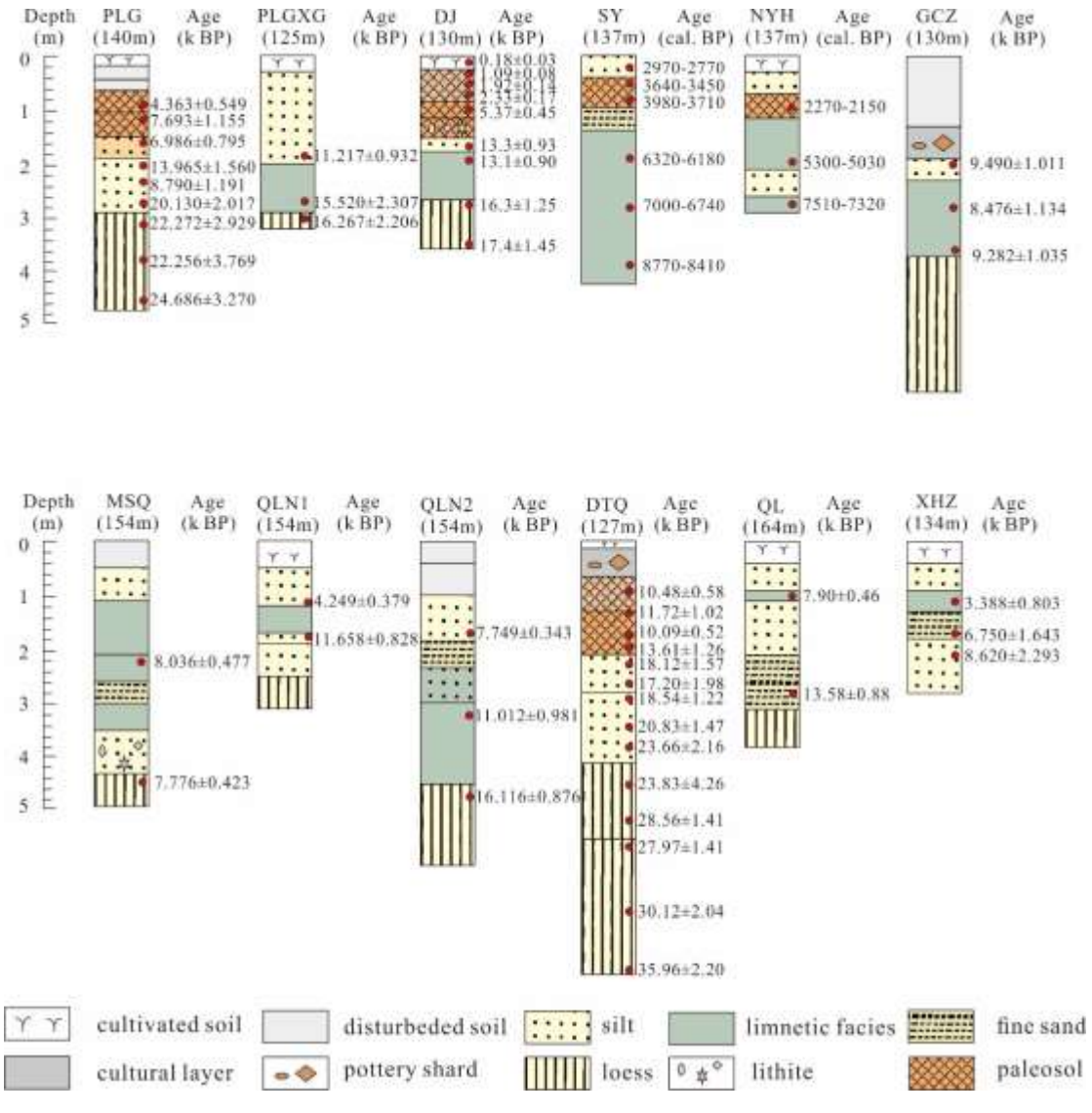


Figure 5. Sediment logs of examined stratigraphic profiles. The positions of sections are shown in figure 3a. The top elevation of every section has been labeled on the stratigraphic diagram. The dates in SY and NHY profiles are AMS ^{14}C ages which have been published in Lu et al (2019).

4.2 Chronological framework of the alluvial landform evolution

The results of OSL dates are summarized in Table 1. The preheating test shows that both the 220 ℃ for coarse-sized samples (90-125 μm) and the 240 ℃ for fine-sized samples (4-11 μm) are appropriate preheating temperatures (Figure 6). The over-dispersion rate of most samples is less than 15% which indicates that the effective dose results of the test are relatively concentrated (Table 1). Some De values with larger over-dispersion rate such as samples no. MSQ03, QLN1-01 and QLN1-02 are reprocessed using the chronological model. The recycling ratio of most samples is between 0.9-1.1 which indicates that the correction of sense sensitive quality change is successful. The recuperations are within 5% which is an acceptable range. OSL decay curves show that the samples have been bleached well. All the above qualities ensure the reliability of the OSL results. Most OSL dates fall into good chronological orders and were consistent with our field estimation of the dates of the stratigraphies except for a few anomalies. Because of the possible incomplete light bleaching or sample exposure, sample no. PLG005 from the PLG site was abnormally young and was therefore not considered here. Similarly, sample no. DTQ1-4 was significantly older than the estimated age. Importantly, although date reverses occurred at the GCZ, MSQ and DTQ profiles, they were within the range of standard deviation and were thus considered alongside field observations to establish chronologies of the sedimentation histories at these locations.

461 Table 1. The results of OSL dating

462

463

Sample No.	Lab. No	Depth(cm)	U/ppm	Th/ppm	K/%	Rb/ppm	Q-De(Gy)	OD(%)	w.c (%)	Q-Dose rate	Q-Age(ka)
PLG 001	L433	80	2.58±1.92	15.3±1.29	2.07±0.44	101±1.62	18.55±0.30	5.13	10.58	4.252±0.530	4.363±0.549
PLG 002	L434	115	2.30±2.37	13.4±1.47	2.03±0.43	102±1.18	30.04±0.92	8.65	11.68	3.905±0.574	7.693±1.155
PLG 003	L435	160	2.35±1.49	13.7±1.20	2.01±0.38	97.7±1.51	27.45±0.67	7.74	11.35	3.929±0.437	6.986±0.795
PLG 004	L436	200	2.17±1.34	11.2±2.22	1.96±0.34	90.6±1.32	51.47±1.38	8.49	9.16	3.686±0.400	13.965±1.560
PLG 005	L437	245	2.26±0.74	13.9±0.95	2.02±0.62	93.4±1.05	35.20±1.19	8.94	9.13	4.005±0.525	8.790±1.191
PLG 006	L438	290	2.10±1.29	11.8±1.19	2.00±0.28	92.5±1.89	73.98±1.64	5.96	10.70	3.675±0.359	20.130±2.017
PLG 007	L439	335	2.24±1.31	12.8±0.42	1.87±0.50	86.5±0.75	81.07±1.98	6.59	11.61	3.640±0.470	22.272±2.929
PLG 008	L440	380	2.22±2.75	11.1±1.05	1.87±0.35	86.0±1.67	76.75±0.75	2.66	12.43	3.448±0.583	22.256±3.769
PLG 009	L441	460	2.07±1.86	12.8±1.28	1.78±0.35	80.9±0.79	85.50±0.74	2.20	12.22	3.464±0.458	24.686±3.270
PLGXG 001	L442	200	2.13±1.34	14.5±0.99	2.23±0.20	118±0.24	45.45±0.27	1.91	13.18	4.052±0.336	11.217±0.932
PLGXG 002	L443	245	1.94±1.19	13.2±0.75	2.05±0.66	105±0.84	57.10±0.38	2.10	13.92	3.679±0.546	15.520±2.307
PLGXG 003	L444	290	1.75±1.94	11.2±1.06	1.90±0.33	86.3±0.99	56.73±0.43	2.40	8.91	3.487±0.472	16.267±2.206
DJ001	PKU L652	8±3	3.71±0.45	10.77±1.49	1.75±0.1		0.55±0.07	12.73	20±5	3.1±0.2	0.18±0.03
DJ002	PKU L653	23±3	2.38±0.40	11.95±1.35	1.75±0.1		3.08±0.11	9.74	20±5	2.8±0.2	1.09±0.08
DJ003	PKU L654	43±3	2.95±0.43	11.16±1.43	1.78±0.1		5.55±0.21	9.01	20±5	2.9±0.2	1.92±0.14

