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Analysis of sedimentary-geomorphologic variation and the living environment of hominids at the Shuidonggou Paleolithic site

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Shuidonggou is one of the most important Upper Paleolithic sites in North China. Due to the presence of rich human remains, animal fossils, abundant sporopollen and unique geological sequence, it is the type site for Late Pleistocene to Holocene human occupation and environmental change in the Ningxia-Inner Mongolia region. Many scholars suggest that the site should be named the "Shuidonggou Formation" of Late Pleistocene in North China. Dating results indicate that ancient human activities at the site took place 30—24 ka (Marine Isotope Stage [MIS] 3). The climate at that time was warmer and moister than present day, and adequate precipitation led to the formation of water pack depressions where broad-leaf trees and sparse forest vegetations, as well as herbivorous animals flourished, making the area suitable for early human hunting, gathering and survival. The Neolithic human occupation happened 9—5 ka at the site, while similar environmental conditions with MIS3 occurred. The absence of human activity record in the region during the Last Glacial Maximum (MIS2) suggests that the environment was too harsh for humans to live there.

Shuidonggou, Late Paleolithic, Paleoenvironment, Shuidonggou Formation

Shuidonggou is one of the earliest Late Paleolithic sites in China. A large number of stone artifacts, ornaments and hearths , as well as many vertebrate fossils were excavated from the site[1−6] (Figure 1). Due to the importance of the site for the study of lithic technology, Paleolithic cultural sequence and human living environment, excavations and research have been conducted by scholars from China and overseas continuously since its discovery. In particular, many multi-disciplinary research projects have been carried out jointly by the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences and the Institute of Archeology of Ningxia Hui Autonomous Region. Recently, many new traces and remains as well as cultural layers were discovered[6], further suggesting that Shuidonggou is important to understanding the migration, dispersion, and cultural exchange of ancient humans in Northeast Asia during the Late Pleistocene[7].

At initial glance, the section of the site looks simple, but the sediments were actually formed by complicated geological processes and environmental changes. For a long time, the study of sedimentary, geomorphology and environment of the site and adjacent areas were largely neglected, hindering our understanding of early human adaptive strategies and behaviors. However, renewed fieldworks and laboratory analyses, in addition to more detailed studies of the sediments micromorphology, have facilitated more detailed understanding of the formation of the Shuidonggou and the surrounding environment.

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Figure 1 Stone artifacts excavated from Shuidonggou Locality 1 (a) and Locality 2 (b).

1 Geomorphological studies of Shuidonggou

1.1 Characteristics of sedimentary geomorphology

Shuidonggou, occupying the west margin of the Ordos block, is located 30 km east of Lingwu County, Ningxia Hui Autonomous Region, and 10 km west of the Yellow River. The site is scattered along the banks of the small Biangou River (part of the river branch is named Shuidonggou) which runs southeast to northwest to the Yellow River. There is one lower hill called Dongshan (1500—1400 MASL) which runs north to south in the eastern part of Lingwu county. The hill stretches to the north and the elevation is reduced to 1305 MASL. Yet the hill was named Heishan which lies 3 km east of Shuidonggou.

One thrust named Heishan-Fengzuizi developed from south to north on the east slope of Dongshan[8], with the topography bent to the west along the fault and sloped to the east respectively. The disintegrated-eroded plain formed by theYellow River during the Pliocene was staggered by the fault movement to form the Lingwu Dongshan. Ancient Yellow River pebbles comprise the highest 5th Yellow River terrace (T5) in the area that is preserved along the slopes. There are many ridges that run into the Yellow River, the upper surface covered by gravel beds. The composition of the gravel is complicated, unconfirmed with the lower Oligocene sediments. The elevation of the hill drops from 1400 MASL at the summit to 1250 MASL in the west, approximately 300—150 m above the present day Yellow River level. Four Yellow River terraces IV—I (T4—T1) were developed from T5 towards the west. The base of T4 is the Qingshuiying Formation, which dates to the Oligocene. Its surface is covered by a pebble layer, 5m in thickness, which contains many psephicity agate gravels, 100—60 m above the Yellow River level. This pebble layer belongs to the Pliocene sediments. The terraces T3—T1 are 30 m, 20 m, and 10—15 m above the Yellow River level. The T3 and T2 are composed of sand-gravel layers and sandy lens. The lower part of T1 is sand-gravel sediments, the upper part is gray-yellow saturated silt loam.

