

Prehistoric water control works in the Loess Plateau: an ancient ditch system at Shuanghuaishu, China

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Abstract

The emergence, on the Loess Plateau of Central China, of settlements enclosed by circular ditches has engendered lively debate about the function of these (often extensive) ditch systems. Here, the authors report on a suite of new dates and sedimentological analyses from the late Yangshao (5300–4800 BP) triple-ditch system at the Shuanghuaishu site, Henan Province. Exploitation of natural topographic variations, and evidence for ditch maintenance and varied water flows, suggests a key function in hydrological management, while temporal overlap in the use of these three ditches reveals the large scale of this endeavour to adapt to the pressures of the natural environment.

Introduction

The Loess Plateau in China is distinguished by its deep valleys, extensive wind-blown sediments and complex landforms (You & Yang [Reference You and Yang2013](#)). Despite the broken and elevated terrain, a multitude of prehistoric settlements have successfully occupied loess hilltops (He [Reference He2017](#); Sun *et al.* [Reference Sun2017](#); Lu *et al.* [Reference Lu2019](#)). The elevation of these hilltop sites and of the adjacent valleys frequently differ by more than 50m (Lu *et al.* [Reference Lu2022](#)). This disparity posed a substantial challenge for the hilltop residents in accessing water and aquatic resources from the river below, and thus the water utilisation methods of ancient hilltop civilisations have attracted scholarly attention (e.g. Renfrew & Bahn [Reference Renfrew and Bahn2007](#); Xia [Reference Xia2012](#); Kielhofer *et al.* [Reference Kielhofer, Fox, Ye and Yang2021](#); Lu *et al.* [Reference Lu2021](#)).

Archaeological surveys and excavations have demonstrated that prehistoric artificial ditches were widespread in the loess region of China (Pei [Reference Pei2004](#); Gu [Reference Gu2016](#); HICRA & SAPU [2018](#); Zhuang *et al.* [Reference Zhuang, Zhang and Xu2023](#)). In many cases, these ditches encircled settlements, their emergence not only signifying the process of early urbanisation—characterised by population concentration and the mobilisation of large-scale, collective labour—but also reflecting human efforts to adapt and modify the natural environment. Circular ditch settlements are therefore central to our understanding of early social complexity and human–environment interactions. On the Loess Plateau, these structures can be traced back to the Yangshao period (7000–5000 BP) (SIA [2011](#)), and exhibit single, double or triple concentric trenches of various sizes and shapes (Gu [Reference Gu2016](#)). The functions of the ditches have been debated from various perspectives—as settlement boundaries, military defence and barriers against wild animals (Qian [Reference Qian2002](#); Xu [Reference Xu2017](#))—yet these features are inherently linked to drainage systems, water supply networks and water storage facilities (Zhuang *et al.* [Reference Zhuang, Zhang, Fang and Wang2017](#)).

The assessment of water management within the ditches primarily relies on archaeological inferences. Indeed, a wealth of information can be extracted from ditch deposits for functional analysis (Boyd & McGrath [Reference Boyd and McGrath2001](#); Penny *et al.* [Reference Penny, Pottier, Fletcher, Barbetti, Fink and Hua2006](#); Fletcher *et al.* [Reference Fletcher2008](#); Brown & Pluskowski [Reference Brown and Pluskowski2011](#); Scott & O'Reilly [Reference Scott and O'Reilly2015](#); O'Reilly *et al.* [Reference O'Reilly, Evans and Shewan2017](#)). Through systematic dating and palaeoenvironmental analysis of stratified sediments, we can elucidate the features, environment and sedimentation of the ditches, enabling a better understanding of prehistoric human–water interactions (Benes *et al.* [Reference Beneš, Kaštovský, Kočárová, Kočár, Kubečková, Pokorný and Starec2002](#); Peña-Monné *et al.* [Reference Peña-Monné2014](#); Kittela *et al.* [Reference Kittel2018](#)).

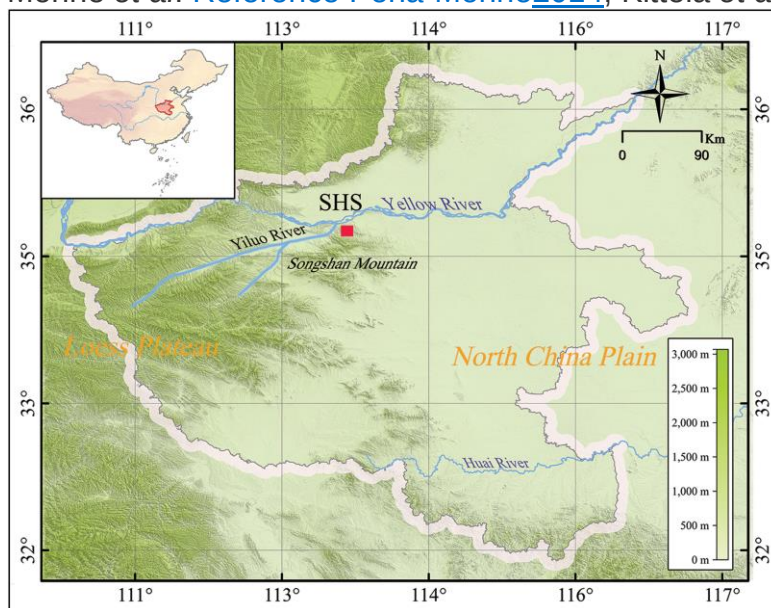


Figure 1. Location of the Shuanghuaishu (SHS) site (figure by Peng Lu).

Shuanghuaishu and its ditch system

The Shuanghuaishu (SHS) site in Central China lies on the eastern edge of the Loess Plateau ([Figure 1](#)). This region, situated between the Songshan Mountain and the Yellow River, displays diverse and complex landforms, including loess hills, river terraces and floodplains. Today, the region has a continental monsoon climate, with an average annual temperature of 14°C and annual precipitation of 600mm, and the zonal vegetation predominantly consists of deciduous broad-leaved forests (Shi [Reference Shi1983](#)). The site is situated on a loess hill, with an altitude of 190m ([Figure 2](#)). Quaternary loess, which can reach a thickness of tens of metres, is mainly deposited in the region. The confluence of the Yellow River and its tributary, the Yiluo River, occurs on the north-western side of the site. Many gullies are extensively developed in the region, deeply incising and fragmenting the site.