DJ004	PKU L655	63±3	2.96±0.43	11.04±1.43	1.62±0.1		6.40±0.13	7.81	20±5	2.8±0.2	2.33±0.17
DJ005	PKU L656	95±5	2.84±0.46	12.65±1.53	1.60±0.1		15.04±0.63	4.19	20±5	2.8±0.2	5.37±0.45
DJ006	PKU L657	170±5	3.16±0.37	9.23±1.22	1.50±0.1		33.99±0.34	1.47	20±5	2.6±0.2	13.3±0.93
DJ007	PKU L658	185±5	2.70±0.37	9.63±1.22	1.70±0.1		34.60±0.44	1.45	20±5	2.6±0.2	13.1±0.90
DJ008	PKU L659	268±3	2.92±0.44	11.14±1.47	1.55±0.1		43.17±1.09	2.52	20±5	2.6±0.2	16.3±1.25
DJ009	PKU L660	353±3	3.78±0.40	8.30±1.33	1.70±0.1		47.90±2.25	4.70	20±5	2.8±0.2	17.4±1.45
GCZ001	L425	200	2.05±1.20	13.0±1.75	1.72±0.27	96.4±1.65	36.48±1.17	8.51	3.06	3.844±0.391	9.490±1.011
GCZ002	L426	280	1.99±1.65	13.6±0.43	1.84±0.44	115±1.60	32.83±0.87	7.47	5.64	3.873±0.508	8.476±1.134
GCZ003	L427	370	2.15±1.22	11.8±0.92	1.65±0.32	85.4±1.62	33.29±0.67	6.32	4.65	3.586±0.393	9.282±1.035
MSQ01	L046	450	2.23±4.1	10.3±2.8	1.66±3.3		30.26±0.83	4.92	6.03	3.415±0.161	7.776±0.423
MSQ02	L047	220	1.97±4.2	9.65±2.9	1.67±3.3		32.32±1.18	11.91	1.35	3.310±0.149	8.038±0.477
MSQ03	L048	180	1.97±4.2	9.06±2.9	1.61±3.3		34.07±1.92	16.59	28.20	3.216±0.144	11.658±0.828
QLN1-01	L049	110	2.05±4.2	9.38±2.9	1.83±3.1		16.4±1.05	20.18	1.61	3.387±0.153	4.249±0.379
QLN1-02	L050	470	1.89±4.3	7.49±3.2	1.78±3.2		60.27±2.10	31.47	3.20	3.874±0.178	16.116±0.876
QLN2-01	L051	320	2.56±3.9	12.1±2.8	1.80±3.1		41.00±4.18	11.75	2.80	3.750±0.174	11.012±0.981
QLN2-02	L052	170	1.86±4.4	8.79±3.0	1.64±3.3		29.34±0.30	3.06	3.9	3.442±0.155	7.749±0.343
DTQ01	20150101	95	2.15±4.1	10.3±2.8	1.99±3.0	93.8±5.4	36.97±1.49	4.17	10±5	3.55±0.14	10.41±0.58
DTQ02	20150102	130	2.08±4.2	10.3±2.8	1.77±3.2	92.9±5.7	38.90±3.04	10.06	10±5	3.32±0.13	11.72±1.02
DTQ03	20150103	170	2.17±4.1	11.0±2.8	1.84±3.1	88.4±6.0	34.92±1.21	8.72	10±5	3.46±0.13	10.09±0.52
DTQ04	20150104	200	2.05±4.2	9.91±2.8	1.88±3.1	90.4±5.8	45.76±3.87	5.34	10±5	3.36±0.13	13.61±1.26

DTQ05	20150105	230	1.95±4.3	10.1±2.8	1.90±3.0	87.4±6.1	60.88±4.72	9.15	10±5	3.36±0.13	18.12±1.57
DTQ06	20150106	260	1.95±4.3	10.7±2.8	2.04±3.0	90.6±5.8	60.77±6.60	10.23	10±5	3.53±0.14	17.20±1.98
DTQ07	20150107	290	2.22±4.1	10.1±2.8	1.92±3.0	95.3±5.6	63.97±3.43	4.33	10±5	3.45±0.13	18.54±1.22
DTQ08	20150108	340	2.10±4.2	10.5±2.8	1.96±3.0	87.0±6.1	72.34±4.29	7.06	10±5	3.47±0.13	20.83±1.47
DTQ09	20150109	380	2.26±4.1	9.88±2.8	1.95±3.0	82.5±6.3	81.63±6.76	8.72	10±5	3.45±0.13	23.66±2.16
DTQ10	20150110	450	2.13±4.2	10.5±2.8	1.80±3.1	88.3±6.1	79.10±13.82	6.69	10±5	3.32±0.13	23.83±4.26
DTQ11	20150111	520	1.59±4.7	8.54±3.0	1.80±3.1	85.5±6.1	85.16±2.55	10.27	10±5	2.98±0.12	28.56±1.41
DTQ12	20150112	570	1.58±4.7	8.61±3.0	1.65±3.3	83.8±6.2	79.47±2.55	7.78	10±5	2.84±0.11	27.97±1.41
DTQ13	NJU2050	690	1.76±0.08	8.48±0.25	1.55±0.05		77.36±2.56	10.99	7.16±5	2.57±0.14	30.12±2.04
DTQ15	NJU2051	800	1.78±0.08	8.21±0.25	1.48±0.05		88.44±1.44	6.98	7.8±5	2.46±0.14	35.96±2.20
DTQ19	NJU2052	1100	1.70±0.08	8.90±0.26	1.72±0.06		106.83±1.33	4.30	6.81±5	2.73±0.16	39.10±2.41
DTQ24	NJU2053	1350	1.61±0.08	7.61±0.24	1.50±0.05		83.42±1.11	4.62	7.3±5	2.38±0.13	34.98±2.51
DTQ26	NJU2054	1590	2.23±0.09	9.10±0.26	1.54±0.05		115.88±3.10	12.25	7.06±5	2.65±0.15	43.77±2.88
QL01	L 080	100	1.81±0.08	10.3±0.29	1.55±0.05	77.50±4.65	24.47±0.30	2.96	10±5	3.10±0.18	7.76±0.46
QL02	L 081	280	1.74±0.08	7.43±0.24	1.32±0.05	62.80±4.52	34.79±1.09	7.67	10±5	2.56±0.15	13.58±0.88
XHZ 01	L495	110	2.08±4.0	11.4±3.2	1.67±0.13	85.3±2.3	12.60±0.10	2.62	1.95	3.719±0.881	3.388±0.803
XHZ 02	L496	172	2.06±1.7	10.5±2.2	1.50±0.88	86.8±2.7	22.86±0.10	1.44	3.11	3.387±0.824	6.750±1.643
XHZ 03	L497	205	1.93±2.1	10.8±2.7	1.60±0.96	80.4±1.8	30.29±0.23	2.39	1.87	3.514±0.934	8.620±2.293