Five terraces are also developed around the east slope of Lingwu Dongshan. The sediments of the terraces are similar with the west slope of Dongshan, and the elevation of T5—T3 are 130 m—150 m, 130 m, and 110 m above the Yellow River level. The surfaces of these terraces on the east slope are even. These terraces are mainly distributed in the piedmont belt south and west to Shuidonggou (Figure 2). Two stage terraces named T1 and T2 are developed along the banks of Shuidonggou, with formation controlled by the same tectonic movements as the Yellow River terraces T1 and T2. The sediments of the terraces along the Shuidonggou banks are formed by a small branch of the Yellow River named the Shuidonggou River.

The Maowusu desert, situated in the northern part of the Ordos block, becomes retracted when extended west to Shuidonggou. The Great Wall was built along the southern margin of the desert during the Ming Dynasty. The Biangou River, which originates from Qingshuiying, runs northwest along the southern edge of the Great Wall. The Biangou becomes the Shuidonggou River after crossing under the Great Wall and eventually running into the Yellow River (see Figure 2).

Shuidonggou Locality 1 was discovered in a cutbank of the right bank of Biangou, its profile just 15 m in thickness. The deposit includes continuous strata from

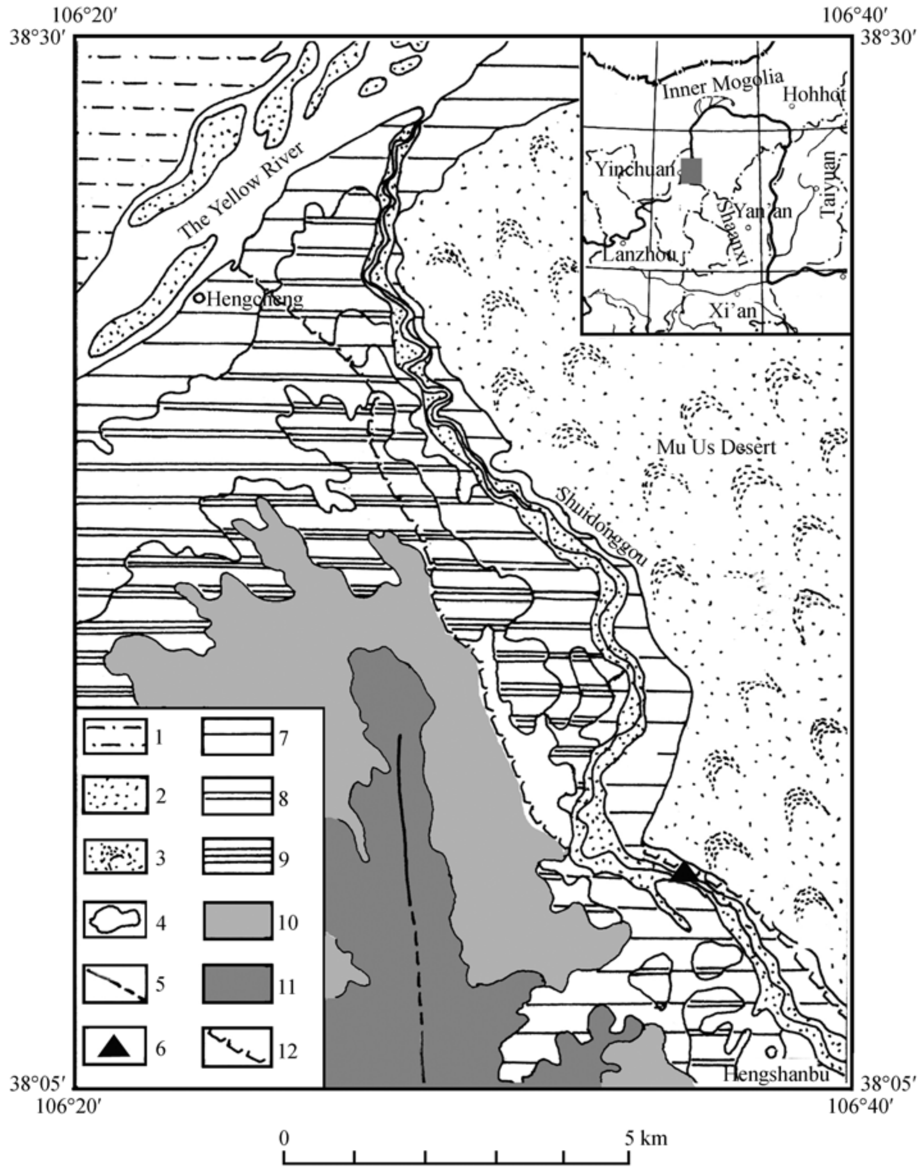

Figure 2 The geomorphologic sketch map of Shuidonggou, Ningxia. 1, Alluvial plain; 2, sand bar and valley flat, 3, desert; 4, the margin of the terrace; 5, fault; 6, Paleolithic site; 7, the first terrace; 8, the second terrace; 9, the third terrace; 10, the fourth terrace; 11, the fifth terrace; 12, the Great Wall.

the Oligocene to the Holocene. Ten stratigraphic layers were identified in the profile (Figure 3(a)):