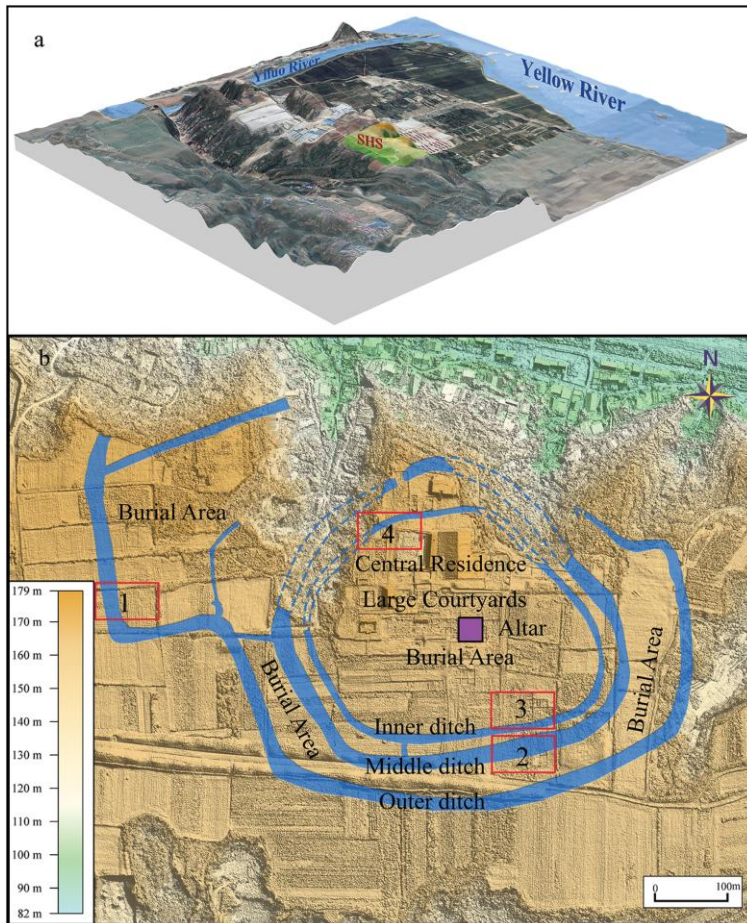


Figure 2. Topography of the SHS site: a) 3D surface model of the region around the site; b) the distribution of human remains at the SHS site, redrawn after ZICRA (2021). Sampling locations on the ditch system are marked by red rectangles (1 – outer ditch section; 2 – middle ditch section; 3 – south-east sections of the inner ditch; 4 – north-west sections of the inner ditch) (figure by Peng Lu & Panpan Chen).

The archaeological remains at the site encompass the Peiligang (9000–7000 BP), Yangshao (7000–5000 BP) and Longshan (5000–4000 BP) cultures. However, the predominant material belongs to the late Yangshao culture (5500–5000 BP). During this period, the SHS site emerged as a regional central settlement (Zhao [Reference Zhao2020](#); Li [Reference Li2021](#); Qi [Reference Qi2021](#)), boasting an expansive area of 117ha (ZICRA [2021](#)). It contained numerous notable features, including a substantial rammed-earth foundation site, large courtyards and houses, a considerable number of tombs and an extensive ditch system (see online supplementary material (OSM) Figure S2).

The ditch system consists of three nearly concentric circular trenches. The inner ditch is 1km long with a depth of 4–6m and an upper width of 6–15m. The middle ditch runs for 1.5km with a depth of 10m and an upper width of 23–32m. Due to ongoing erosion by the Yellow and Yiluo rivers (Chen *et al.* [Reference Chen2022](#)), the full course of the outer ditch is unknown ([Figure 2](#)); the residual length is 1.6km with a depth of 8–11m and an upper width of 13–18m. The central residence and three large courtyards are situated within the inner ditch, while several burial areas are found between the middle and outer ditches. The sequential construction and/or the concomitant use of the three ditches at the SHS site is a subject of contention (Gu [Reference Gu2023](#)). The results of our chronometric and sedimentological

analyses provide an opportunity to reassess the construction, utilisation and abandonment history of the three ditches.

Depositional sequence

Four stratigraphic sections were selected from the three ditches for comprehensive sedimentological analysis. Two sections are situated in the inner ditch (to the north-west and the south-east), one is in the middle ditch and another is in the outer ditch ([Figure 2](#)).

The co-ordinates of the south-east section within the inner ditch are 34°48'50.22"N, 113°05'18.45"E, at an altitude of 180m from the top. The section is 6m deep and is divided into 39 layers based on soil texture, colour and inclusions ([Figure 3](#)). Layers 1–12 consist of fine yellow-brown sand and contain a few brown clay layers. Some layers exhibit clear signs of multiple artificial dredging processes. Layers 13–29 display distinct evidence of alluvial deposition, but the bedding is highly disordered because of a prehistoric earthquake event (Hu *et al.* [Reference Hu2023](#)). Layers 30–39 consist predominantly of fine sand intermixed with a limited amount of silt, exhibiting minimal presence of cultural artefacts. At the bottom, some natural loess has been exposed.

The co-ordinates of the north-west section within the inner ditch are 34°48'58.45"N, 113°05'09.93"E, at an altitude of 182m. The upper part of the section (1.1m depth) is predominantly characterised by the cultural sedimentation above the ditch. In addition to 0.2m of cultivated topsoil, all other accumulations in this part of the section consist of cultural layers, primarily composed of fine brown sands containing pottery pieces and burnt red soil particles. The lower part of the section consists of ditch sediment, which can be divided into 10 layers. Layers 1–2 consist of bedding soil for a house foundation, which is 0.3m thick and predominantly composed of silt with some pottery pieces. Layers 3–8 consist of deposits following the abandonment of the ditch, with a thickness of 1.45m. They are also composed of silt, along with some pottery pieces and particles of burnt red soil. Layers 9–10 consist of 0.3m of alluvial sediments, which are composed of pure fine sand with level bedding ([Figure 4](#)).