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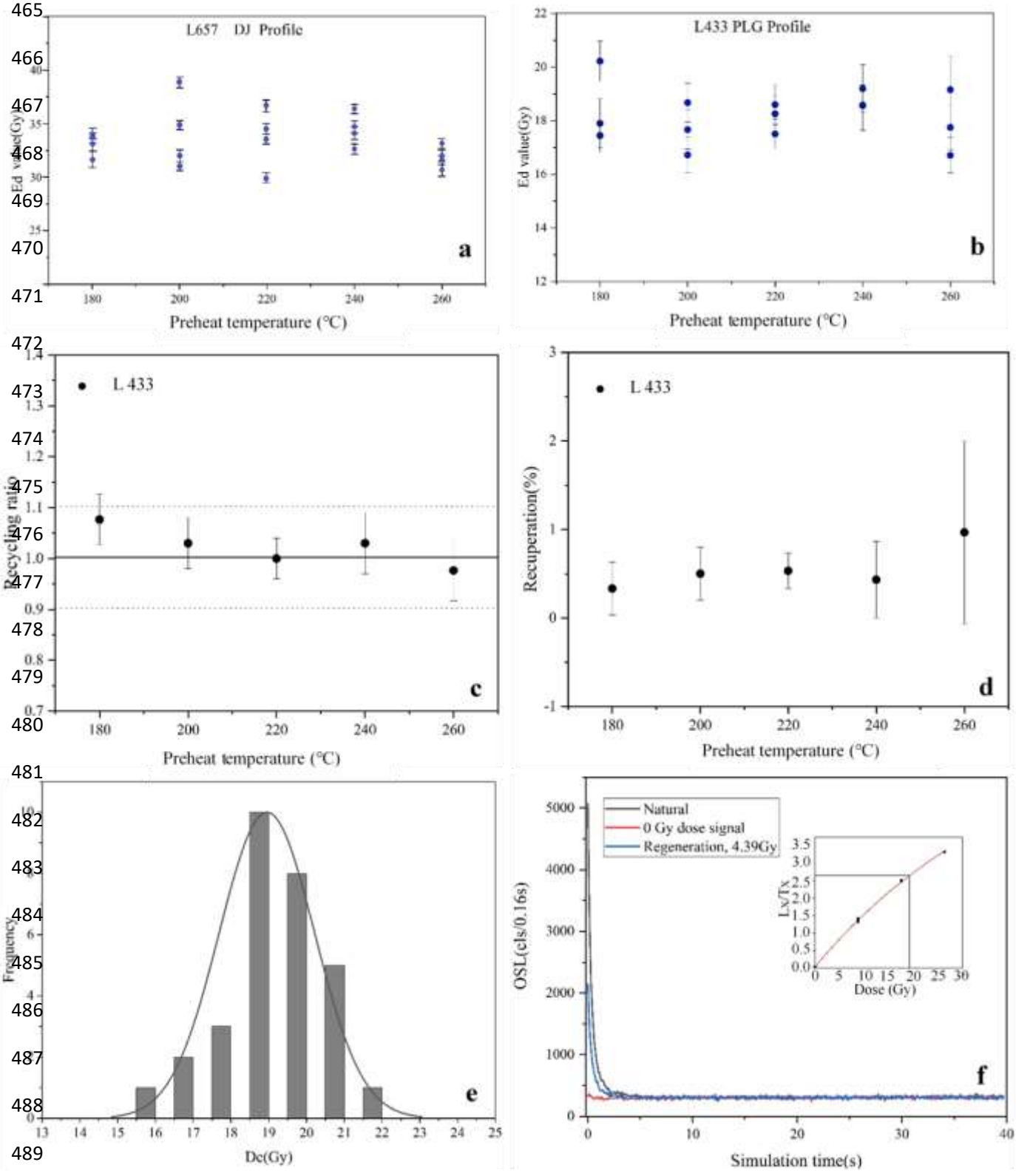


Figure 6. Graphs showing OSL dating procedures. a. Preheating test for sample no. L660 of the DJ profile shows that 220 ℃ is an appropriate preheating temperature for coarse-sized samples (90-125 μm); b. Preheating test for sample no. L433 of PLG profile shows that 240 ℃ is an appropriate preheating temperature for fine-sized samples (4-11 μm); c. Recycling ratio of the

sample no. L433 of PLG profile; d. Recuperation of the sample no. L433 of PLG profile; e. The recycling ratio histogram for all measured aliquots of sample no. L433; f. The decay curves and growth curve for sample no. L433.

Our 14C dating results (Table 2) accord well with the OSL dates. Both the SY and NYH profiles are located on alluvial terraces T2 along tributary gullies, with similar sedimentary sequences (Lu et al, 2019b). The ages of the alluvial sediment in these sections fall between 4000-8000 a BP (Table 3). The OSL results provide the sedimentation ages of the other two terraces at XHZ and QLN1. The alluvial sediments of these sections also fall between 8000-4000 a BP. These indicate that the tributary gullies were at an accretion state during 8000-4000 a BP. After 4000 a BP, the regional river system began a downcutting process which led to the formation of alluvial terraces T2. Unfortunately, there are few alluvial terraces T2 preserved on either side of the main rivers such as the Shuangji River and Zhenshui River in the region. Rather, they are found in scattered distribution along the tributary gullies.