Holocene

⑩ Gray-yellow silt and silted loam, bearing level bedding, loose. 2—3 m in thickness.

~~~~~~ erosional surface Ⅳ ~~~~~~

⑨ Gray-green and gray-white silt and sandy loam, bearing level bedding and snail shells, loose. 1.5 m in thickness.

⑧ Gray sandy loam and loam, bearing gray-black charcoal strip, level bedding and plant debris and snail shell fossils. 1—2 m of the maximum thickness.

⑦ Light yellow silt and bottom gravel bed. The separation of silt is good, bearing level bedding, loose. The bottom is thin gravel bed or gravel lens. The thickness of the layer is 2m. Polished stone axes and millstones were discovered in this layer, called the "Upper Cultural Layer".

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Pleistocene

⑥ Gray-yellow loess-like fine sand, loose, bearing level bedding and vertical joint. The layer looks like loess but the granularity is thicker than the loess. Paleolithic stone artifacts and mammalian fossils such as *Coelodonta antiquitatis*, *Equus przewalskyi* fossils were discovered in this layer. The level was named "Shuidonggou Layer" or the "Lower Cultural Layer". The thickness of the layer exceeds 7—8 m, and the summit of the layer is the surface of terrace T1.

⑤ Gray-green clay and loam. Bearing level bedding, ferrugi-

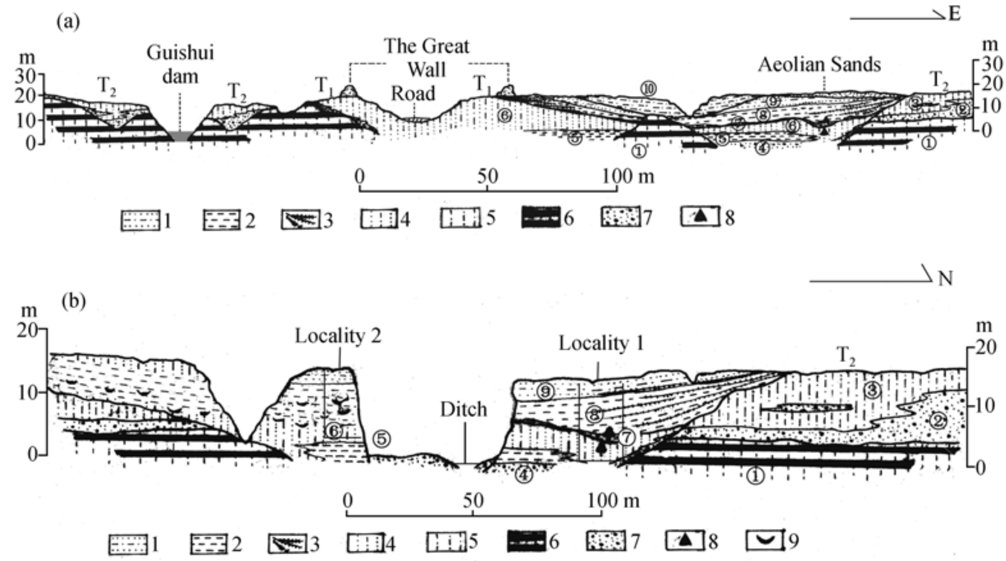

Figure 3 (a) Quaternary geological and geomorphologic profile at Shuidonggou Locality 1. (b) Quaternary geological profile from Locality1 to Locality 2 at Shuidonggou. 1, Sandy loam; 2, loam; 3, charcoal belt; 4, silt; 5, loess-like soil; 6, red loam; 7, sand and gravel; 8, Paleolithic site; 9, hearth.

nous rust spot and bone fossil fragments. The thickness is 1 m.

④ Gravel layer, filled with red sandy loam, partially exposed, visible thickness is less than 1 m.