The co-ordinates of the middle ditch section are 34°48'49.53"N, 113°05'18.54"E, at an altitude of 180m. The upper opening of the ditch (G14) attains a maximum width of 32m in this section ([Figure 5](#)). The section has a depth of approximately 10m and is divided into 35 layers. Layers 1–16 predominantly consist of fine yellowish-brown sand and contain a high proportion of cultural material. Layers 17–34 consist of yellow-brown silt and fine sand with distinct horizontal stratification, containing less cultural material. At the bottom of the section, layer 35 exhibits characteristics typical of natural loess. Towards the top of the southern part of the section, there is another smaller trench (G13) with an opening width of 16m and a depth of 1.5m. The sediments in this trench are also predominantly composed of yellowish-brown clayey fine sand, interspersed with cultural material.

The co-ordinates of the outer ditch section are 34°48'53.11"N, 113°05'01.63"E, at an altitude of 181m. The section is approximately 10m deep and is divided into 32 layers ([Figure 6](#)). Layers 1–5 are predominantly composed of a dark-brown silty clay, which contains a limited number of Longshan cultural relics. The formation of these layers is attributed to hydrological processes, suggesting an origin as natural alluvial

sediments following ditch abandonment. Layers 6–22 are dominated by fine brown sands, which contain a multitude of late Yangshao pottery sherds and burnt red soil. Layers 23–30 consist of conspicuous dark grey clays with a few cultural relics, representing natural fluvial and alluvial sediments. No cultural material was found in layers 31 and 32, which are closely associated with the late Pleistocene aeolian loess commonly distributed in the region.

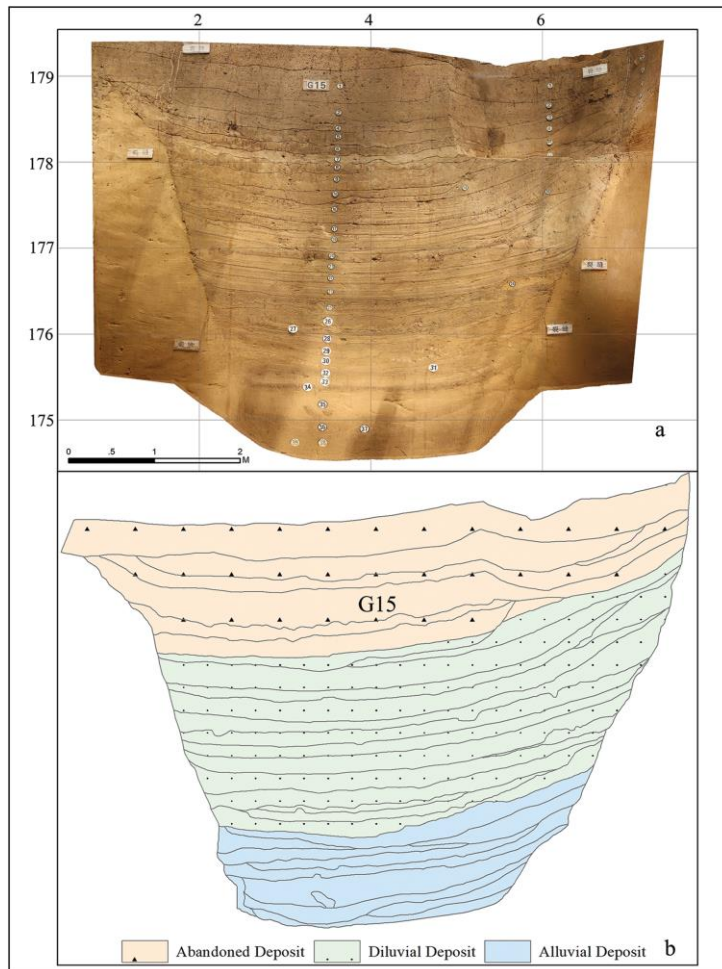


Figure 3. South-east section of the inner ditch: a) orthoimage; b) stratigraphy (figure by Zhen Wang & Peng Lu).

Chronology

To establish a reliable chronological framework for the ditch system, we collected a substantial number of sequential samples for radiocarbon dating from the middle ditch section and the two inner ditch sections. In addition, sediment layers in the outer ditch section were dated using optically stimulated luminescence (OSL) due to the limited availability of radiocarbon dating materials. The overlying strata of the north-west inner ditch section were also dated using OSL. Radiocarbon dating was conducted at Peking University and Beta Analytic, and OSL dating at the Institute of Geographical Sciences, Henan Academy of Sciences (see OSM for full details).