523 Table 2 The results of radiocarbon dating (Lu et al, 2019b)

524

Sample Code	Sampling Site	Lab codes	Texture	Dating materials	Depth （cm）	^{14}C age (BP)	Calibrated age cal BP(2σ)
SY205	Shiyuan	BA07087	loess	organic sediment	12-14	2775+/-40	2970 - 2770
SY189	Shiyuan	BA07086	paleosol	organic sediment	44-46	3330+/-40	3650 - 3160
SY177	Shiyuan	BA07085	sand	organic sediment	104-106	3560+/-40	3980 - 3720
SY117	Shiyuan	BA07083	limnetic facies	organic sediment	188-190	5455+/-40	6320 - 6180
SY74	Shiyuan	BA07081	limnetic facies	organic sediment	274-276	6045+/-45	7010 - 6750
SY18	Shiyuan	BA07079	limnetic facies	organic sediment	386-388	7800+/-60	8770 - 8420
NYH003	Niuyuhuan	Beta- 25589	paleosol	organic sediment	90	2120+/-30	2345-2295 2270-2155
NYH002	Niuyuhuan	Beta-425588	limnetic facies	organic sediment	195	4350+/-30	5300-5035 5005-4980
NYH001	Niuyuhuan	Beta-425587	limnetic facies	organic sediment	275	6380+/-40	7480-7415 7390-7370 7355-7330

525

526 Most OSL ages of the alluvial sediments on terraces T3 are largely concentrated between
527 13000- 8000 BP (Table 3). Despite the age of PLGXG is a little old, it is still within the margin of
528 error. The Depth-Age Model of the DJ profile shows that the lacustrine deposits at 270-180 cm deep
529 also have an age of between 13000-8000 BP (Figure 7). The presence of lacustrine deposits suggests
530 it was a rive aggradation process during the time. After 8000 BP, the regional rivers began to incise
531 the landscape. This was followed by a stage of landscape stability which formed the loess-palaeosol
532 sequences on the terraces.

533

Table 3 Summary of the age of alluvial deposits in terraces T3 and T2

Geomorphic position	Profile	Sedimentary facies	Age (ka BP)
Alluvial terraces T3	PLGXG	Lacustrine facies	15.520±3.207
	DJ	Lacustrine facies	13.1±0.9
	GCZ	Lacustrine facies	8.476±1.134 – 9.282±1.035
	MSQ	Lacustrine facies	8.036±0.477
	QLN2	Lacustrine facies	11.012±0.981
	QL	Lacustrine facies	7.90±0.46
Alluvial terraces T2	SY	Lacustrine facies, Fluvial faces	8.770 – 3.980
	NYH	Lacustrine facies	7.510 – 5.030
	QLN1	Lacustrine facies	4.249±0.379
	XHZ	Lacustrine facies, Fluvial faces	3.388±0.803 – 6.750±1.643

The Depth-Age Model of the PLG profile shows that the alluvial terraces T4 enjoyed a relatively stable hydrological environment since 14000 a BP during which soil sequences developed whilst loess continued to accumulate as evidenced by the presence of typical loess-palaeosol sequence. The field survey and laboratory sediment analysis showed that there were some older age (18000-14000 a BP) sheet flow deposits in the PLG profile, but with an overall limited distribution. We estimate the terraces formed before 30,000 a BP according of the OSL date of the sample collected from the bottom of PLG section (Figure 7b).

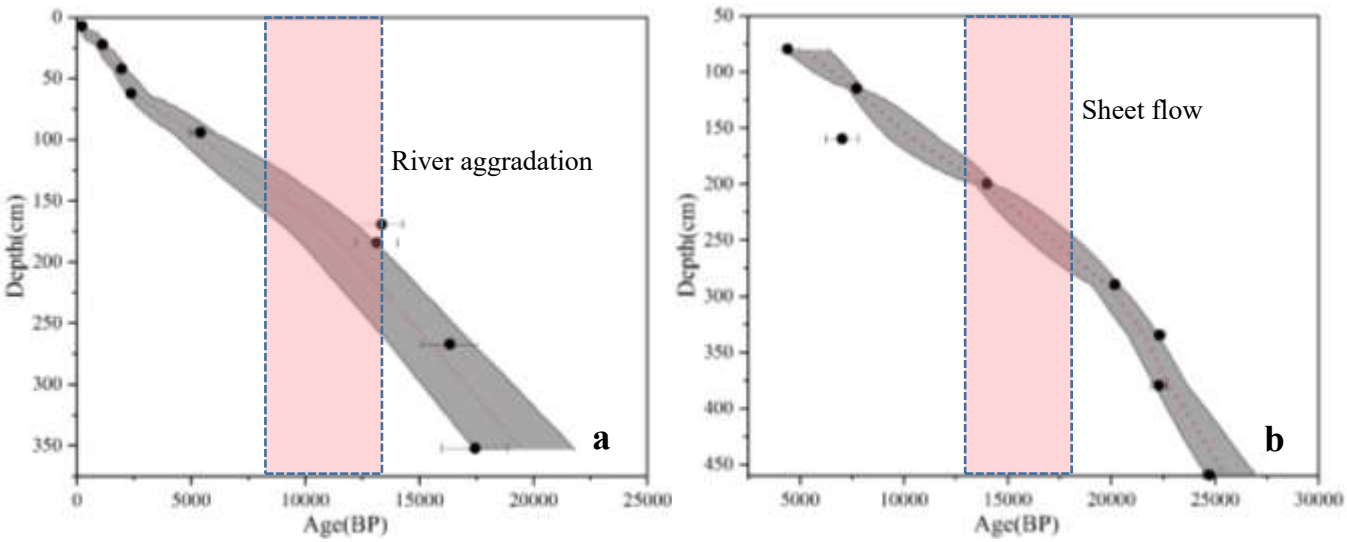


Figure 7. Depth-Age Model. a. The DJ profile shows an episode of river aggradation between 13000-8000 BP (red part); b. The PLG profile shows a local sheet flow 18000-14000 BP (red part);

4.3 Reconstructing late-Pleistocene and Holocene sedimentation histories: particle size and soil micromorphology of the PLG and DJ profiles