~~~~~~~~ erosion surface II ~~~~~~~~~

③ Gray-yellow sandy loam and gravel layer. The level bedding and vertical joint are developed in the saturated silt loam. Compact structure, harder, imbedded with gravel lens. The thickness of the layer is 8—9 m. The summit of the layer is the surface of terrace T2.

② Gravel layer. The composition is mainly red sandstone and limestone with poor separation. The thickness of the layer is nearly 1 m.

~~~~~~~~ erosional surface I ~~~~~~~~

Oligocene

① Brown-red loam, bearing level bedding. The loam is hard when dried and split to fragments. The layer formed the base of terrace T2 around the site, and the summit of the layer is an erosional surface. The emerging thickness is nearly 5—7 m.

Shuidonggou Locality 2 is situated in the southern side to Locality 1. The distance between the two localities is a bout 200 m, the profile of Locality 2 outcrops Layers 5 and 6, with 15 m in thickness. Layers 1 and 2 are emerged at the bottom in Locality 2 towards the east[7] (Figure 3(b)).

Our understanding of the structure, sedimentary facies and age of the profile has changed over time. Initially, P. Teilhard de Chardin assigned the layer ① of brown-red loam to the PengDi epoch[9], which corresponds to the Baode red loam. In 1956, Yang ZhongJian (C.C. Young) et al. associated some complete vertebrate fossils with the Oligocene (originally Qingshuiying Bed[10], now Qingshuiying Formation). Our understanding of the profile has also changed. P. Teilhard de Chardin originally placed the ②-③ layers and ④-⑥ layers in one terrace stage with the same age. However, in 1991, an erosional surface was identified between ②-③ layers and ④-⑥ layers by Sun JianZhong et al.[11], thus distinguishing different terrace stages. Our recent field surveys support the observations made by Sun JianZhong and others. We confirmed that the ②-③ layers belong to sediments of terrace T2, and we found clear evidence supporting the existence of terrace T2 in north of the Great Wall. The ④-⑥ layers belong to the sediments of terrace T1. Layer ⑦ to top of the sediments are placed broadly in the Holocene. However, an erosional surface was also discovered by Sun JianZhong and others between Layer ⑨ and Layer ⑩.

Lastly, the sediment from layer ③ to the top of the profile was referred to as "loess" by previous researchers. However, the sediment facies is actually more complicated than originally proposed. We determined that Layer ② and Layer ③ belong to an alluvial-diluvial face of a sand-gravel layer and sandy loam embedded with gravel lens, Layer ④ to a riverbed face gravel layer, Layer ⑤ to sediments from a small lake, Layer ⑥ is a valley flat face of sandy loam with loess character, and Layers ⑦-⑩ belong to a saucer lake logged sediments in the depression formed by the formation of terrace respectively. The erosional surface is not incised across the sediments of T1; it was not formed by retrogressive erosion. The erosional surface among the sediments and T1 as well as Layers ⑨ and ⑩ were formed by climate changes.

1.2 The age of the strata

Since 1984, various chronometric methods have been used to date the Shuidonggou deposits[7,11−13] (Table 1).

The materials used in dating of Locality 1 by Li XingGuo and others were provided by Zhou and Liu[13]. The two dating results in the excavation report published by the Ningxia Museum indicate a Late Pleistocene age[14], which probably belong to the same data that Li XingGuo published (PV-331and PV-317), with slight variation due to correcting. It should be pointed out that the dating results of PV—331 and PV-317 differ greatly. Researchers generally consider the young age for PV-331 (16760±210 aBP) to be a result of contamination of organic carbon. Most researchers adopt the old date of 25450±800 aBP. The oldest dates of 38000—34000 aBP derived from the U-series method published by Chen Tiemei differs greatly with the data published by Li Xingguo. These old dates need further validation. The dating results of the Neolithic deposits are generally accepted by most researchers. Among the dates published by Sun JianZhong and others, the upper cultural layer (5940—8190 aBP) is the same as that by Li Xingguo and others[11].