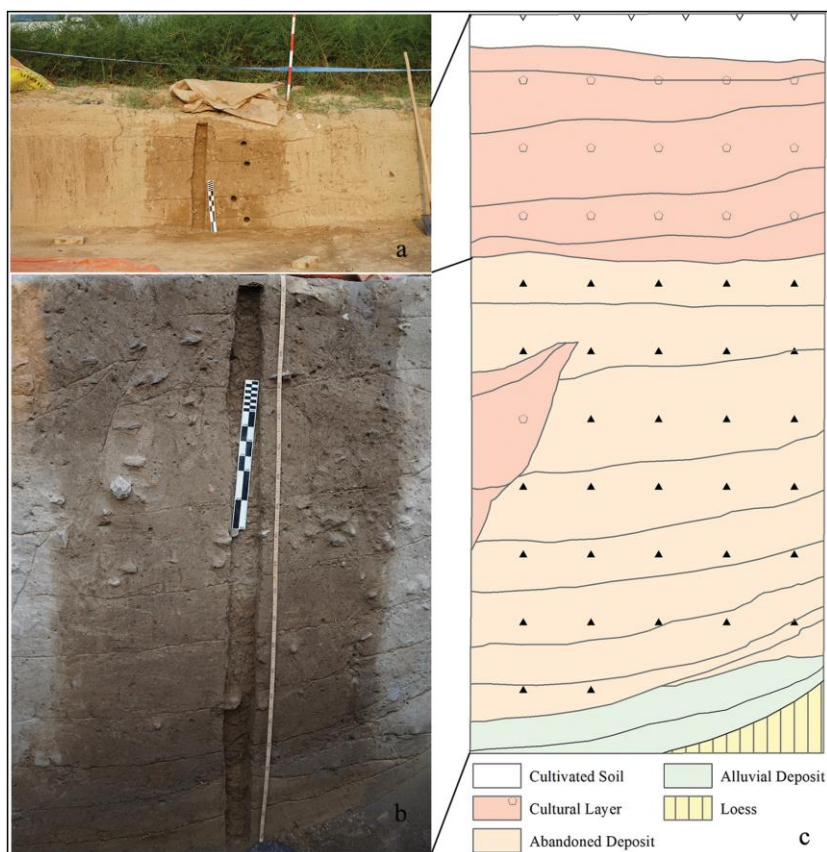


Figure 4. North-west section of the inner ditch: a) upper part of section, showing sampling; b) lower part of section; c) stratigraphy (figure by Zhen Wang & Peng Lu).

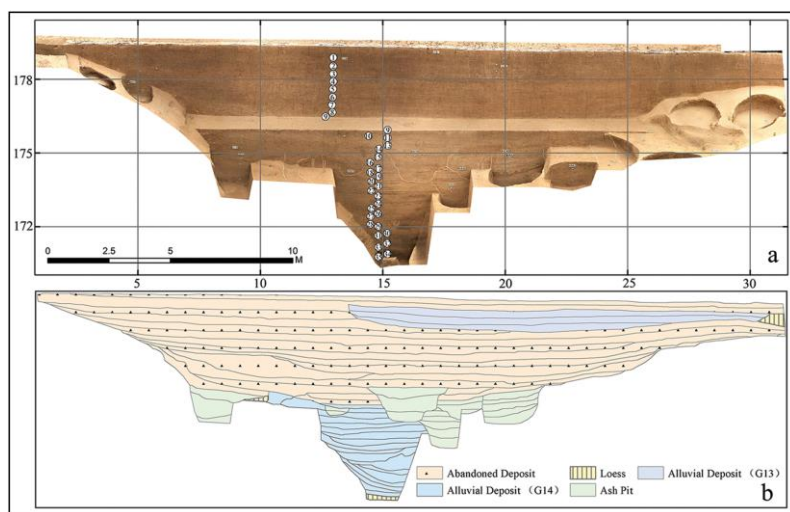


Figure 5. Middle ditch section: a) orthoimage; b) stratigraphy (figure by Zhen Wang & Peng Lu).

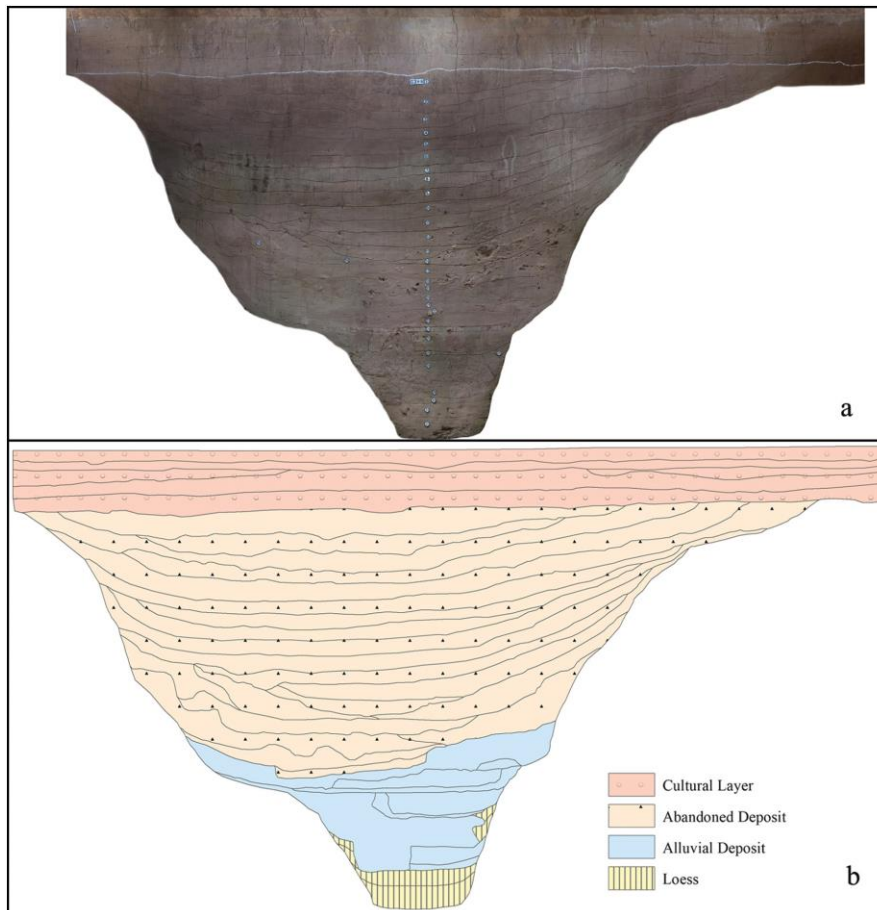


Figure 6. Outer ditch section: a) orthoimage; b) stratigraphy (figure by Jiqin Zhang & Peng Lu).

A total of 42 radiocarbon and 11 OSL dates were obtained from the inner, middle and outer ditches (Tables S1 & S2). There are 19 radiocarbon dates from the south-east section of the inner ditch, and most fall within the range of 5300–4800 cal BP. The ages of layers 1–12, representing the sedimentation of the ditch following its abandonment, are predominantly concentrated between 5100 and 4800 cal BP. Meanwhile, the age range of layers 13–29, representing ditch utilisation, is predominantly concentrated within the period of 5300–5100 cal BP. Bayesian modelling of the data indicates that the ages of ditch utilisation, abandonment and when it was filled in are estimated at 5125 ± 66 BP, 5017 ± 25 BP and 4971 ± 51 BP, respectively (Figure 7a).