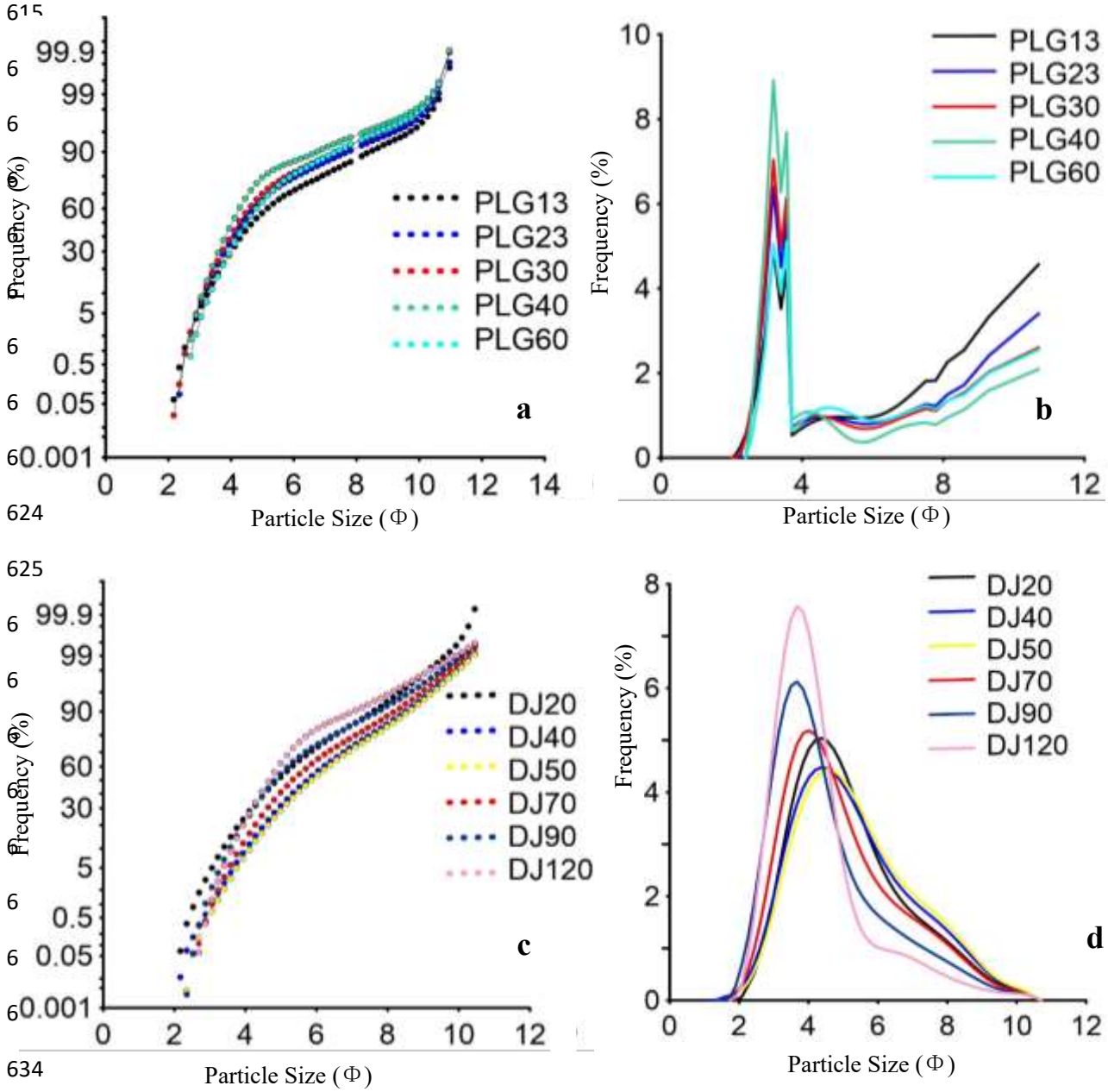
Results of the selected sediment samples from the PLG and DJ profiles that were analyzed for particle size distribution are presented in Figure 8. The frequency cumulative curves of sample no. PLG-60 show that saltation particles smaller than 4φ account for 10%, whilst the suspended load particles larger than 4φ were more than 70%. Other particles fall into the intermediate size range. Overall, such a distribution pattern indicates that the sediments were of typical wind-blown loess being deposited during the late Pleistocene. Micromorpholoigcal features of the soil thin section collected from the same layer (Layer 8; Figure 9) at the site further confirm the poor-sorting and coarse-size nature of the wind-blown sediments that came from a nearby source. The presence of abundant calcitic features in the thin section suggest a relatively dry condition during the time. For the frequency cumulative curves of samples nos. PLG-40, PLG-30, and PLG-23, particles smaller than 4φ account for 70%. The remaining 30% are suspending particles. The distribution of two narrow peaks on their frequency curves points to a good sorting of the sediments under strong hydrodynamic conditions. These results illustrate that layers 5, 6, and 7 in the PLG profile represent

581 a sedimentation environment resembling that of a point bar and floodplain. Soil thin sections from
582 these layers (PLG005, PLG004 and PLG003) reveal similar scenarios of sedimentation and post-
583 depositional processes. The groundmass of thin section no. PLG005 is characterized by rounded-
584 shaped minerals and the significantly reduced calcite in the groundmass, whilst the presence of some
585 thin clay coatings indicates incipient soil formation. The sediments gradually became more poorly
586 sorted from PLG004 to PLG003, but with increased pedofeatures indicative of soil formation. These
587 results suggest that, interestingly, whilst the sedimentation environment on the alluvial settings
588 continued to be volatile, there was increasing disturbance on the surface, as evidenced by the
589 presence of dusty clay coatings, which was probably caused by human or related cultural activities
590 (Figures 9b and 9c). Comparatively speaking, the percentage of particles smaller than 4φ accounted
591 for ca.10% as shown by the frequency cumulative curves of sample no. PLG-13, whilst the
592 frequency curves suggest that the sediments were overall poorly sorted (Figure 8). Furthermore, the
593 significant proportion of clay-sized particles also indicates strong degree of soil formation during
594 the middle Holocene. The latter was accompanied with intensified human activities as evidenced by
595 the micromorphological features of abundant charcoal and clay textural features in thin section no.
596 PLG002 (Figure 9d).

597 Amongst the examined samples from the DJ profile, samples nos. DJ-90 and DJ-120 contained
598 ca.70% of bedload-movement and saltation particles. Given their narrow-peaked distribution, they
599 represent well-sorted lacustrine sediments deposited during the late phase of the late Pleistocene.
600 The light grayish colour of the sediments also suggests post-depositional gleying and redoxmorphic
601 processes. The other four samples (nos. DJ-20, DJ-40, DJ-50 andDJ-70) contained only 10% of
602 saltation particles, in contrast to 90% of suspended load sediments. The sediments are poorly sorted
603 with increasing percentage of coarse-sized particles. The concentration of fine-sized particles in
604 sample no. DJ-50 indicates strong degree of soil formation before chemical weathering became
605 weaker again in the profile as suggested by the decreasing percentage of clay in the sediments
606 (Figure 8).

607 These results are consistent with published studies which confirm that the sediment source for
608 late Pleistocene and Holocene loess in the eastern Songshan region mainly came from the Yellow
609 River floodplain situated to the east of the Mengjin section of the river (Jiang et al, 1997; Yang YM

et al, 2005; Pang et al, 2008). Its size gradually decreased eastwards as wind blowing activities became more distant from the source area. Comparing with other published similar studies in the adjacent areas (Lu et al, 2021; Xu et al, 2013) our results of particle size distribution of samples from the PLG and DJ profiles show that the late Pleistocene and Holocene sediments are dominated by silt-sized particles of loess or reworked loess.



Fgure 8. Particle size distribution for the PLG and DJ profiles. a. Cumulative probability curves of the PLG profile; b. Frequency distribution curves of the PLG profile. c. Cumulative probability curves of the DJ profile; d. Frequency distribution curves of the DJ profile. According to the results, samples no. PLG-23, PLG-30 and PLG-40 should represent fluvial facies, whilst samples no. XD-

90、XD-120 should represent limnetic facies. The others are all loess deposits.