The dating results of the second cultural layer of Locality 2 published by Gao Xing and others were made on burned charcoal from the fire pit and ostrich egg shells. The dating were done by two separate laboratories and produced very similar results. The age between the lower cultural layer of Locality 1 and the second cultural layer of Locality 2 is 29000—24000 aBP after comparing with the results of Li Xingguo and Chen Tiemei and others studies[7]. It should be noted that the excavation of Locality 2 was carried out more recently, which resulted in the identification of several cultural layers because of the finer classification and control of the strata. The cultural remains are plentiful in the second cultural layer, with many materials suitable for chronometric dating present. The excavation of Locality 1 was done before modern excavation techniques were employed, thus, the subdivision of strata is not precise compared to the excavation of Locality 2. The different Paleolithic beds of Locality 1 were grouped together. Therefore, it is difficult to determine the relationship between Locality 1 and Locality 2 at the moment.

Table 1 Dating results of Shuidonggou

Sample number	Material	Locality and layer	Dating results (aBP)	Methods	Source
PV—330	bone	Loc.1 layer ④ (upper cultural layer)	5900±70	^{14}C	Li Xingguo et al.[13]
PV—316	spiral shell	Loc.1upper cultural layer	8520±150	^{14}C	Li Xingguo et al.[13]
PV—331	Cervids bone	upper part of Loc.1 layer⑧	16760±210	^{14}C	Li Xingguo et al.[13]
PV—317	carbonate concretion	Loc.1 layer ⑥ (lower cultural layer)	25450±800	^{14}C	Li Xingguo et al.[13]
82042	*Equus* teeth	Loc.1 layer ⑥ (lower cultural layer)	38000±2000	U-series	Chen Tiemei et al.[12]
82043	*Equus* teeth	Loc.1 layer ⑥ (lower cultural layer)	34000±2000	U-series	Chen Tiemei et al.[12]
S25	sludge	Loc.1 layer ⑧ (upper cultural layer)	5940±100	^{14}C	Sun Jianzhong et al.[11]
S31	ashes bed	Loc.1 layer ⑧ (upper cultural layer)	7436±101	^{14}C	Sun Jianzhong et al.[11]
S37	spiral shell diatom bed	Loc.1 layer ⑧ (upper cultural layer)	8190±120	^{14}C	Sun Jianzhong et al.[11]
	animal fossil	Loc.1 lower cultural layer	17250±210	^{14}C	Ningxia Museum[14]
	carbonate concretion	Loc.1 lower cultural layer	26230±800	^{14}C	Ningxia Museum[14]
hearth 1	charcoal	Loc.2 second cultural layer	26350±190	^{14}C	Gao Xing et al[7]☆
hearth 2	charcoal	Loc.2 second cultural layer	25670±140	^{14}C	Gao Xing et al[7]☆
hearth 3	ostrich egg shell	Loc.2 second cultural layer	26930±120	^{14}C	Gao Xing et al[7]☆
hearth 4	charcoal	Loc.2 second cultural layer	26830±200	^{14}C	Gao Xing et al[7]☆
hearth 5	charcoal	Loc.2 second cultural layer	25650±160	^{14}C	Gao Xing et al[7]☆
hearth 6	charcoal	Loc.2 second cultural layer	26310±170	^{14}C	Gao Xing et al[7]☆
hearth 7	charcoal	Loc.2 second cultural layer	29520±230	^{14}C	Gao Xing et al[7]☆
hearth 10A	charcoal	Loc.2 second cultural layer	23790±180	^{14}C	Gao Xing et al[7]☆
Beta207935	ostrich eggshell	Loc.2 second cultural layer	28420±160	^{14}C	Gao Xing * ☆
Beta207936	charcoal	Loc.2 second cultural layer	28330±170	^{14}C	Gao Xing * ☆

* Unpublished data. ☆ using AMS^{14}C dating methodology.

Judging from the above discussion, it can be inferred that hunter-gatherer activities at Shuidonggou occurred between 29000－24000 aBP, which is equivalent MIS3[14]. The Neolithic occupation at Locality 1 (the upper cultural layer) took place between 5900—8520 aBP.