Four OSL dates were obtained from the sedimentary strata in the upper part of the north-west section of the inner ditch. The data suggest that the ditch was filled around 4910 ± 250 BP, followed by the deposition of subsequent layers during 5000–3500 BP. A total of 12 radiocarbon dates were obtained from the ditch sediment in the lower part of the section (see above). Dates were obtained from strata on both the east and west walls of the ditch and these exhibit a high degree of consistency. The age distribution predominantly falls within the range of 5300–4800 cal BP, which is comparable to the age range of the south-east section of the inner ditch. The age of layer 9, representing the utilisation of the ditch, is estimated to be around 5300–5000 cal BP. Meanwhile, the ages of layers 2–8, which represent the periods of ditch abandonment, are predominantly concentrated within the range of 5000–4800 cal

BP. Bayesian modelling places the estimated ages for ditch utilisation, abandonment and end at 5154 ± 179 BP, 4957 ± 49 BP and 4752 ± 53 BP, respectively (Figure 7b). A total of 11 radiocarbon dates were obtained from the sediment section of the middle ditch. The bottom alluvial deposit (G14-L27, 28, 29), which represents the early utilisation of the ditch, dates to a period ranging from 5300–5000 cal BP. The middle sediment of G14-L19 and G14-L21, representing the late utilisation of the ditch, dates within the time frame of 5300–4900 cal BP. The ages of two post-abandonment sediments (G14-L5 & G14-L6) are determined to be within the range of 3500–3800 cal BP, while dates from the upper sediment (G14-L2, G13-L1 & G13-L2) suggest that the middle ditch was filled relatively recently, approximately 2500 cal BP. Bayesian modelling suggests that the periods for ditch utilisation, abandonment and end are 5257 ± 130 cal BP, 5044 ± 178 cal BP and 2011 ± 448 cal BP, respectively (Figure 7c). Seven OSL dates are available from the sediment section of the outer ditch. Three samples were collected from the natural loess of the ditch bank, indicating ages older than 10 000 BP. The other four samples are from abandonment sediment and exhibit a sequential order in dating. Application of a Bacon age-depth model demonstrates a consistent deposition rate and stable deposition process, which also implies reliable dating results. The sediment at the bottom of the sequence was deposited about 5000 BP, indicating that the ditches must have been in use slightly earlier. Dating of the sediment at the top of the sequence indicates that the final filling of this ditch also occurred relatively late, around 2500 BP.

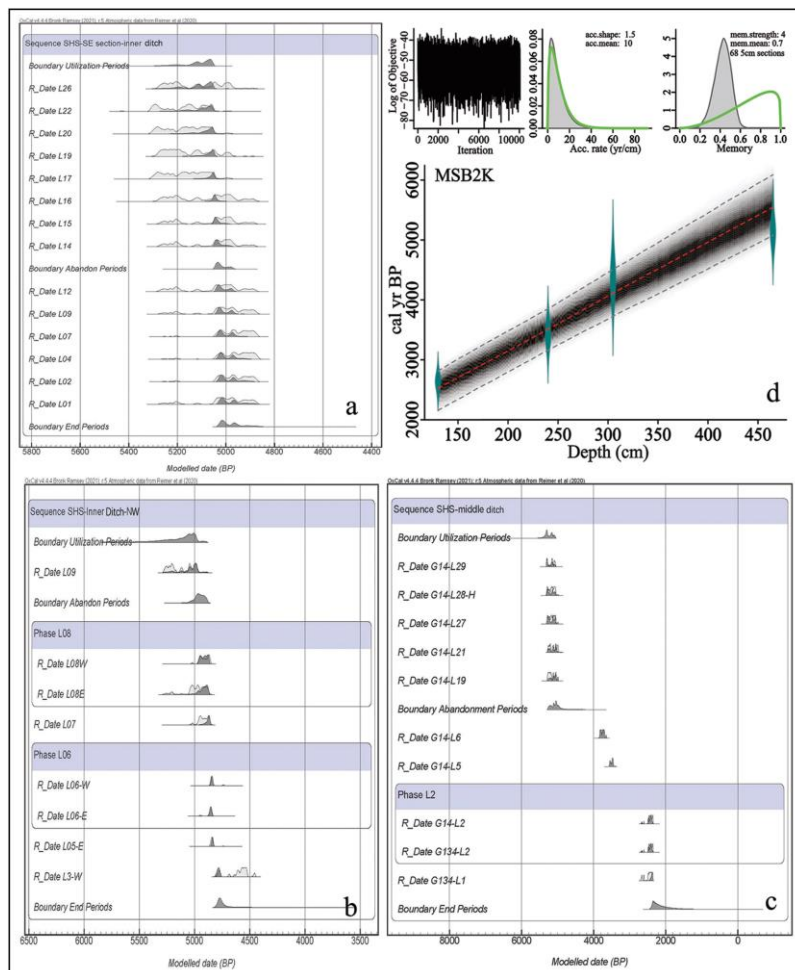


Figure 7. Chronology: Bayesian models for radiocarbon dates from the south-east (a) and north-west (b) sections of the inner ditch and for the middle ditch section (c); Bacon age-depth model for the outer ditch section (d) (figure by Panpan Chen).

Particle size analysis

Due to its location in a typical loess region, the sediments within the SHS ditches exhibit a clear association with loess deposition. Particle size analysis reveals that the sediment components filling the ditches are very similar to natural loess, which is predominantly composed of silt. This indicates that the original deposits within the ditches are also composed of natural loess. However, due to the influence of secondary transportation and human activities, the characteristics of the infilling sediments differ substantially from those of natural loess: the sorting of sediments is poorer and the relative composition also differs (Figure 8).