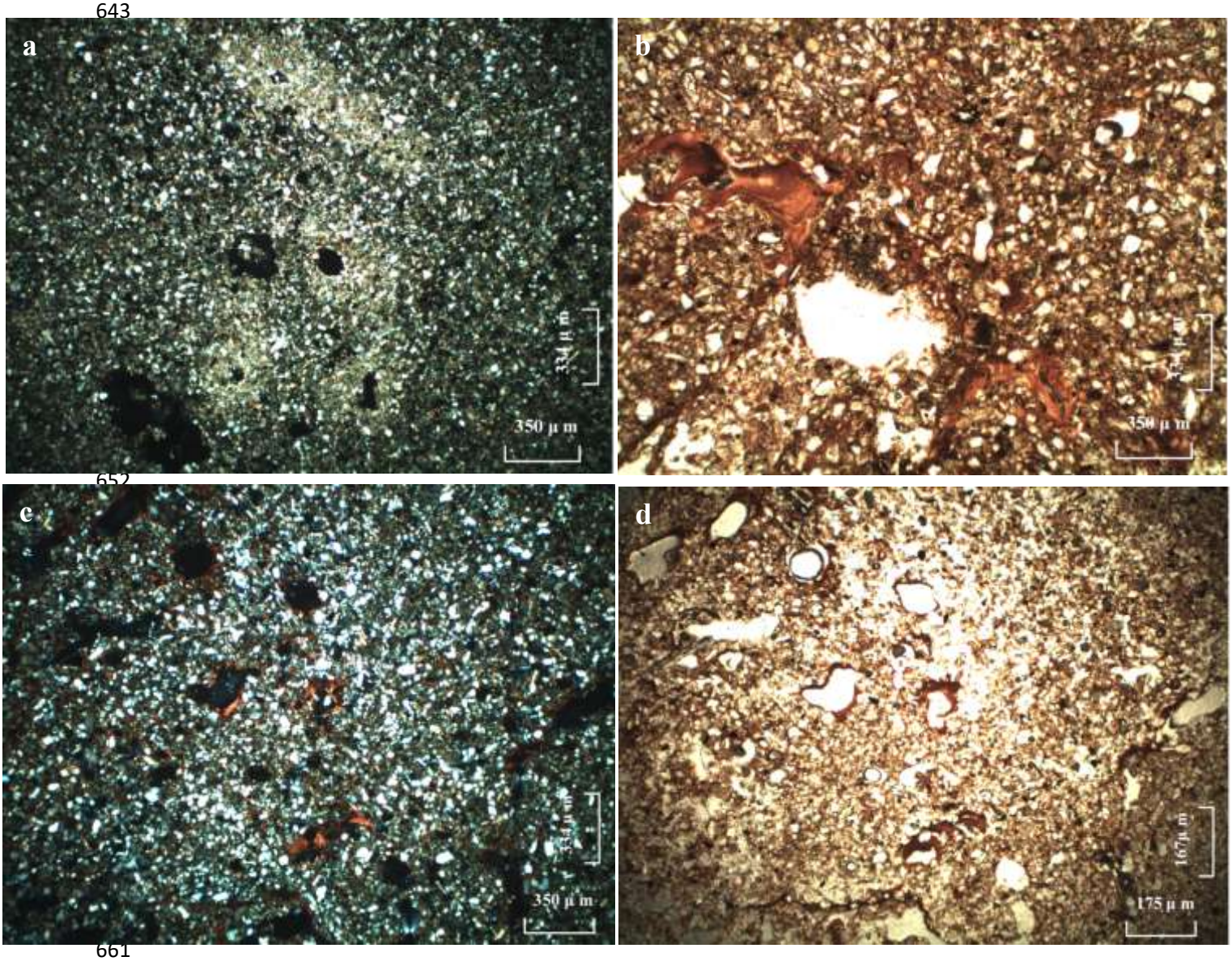


Figure 9 Microphotographs of thin section slides from the PLG profile. a. sample no. PLG006, calctic nodules and coatings and hypo-coatings. Note that well-sorted wind-blown very fine sand-sized sand and silt in the groundmass, containing abundant quartz and micas; b and c. sample no. PLG004, clay coatings with layered structure and modest birefringence, PPL and XPL; d: sample no. PLG002-bottom, clay textural features with layered structure in micro-charcoal and organic rich groundmass. PPL.

5. Discussion

5.1 Evolution of late Pleistocene to Holocene alluvial landscapes

Combining field survey data, chronological data, and results of particle size and micromorphological analyses, we were able to reconstruct evolution of late Pleistocene to Holocene alluvial landscapes in the Shuangji River region. Our data suggest that Tertiary red clay landforms experienced multiple cycles of alluvial aggradation and incision since the early Pleistocene, but most of these alluvial activities were confined within the massive incised valley that was created during an episode of large-scale alluvial incision in the early Pleistocene (Figure 10). This valley was, however, almost completely filled by reworked loess through continuous alluvial aggradation by the middle phase of the late Pleistocene. The accreting river channel means that the river water was closer to the surface of the terraces or tablelands which became prone to be inundated. Before 20000 BP, rivers in the region experienced another episode of alluvial incision, from which alluvial terraces T4 emerged. This incision event was of a smaller scale compared to the early Pleistocene one. Loose sediments blanketed on the incised river valley. By the terminal Pleistocene, a prolonged period of alluvial accretion resumed and the river valleys were once again filled with alluvial sediments, which were distributed widely in the region.

River downcutting began again from around 8000 BP. Narrow and shallow river valleys were created during this small-scale alluvial incision. It also resulted in the formation of alluvial terraces T3, which are most widely preserved today (Figure 10). In the ensuing event of river accretion between 8000-4000 BP, major rivers such as the Shuangji River and their tributaries all experienced siltation, which further shortened the height between the river water and surface of the alluvial terraces T3. Along the edge of the alluvial terraces T3 and T4 some small-sized lakes and wetlands appeared as the regional hydrological condition improved. By around 3500 BP, rivers began to incise again and most lakes and wetlands on the alluvial terraces T3 and T4 gradually disappeared. This large-scale river downcutting also eroded most of the alluvial terraces T2 along the Shuangji, Zhenshui and other major rivers in the region. It was only on tablelands and low hills that parts of the alluvial terraces T2 were preserved. The last stage of Holocene alluvial history witnessed another cycle of alluvial incision-aggradation during the historical times, directly responsible for the formation of modern river terraces T1.

Our research also suggested that the Shuangji River and Zhenshui River formed exceptionally deep incised valleys in 30000-20000 a BP and 10000- 8000 a BP, coinciding with the formation of alluvial terraces T4 and T3, respectively. The heights from the tops of the alluvial terraces T3 or T4 to their corresponding valley bottoms were very large. Although the river accretion narrowed the heights during 8000-4000 a BP, channels of the Shuangji River, Zhenshui River and other major regional rivers were confined within these deep valleys. These rivers never overflowed the tops of alluvial terraces T3 and T4 again. At the same time, alluvial accretion also occurred in some tributary gullies and led to the formation of many small lakes on the terraces. Such changes would have provided an optimal hydrological condition conducive to growth of prehistoric settlements on the terraces, which is discussed below.