1.3 The geomorphological history of the Shuidonggou region

During the Quaternary several terraces were formed by the intermittent uplift of crust and the erosion of the Yellow River and its branches in the Shuidonggou region. By the Late Pliocene, the Heishan-Fengzuizi thrust fault became active which resulted in the emerging of Lingwu Dongshan and the terraces sloping to the Yellow River west of Dongshan. During MIS5-MIS4, the alluvial-diluvial plain was broadly developed, probably due to increasing precipitation. Right before the advent of MIS3 the crust uplifted, which resulted in the undercutting of the river and the alluvial-diluvial plain to become terrace T2. During MIS3 due to a moister and milder climate, as well as an increase in precipitation, some basins were formed in different parts of the river course, resulting in the formation of gray-green loam of layer ⑤. In the meantime, the thick river sediments were developing because of stable tectonic movement, resulted in the formation of the small relief alluvial-diluvial plain.

After the postglacial stage (8000—5000 aBP), because the climate was appropriate and precipitation increased, the erosion of the upper reach of the river became strong, resulting in a thick accumulation in the lower reach, the Layers ⑦-⑩ lacustrine faces sediments of Holocene were developed as a result. A moderate erosion process between Layer ⑨ and Layer ⑩ also occurred due to fluctuations in the climate. At 4000 aBP, the crust uplifted once, and the present geomorphologic landscape was formed by a strong retrogressive erosion. Although strong tectonic movement has not taken place in the region during the Late Quaternary, because of the special geological environment, evidence is present in the sedimentary and geomorphologic sediments of a moderate uplift of the crust and climatic fluctuations.

2 Late Quaternary environment at Shuidonggou

2.1 Sporopollen records

Deep sporopollen analysis had been done by Zhou, Sun and Li et al.[4,11,15] of the Shuidonggou materials. The sporopollen analysis results indicate that woody pollen amounts to 24.4% sporopollen, 75.4% herb pollen, and 0.2% fern spores. *Pinus*, *Picea* and *Nitraria* are the dominant flora, and *Querces*, *Betula*, *Acer* and *Salix* are also represented. Herb plants include Ephedra, Chenopodiaceae, *Artemisia*, and Gramineae, Legumiosae, Saxifragaceae, Rubiaceae, Labiatae, *Sparganium*, *Typha*, Cyperaceae, and Compositae[4]. *Nitraia*, *Ephedra* and Chenopodiaceae are arid zone plants, which indicates a grassland environment. *Quercus*, *Typha* and *Sparganium* indicate a moister climate. The ecological environment of Shuidonggou was probably characterized by broadleaf tree vegetation. Dating results indicate that the strata was formed between 29—24 ka, equal to MIS3. Although the area was in the arid grass belt, increasing precipitation resulted in the increase of the *Quercus*, *Acer* and *Salix* in the region.

The Holocene sporopollen analysis are the most detailed, with the results consistent between different researchers[4,11,16]. Li Bingcheng[16] divided the sporopollen diagram into three sporopollen zones, dominated by arid grasses, but with an increase in broadleaf arbor and aquatic plants due to increases in precipitation.

The upper sporopollen analysis results indicate that the lower and upper cultural layers of Shuidonggou were formed in the relatively productive environment. The climate provided suitable conditions for plants and animals to excel, as well as the hunter-gatherers who utilized these resources.

2.2 Vertebrate fossil records