End-member modelling reveals that the sediments within the ditches can be classified into three distinct components: fine clay (C_1 , $<1\mu\text{m}$), fine silt (C_2 , $5\text{--}15\mu\text{m}$) and coarse silt (C_3 , $30\text{--}40\mu\text{m}$) (Liu *et al.* Reference Liu, Liu and Sun2021). The C_3 component, which constitutes the predominant composition of the original loess, exhibits the highest proportion among the ditch sediments. The C_2 component shows a wider particle-size range and poorer sorting compared with the original deposit, indicating that low-energy surface runoff played a significant role in the formation of this sediment. Although the C_1 component is relatively minor in the ditch sediments, its exceptionally fine particle size and excellent sorting suggest a profound influence from a quiescent aquatic environment (Figure 9).

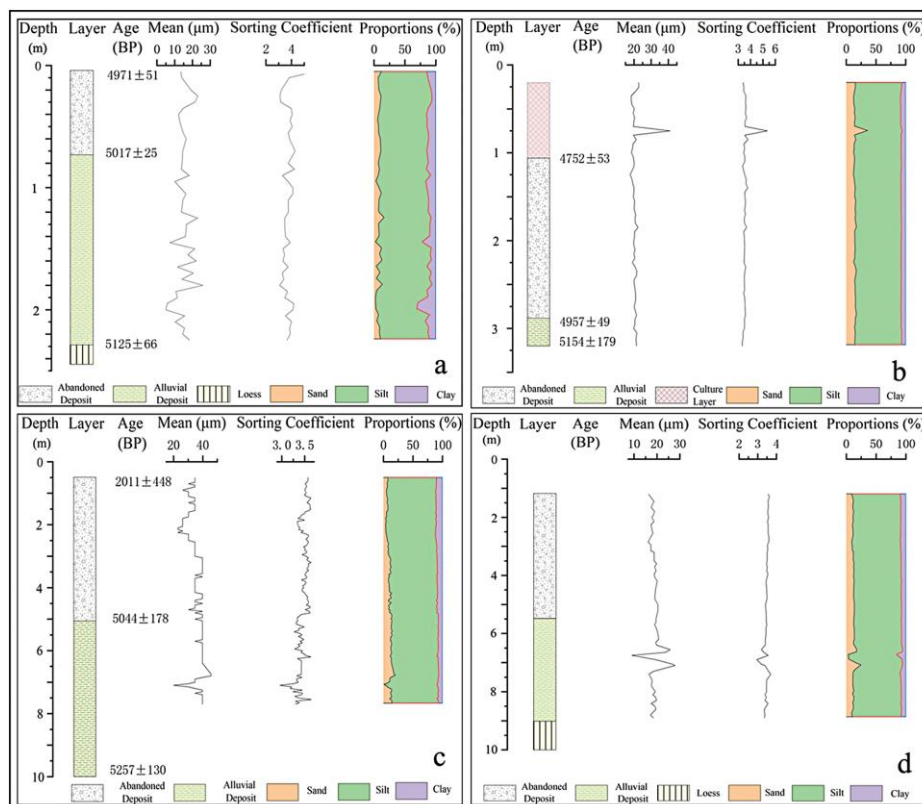


Figure 8. Particle size analysis for ditch sediments: a) south-east section of inner ditch; b) north-west section of inner ditch; c) middle ditch section; d) outer ditch section (figure by Peng Lu).

The south-east section of the inner ditch exhibits three distinct grain size characteristics, indicative of varying sedimentary environments. The upper post-abandonment deposits, such as sample SHS NB-8 (Figure 9), exhibit similarities to the primary deposit, which predominantly consists of natural loess. However, the increased presence of the C₁ component suggests that the low-lying terrain within the ditch facilitated water accumulation, highlighting the crucial role of aquatic environments in upper deposit formation. In the lower section, the sample SHS NB-14 represents a rare occurrence of fluvial-like facies sediments with stronger hydrodynamics, as evidenced by the presence of three distinct peaks in the cumulative curve of particle size. The reduced particle size of the C₂ component implies improved sorting of sediments, attributed to a stronger transporting force. The SHS NB-20 sample exemplifies the predominant accumulation characteristics in the lower section during periods of ditch utilisation. The increased proportions of the C₁ and C₂ components indicate the persistent influence of the aquatic environment during the deposition process.

Due to the higher terrain and shallow ditch depth, the north-west section of the inner ditch has preserved extremely thin layers of silted strata that signify the utilisation of this ditch. The depositional feature observed in this area, distinct from the south-east section, not only signifies the dynamic nature of water flow within the ditch during periods of utilisation but also the influences on particle-size distribution patterns of sediments found at this specific location. The components representing the cultural layer (sample SHS-75), abandonment deposits (sample SHS-118) and ditch utilisation (sample SHS-124) exhibit similar characteristics, indicating a comparable sedimentation process and hydrodynamic conditions during these periods. The slightly increased C₂ component observed in sample SHS-124 may be attributed to stronger water flow and transport energy during the operational periods of the ditch.