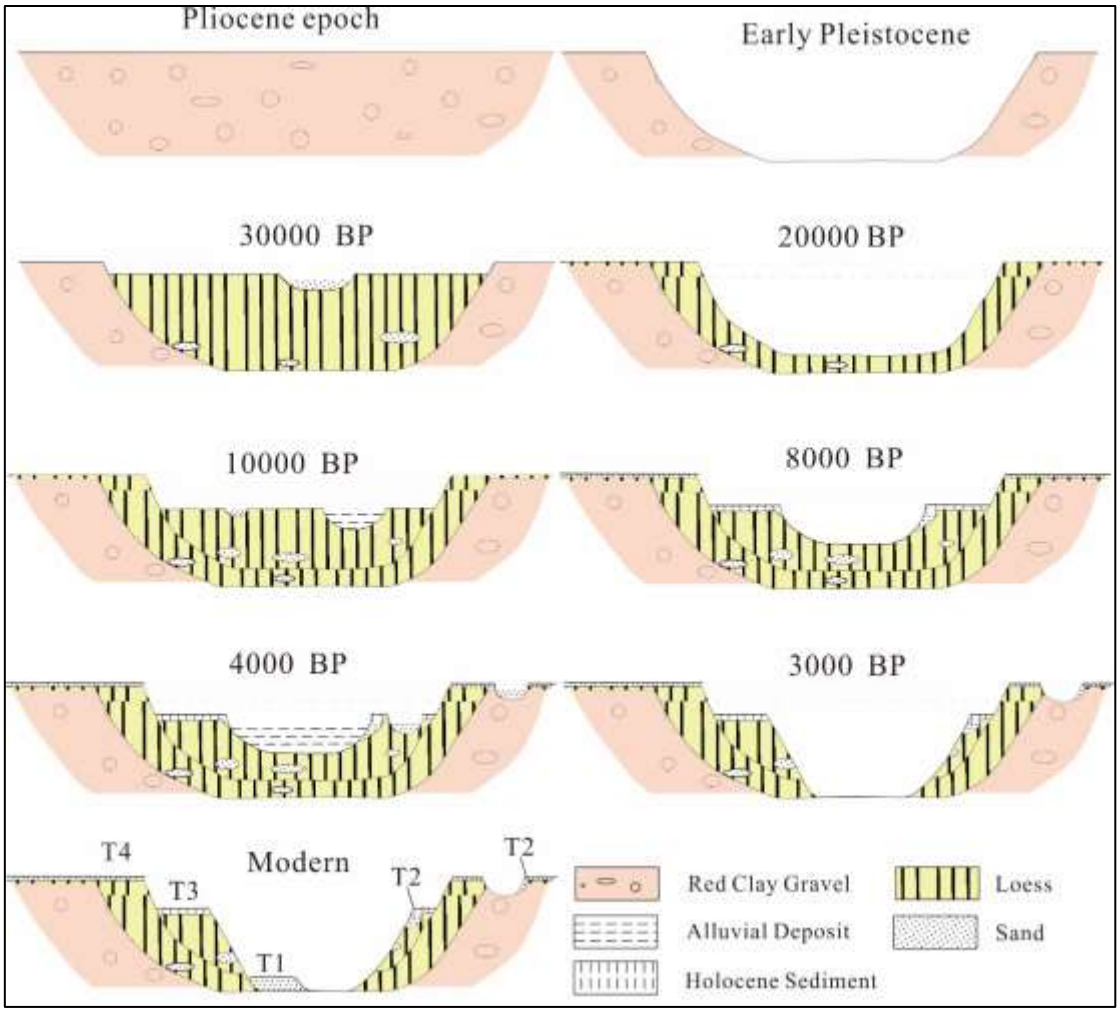


Figure 10. Reconstruction of alluvial geomorphological evolution since the late Pleistocene (**Pliocene epoch:** alluvial fan in the eastern foot of Songshan Mountain; **Early Pleistocene:** Large

deep valley were formed after a mass undercutting erosion; **30000 BP:** The valley was almost filled in after a large scale accretion; **20000 BP:** New valley after a undercutting erosion emerged again; **10000 BP**: small water areas appeared after an accretion; **8000 BP:** shallow valley appeared after a undercutting erosion; **4000 BP**: water areas occurred after an accretion; **3000 BP**: deep valley was formed after a mass undercutting erosion; **Modern:** present valley shape).

There is a correlation between evolution of alluvial landforms and Holocene climate change in Shuangji River Basin. Recent speleothem $\delta^{18}O$ records in central China show weakened summer monsoon events during the Holocene (Cai et al, 2021), including the so-called 8.2ka and 4.2ka events, when the region experienced periods of climate variability. The development process of Holocene alluvial terraces in Shuangji River valley roughly correspond to these climate events, although the exact mechanisms responsible for this process are open to further scientific investigations.

5.2 Impact of alluvial landscapes on prehistoric settlement distributions

The geomorphological changes reconstructed above are closely related to succession and growth of prehistoric settlements in the Shuangji River Basin. Although the evolution of late Pleistocene and Holocene alluvial landscapes is characterized by multiple cycles of alluvial incision and aggradation, these events were of various magnitudes and scales and had different impact on the geomorphological and ecological conditions of the region. The massive-scale early Pleistocene alluvial incision profoundly shaped the geomorphological characteristics of the region. The hills and valleys systems, separated by the remnant Neogene red-clay and boulders, became the geomorphological spaces atop of which late Pleistocene and early Holocene alluvial terraces T4 and T3 developed and evolved. Amongst these cyclic alluvial activities, those middle Holocene river downcutting and aggradation events were of relatively smaller scale. Despite the extended episode of the middle Holocene alluvial accretion, much of the surfaces of alluvial terraces T4 and T3 were never inundated as we did not find traces of sediments that were related to floods on these surfaces, contrary to Xia et al.'s suggestion (2003). However, as aforementioned, there existed many small lakes and wetlands along small river valleys which were separated by loess belts and never

755 conjoined. They were fed by surface runoff flowing through the slopes and other landforms in the
756 valleys and overall did not cause disastrous impact on the surfaces of the alluvial terraces T4 and
757 T3. Such a dual stability of the middle-Holocene geomorphological and hydrological landscapes on
758 the alluvial terraces T4 and T3 was critical to the growth and expansion of prehistoric settlements
759 in the region.