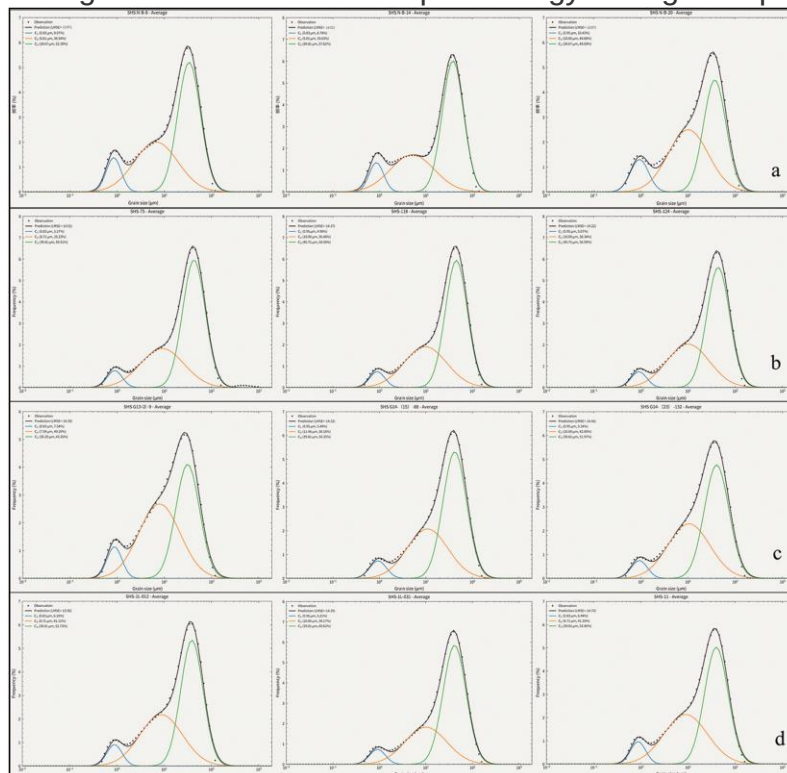


Figure 9. End-member modelling of particle size: a) south-east section of inner ditch; b) north-west section of inner ditch; c) middle ditch section; d) outer ditch section (figure by Peng Lu).

The results of particle-size analysis in the middle ditch section indicate that these sediments have undergone the most intense hydrological processes. The sample SHS G13-(2)-9 represents deposits within the newly formed ditch; these resulted from water erosion following the abandonment of the ditch as a result of the low regional topography. The presence of higher C_1 and C_2 components in these deposits suggests the occurrence of more intense hydrodynamic conditions during sedimentation. The sample SHS G14-(15)-88, representing post-abandonment sediments, exhibits a higher C_2 component, indicating the contribution of surface runoff to these deposits. The increased C_2 component in sample SHS G14-(23)-132 suggests that an aqueous environment played a pivotal role during the deposition process.

The profile of the outer ditch is also predominantly composed of post-abandonment sediments. The two representative samples (SHS-1L-012 & SHS-1L-031) exhibit a composition similar to that of the original deposits. The higher C_2 component within sample SHS-1L-012 suggests the substantial role of the water environment during certain periods. The C_2 component in the SHS-W-11 sample is higher and the particle size smaller, suggesting an increased influence of aquatic conditions during periods of ditch utilisation.

Soil micromorphology

Soil micromorphology was analysed in two sediment sections from the inner ditch to elucidate the depositional environment and processes in detail. The results show that the main matrix of silted strata in the bottom of the north-west section, which represents sedimentation during ditch utilisation, is a typical secondary loess. Additionally, a substantial proportion of these deposits comprise minerals that exhibit poor sorting, larger grain sizes and limited roundness. Some heterogeneous soil aggregates and charcoal, which underwent distinct processes of erosion, short-distance transportation and re-accumulation in the ditch, are also found in some samples from the bottom part of the ditch fills ([Figure 10](#)). Overall, the thin sections reveal a distinct sedimentary regime primarily characterised by coarser grains, as well as generally large-sized and poorly sorted inclusions, such as the aforementioned heterogeneous aggregates, which are transported and deposited by strong hydrodynamic forces. Meanwhile, the increased presence of pedofeatures, including iron-manganese nodules, clay coatings and calcite coatings, suggests repeated processes of flooding, drainage and soil formation within this part of the ditch.

The middle to upper parts of the inner-ditch deposits represent the gradual silting and abandonment processes of the north-west section. Micromorphological evidence shows multiple sedimentation and post-depositional processes occurring simultaneously, including alluviation, slope deposition and anthropogenic action, as well as brief episodes of soil development during sedimentation intervals. These thin sections typically contain heterogeneous soil aggregates, calcite concretions and relatively large-sized, poorly sorted minerals with mostly angular shapes. The proportion of these materials remains relatively stable, with minimal variation observed between thin sections. Some thin sections show significant slope deposits, such as larger calcium carbonate concretions and minerals, which must have been colluvial deposits from the bank of the ditch eventually deposited into the infill. The sediments contain relatively more abundant charcoal and organic matter in comparison to the underlying layers. Although most examined thin sections contain a

greater amount of pedofeatures, the clay coatings are generally of finer texture. Additionally, there are more calcite coatings, indicating a drier sedimentary environment with only episodic wet events.

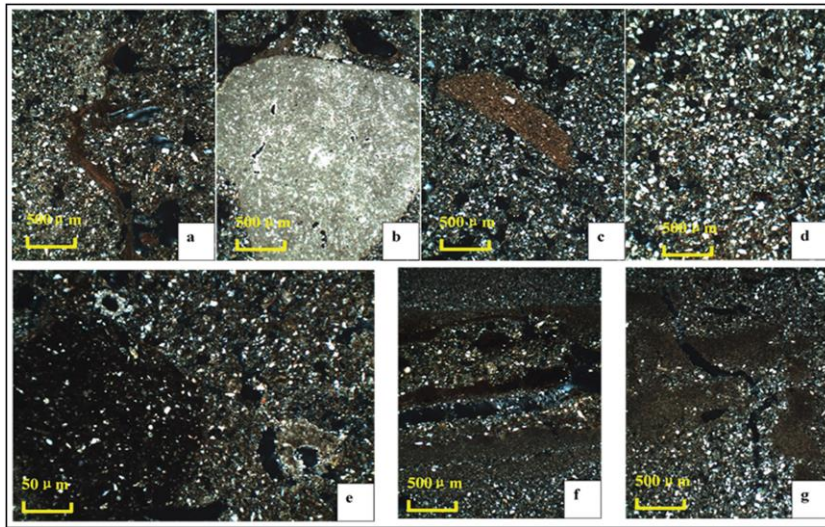


Figure 10. Soil micromorphology of ditch sediments: a) dusty clay coatings, some superimposing on small calcite nodules, from sample SHS11; b) large, pebble-sized calcium carbonate (calcrete) nodules, deposited through colluvial processes, from sample SHS9; c) heterogeneous aggregates from sample SHS11; d) fine sediment laminae alternating with coarse-sized sediments, also deposited horizontally, from sample SHSNH3; e) calcite coatings, also note the large, darkish, organic-rich aggregate, from sample SHS4; f) abundant sediment crusts, mainly consisting of fine-sized particles from sample SHSNH2; g) disrupted sediment crusts from sample SHSNH4. All images were taken under cross-polarised light (figure by Yijie Zhuang).

The sedimentary process observed in the south-east section of the inner ditch is dominated by alternating layers of coarse and fine grains, indicating more intense hydrodynamic conditions compared with those in the north-west section. The thin sections exhibit a stronger vertical variation in the proportion of coarse-grained minerals characterised by low roundness and moderate sorting. A large quantity of coarse-grained minerals is deposited horizontally at the bottom of the section. In the immediately overlying unit, there is a substantial decrease in the abundance of coarse-grained minerals, accompanied by an increase in heterogeneous soil aggregates, pointing to constantly fluctuating hydrological conditions and material sources. The soil micromorphology also finds that the deposition process is not continuous within the ditch. The deposits from both the ditch utilisation and abandonment periods show a higher abundance of sediment crusts, as well as calcite coatings and clay coatings formed during sedimentation hiatuses. The prevalence of sediment crusts suggests arid conditions in the ditch. The presence of horizontal iron-manganese nodules in the middle layers also indicates a transition from wet to completely arid conditions, resulting in a shift from reducing to oxidising environments within the ditch.

Discussion

The life cycle of the prehistoric ditch systems at the SHS site

Our suite of radiocarbon dates constrains the periods of utilisation of both inner and middle ditches to 5300–5000 cal BP. This suggests that both the inner and outer ditches were likely used concurrently for extended periods, although their initial construction dates potentially differ. OSL dating of the outer ditch indicates that its construction occurred during a similar period to that of the inner and middle ditches, suggesting a period of overlap when all three trenches were used. This not only ties in with the deliberate planning of the three ditches—defining specific functional boundaries within the settlement—but also highlights the prominent position of the SHS site as a regional central settlement. The abandonment of the three ditches also occurred almost simultaneously around 5000–4800 cal BP. From then on, these ditches were no longer maintained and were quickly filled with large amounts of sediment through both artificial and natural processes. The inner ditch was the first to be filled in at 4800–4700 cal BP, owing to its smaller scale and shallower depth. The middle and outer ditches were ultimately filled in much later (c. 3000–2000 BP). The life cycle of the prehistoric ditch systems at the SHS site can therefore be divided into several stages. Around 5300 BP, the inner, middle and outer ditches were successively constructed. By approximately 5100 BP, the triple-ditch system was complete and functioning. Then, at around 5000–4900 BP, all three ditches began to be abandoned; by 4800–4700 BP, the inner ditch was filled in and by 3000–2000 BP the middle and outer ditches were also filled in.

The water control function of the SHS ditches

The potential function of the ditches has provoked much discussion (Guo *et al.* [Reference Guo, Li, Yang and Hou2016](#); Zhao *et al.* [Reference Zhao, Yang and Zhang2023](#); Chen & Qin [Reference Chen and Qin2024](#)). While the ditch system may have served various functions, our analysis indicates that water management was likely an important objective in its construction.

Collectively, the results of particle size analysis and soil micromorphology indicate that the SHS ditch system experienced both prolonged hydrological action and pronounced changes in hydrodynamic forces through time, encompassing both quiescent water and high-energy flows (Figures S3–S6). Evidence for substantial surface runoff in the composition of ditch sediments further suggests that the ditch system served a distinct function in efficiently collecting natural precipitation. These findings strongly indicate the core role of the ditch system in facilitating the collection, transportation and storage of water resources at the SHS site.

Furthermore, these water resources may have been actively managed. The ditches were intentionally constructed with higher elevations in the north-west and lower elevations in the south-east, taking into consideration the regional topography, to ensure optimal water flow. Several silt removal operations were also identified during the period of ditch utilisation, specifically at layers 12, 24, 31 and 37 in the south-west section of the inner ditch. Together, these suggest that managing water was a crucial function of the ditch system, and that the system was actively maintained.

Human adaptation to the environment

The construction and utilisation of the SHS ditch system represent human adaptation of and to the natural environment, on a monumental scale. Situated at the top of a loess tableland, the SHS site is approximately 80m above the current water level of the Yellow River. Although regional rivers underwent substantial siltation during 8000–3000 BP, there remained a considerable disparity in elevation between the platform top and the Yellow River, which posed fundamental challenges for the harnessing of water resources by inhabitants of the settlement. In this context, the effective management of water resources through a ditch system would confer a substantial advantage for communities occupying high-elevation platforms for an extended period. Arguably, groups could only begin to exploit flat and flood-resistant platform tops for habitation and agriculture once this means of resolution for water collection and storage predicaments was devised (Zhong & Zhao [Reference Zhong and Zhao2023](#)).

While warm and humid conditions prevailed on the Loess Plateau during the Holocene, the climate was characterised by pronounced fluctuations, meaning that there were substantial seasonal variations in precipitation, despite an overall abundance of rainfall (Marcott *et al.* [Reference Marcott, Shakun, Clark and Mix2013](#); Chen *et al.* [Reference Chen2015](#); Cai *et al.* [Reference Cai2021](#)). The ditch system at the SHS site could effectively regulate these seasonal variations. During the rainy season, the robust drainage capacity of the ditch system would swiftly drain water away from the settlement, thereby mitigating the risk of inundation during intense precipitation events. Conversely, the ditches could also store water, alleviating pressure on the water reserves within settlements during periods of drought.

Conclusion

Around 5300–5000 BP, the monumental-scale artificial infrastructure of a triple-ditch system was constructed at the SHS settlement on the Loess Plateau. Although the original construction dates for each may differ, the inner, middle and outer ditches were concurrently used during specific periods. This prehistoric ditch system probably served a variety of functions, but water management was probably a principal function. By purposefully collecting, transporting and storing natural precipitation, the ditch system effectively managed water resources on the hilltop, 80m above the valley floor. The construction of the ditch system facilitated long-term habitation on the elevated plateau, mitigating seasonal abundance and scarcity of precipitation during the Holocene period. Thus the ditch system, at the SHS site and at others across the Loess Plateau, served as a crucial mechanism through which the ingenuity of ancient communities allowed them to navigate the intricacies of the natural environment.

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