760 Most Neolithic and Bronze-Age settlements were located on the surfaces of the alluvial
761 terraces T3, whilst some were scattered on those of the alluvial terraces T4. Even during the peak
762 of the middle Holocene event of protracted alluvial aggradation, the surfaces of the alluvial terraces
763 T4 remained 20 m higher than the river water, rendering them optimal places for prehistoric
764 occupation. Another beneficial factor was that, whilst such places were high up from river water,
765 there was abundant water in the small valleys and small lakes during the Holocene humid period
766 (also see Chen FH et al, 2015; Li GQ et al, 2020), which provided sufficient water to the daily
767 consumption of the settlements and dryland agriculture. Although t the surfaces of the alluvial
768 terraces T3 were of relatively altitude, they were hardly inundated even during the maximum flood
769 level. This hydrological environment surrounding sites on the alluvial terraces T3 was convenient
770 to not only the expansion of mixed agriculture of millets and rice, but also to the construction of
771 large-scale water management facilities such as moats which were often connected to natural rivers.
772 Examples of the latter include moats at the Xinzhai and Guchengzhai sites. Because of the flat
773 terrains and optimal hydrological condition, the alluvial terraces T3 were occupied by a large
774 number of Neolithic to Bronze-Age settlements. Indeed, such favourable environmental conditions
775 sustained continuous growth and expansion of prehistoric settlements (Lu et al, 2015), culminating
776 with the rise of large-scale central walled towns by the late Longshan and Xinzhai period, including
777 such as the aforementioned Guchengzhai and Xinzhai sites where large-sized palaces were built
778 (SACRCPU and ZICH, 2008; Cai QF and Ma JC, 2002; Zhang XH, 2019). By the Xia-Shang period,
779 the pronounced rise of the Wangjinglou site with an enormous walled enclosures and other urban
780 infrastructures marked the unparalleled importance of this region in the civilizational discourse on
781 the Central Plains (Gu, 2016).

782

783 **5.3 Basin-scale landscape stability, prehistoric cultural developments and the emergence**

of civilization on the Central Plains

Several regions in prehistoric China were homes to many developed cultures, such as the Ganqing region of the Upper Yellow River valley, the Haidai region in the Lower Yellow River valley, the Sichuan Basin of the Upper Yangtze River valley, the Jianghan Plain of the Middle Yangtze River valley, and the Taihu Lake region of the Lower Yangtze River valley as well as the West Liao River valley. Many of these early cultures experienced, however, a sudden decline or collapse or were replaced or succeeded by other cultures during the late Holocene, coinciding with some of the Holocene climate events (Su, 2009; Liu L, 1998; IACASS, 2010). Of the most notable and well-studied example was the Lower Yangtze River, or more specifically, the Taihu Plain surrounding the Yangtze Delta region. After the early venture into the low-lying coastal land by the Kuahuqiao people (8000-7500 BP), the region saw an occupational hiatus until the Majiabang culture period (7000-5900 BP). The continuous development of regional cultures, evidenced by the dramatic increase of settlements and other factors such as intensified rice agriculture, culminated during the Liangzhu culture period (5300-4300 BP) with the rise of an enormous city site with developed urban and hydraulic infrastructures and magnificent material culture (Zhuang and Du, 2021). The rise and prosperity of the prehistoric cultures in the region were closely intertwined with environmental change, especially Holocene sea-level fluctuations and associated geomorphological development. As demonstrated by many studies, the emergence of land and improved hydrological regimes in the region fostered the continuous development of the Majiabang, Songze (5900-5300 BP) and Liangzhu culture (Wang S et al, 2020; Jin et al, 2019). The decline of the Liangzhu culture has now also been popularly linked to the late-Holocene climate and environmental change on the Yangtze Delta region. The widespread presence of the yellowish flood deposits, directly superimposing the Liangzhu layer, is considered as one of the most direct evidence that region-wide floods contributed to the demise of the Liangzhu Civilization (He et al, 2019), along with other reasons. Compared to such ebbs and flows of prehistoric cultures in the Yangtze Delta region, the Central Plains of the Middle Yellow River experienced a remarkable continuum of development of prehistoric cultures. Such a developmental trajectory is considered to be a representative of the unification and continuity of the Chinese civilization. Whilst many factors acted in concert to shape such a unique characteristic of prehistoric culture development on the Central Plains, the prolonged

stability of the middle to late Holocene landscape also played a key role in this process.

Situated between the Loess Plateau and the North China Plain, the geomorphological characteristics of the Central Plains are shaped by both loess accumulation and alluvial processes. Loess tablelands are one of the most prevalent landforms in the region. Such geomorphological units are often situated on high-altitude place with a flat and broad surface which continues to receive wind-blown loess throughout the late Pleistocene to Holocene. Specifically, according to the geomorphological history of the Shuangji River, the loess tablelands can be divided into several categories according to their altitudes, sediments and chronologies. These include low-rising river terraces, high-altitude river terraces and tablelands, all suitable for prehistoric occupation. Prehistoric communities living on these places adapted to different hydrological and geomorphological conditions. The low rising river terraces were particularly attractive places to the prehistoric communities as they provided ample water resources whilst also keeping away from floods. Agriculture flourished on these low-rising fertile lands and gradually advanced forms of water management facilities were also built. These would have been an important precondition for the steady and continuous cultural developments of the Central Plains region, and for its eventual rise as a one of the most typical cultural entities of the Chinese civilization.

Despite being a relatively small-sized river basin, the Shuangji River valley and its diverse landforms experienced almost uniform and synchronous geomorphological changes during the Holocene, especially during the middle to late Holocene. Such a synchronicity and stability of Holocene alluvial landscapes are related to several geological and environmental factors. First, the massive-scale early Pleistocene river downcutting shaped the backbone of the region's Quaternary environment and as we have demonstrated above, most geomorphological processes were confined within the space of the Pleistocene river valley. Second, the tempo and scale of alluvial aggradation and incision are also inherently related to the properties of loess which continues to accumulate during the Holocene and is easy to be reworked through alluvial processes. Coupled with the fact that loess is well known for its fertility to agricultural production and the stable hydrological condition on the loess landscapes, the Shuangji River sustained continuous cultural developments on the Central Plains and the unique human-environment interaction in the basin also profoundly defined the developmental trajectories of the Chinese Civilization. In the dramatic cultural changes

and environmental vagaries during the late Holocene, the landscape stability in the Shuangji River basin became an even more advantageous factor in fostering the emergence of Chinese civilization on the Central Plains whilst cultures in other contemporary regions declined.

6. Conclusion

Evolution of alluvial geomorphology during the Holocene in the Shuangji River Basin of the Central Plains is reconstructed by multi-scalar evidence derived from our field surveys and laboratory analyses of the sediment and dating samples. Our results show that the Neogene alluvial fan was incised into a wide valley by the river during the early Pleistocene. This wide valley constituted the geomorphological space that reframed regional alluvial processes. About 20, 000 BP and 10,000-8,000 BP, regional rivers started to incise the loess landform again and created the alluvial terraces T4 and T3, respectively. These alluvial terraces maintained an overall remarkable stability, withstanding subsequence geomorphological processes, and became the main arena of successive prehistoric to Bronze-Age human occupation. Since then, these alluvial terraces were, to a large extent, free from the impact of large-scale floods even during the large-scale alluvial siltation during 8,000-3,000 BP. Amongst many other factors, the stability of the Holocene landscape, especially those locations such as alluvial terraces and loess tablelands with optimal hydrological and soil conditions was one of the most fundamental factors that contributed to the steady settlement and population growth and intensifying agricultural production. These laid an important foundation for the prehistoric cultural development in Shuangji River Basin and contributed to the unparalleled cultural continuity on the Central Plains.

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