Many vertebrate fossils were excavated from the upper and lower cultural layers[5]. The fossils from the upper cultural layer include *Equus przewalsky*, *Cervus* sp., *Gazella przewalskyi*, *Equus hemionus*, and *Struthio* sp. The vertebrate fossils from the lower cultural layer include *Coelodonta antiquitatis*, *Equus przewalskyi*, *Equus hemionus*, *Cervus* sp., *Bubalus* sp., *Gazella przewalskyi* and *Struthio* sp. etc.

Boule et al.[17] listed *Equus hemionus*, rhinoceros, hyena, gazelle, Africa gazelle, *Bubalus* sp. and *Struthio* sp. in the assemblage, but the description and discussion were not done by him. Based on this faunal data we draw the following conclusions:

First, the taxa from the lower cultural layer are also present in the Salawusu fauna of the Late Pleistocene. Second, nearly all of the taxa were living in the grassland zone, with most taxa suitable to live in an arid and cold climate. Presence of the *Bubalus*, normally adapted to warm environments, indicates that warm climate occurred occasionally. *Struthio* can adapt to subtropical zone desert and grassland environments. In sum, it can be deduced that the climate was relatively dry, but warmer and moister than during the glacial stage, which was suitable for the survival of grassland taxa. The sporopollen analysis results also support this environmental reconstruction.

The taxa from the upper cultural layer are similar to that from the lower cultural layer, indicating the environment was similar.

2.3 Ancient human living environment

Study of the environmental change in arid and semi-arid regions of China indicates that the average annual temperature during MIS3 in the Weinan region of Shannxi Province was 1－2℃ higher than at any time during the Holocene, with annual precipitation 100－150 mm greater[18]. Since the climate is controlled by changes in the westerly and East Asian monsoon systems, the climate has been unstable, with four short time scale arid events identified in Holocene[19]. The climate during MIS3 in the Salawusu river basin of Inner Mongolia was warm and moist, but nine cold-arid events are also recorded[20]. The climate in Badain Jaran Desert since 30000 years ago also represents similar fluctuating processes[21,22].

Shuidonggou is located in the arid region of northwest China. The climatic and environmental characteristics during MIS3 and the Holocene were similar, with the climate warmer and moister than during the present. The sporopollen analysis and the vertebrate fossil diversity indicate that a broadleaf tree vegetation was predominant during human occupation. At that time, water pack depressions emerged in some zones, plants were more flourishing, and many broadleaf trees grew in the adjacent regions, which indicates the climate was more convenient than today. The topography in the surrounding region was plain and wide, with deserts emerging. The arid grass environment was suitable for the survival of various herbivore animals. This environment provides the basic conditions for ancient human occupation. They could hunt as their main activity, inhabit the near water regions such as river banks and lake margins, leaving behind stone artifacts, ornaments and hearths. However, humans had to be adaptive because many times the climate became cold. This needs further study.

3 Discussion and conclusion

Shuidonggou is located in the transitional area from the central Asia arid region margin to semi-arid region, with the annual temperature and precipitation about 8℃ and 200 mm. The vegetation is transitional between grass and desert. Ancient humans with low productivity could not survive in the present environmental conditions.

The Shuidonggou area is located in the west margin of the stable Ordos block, with the west conjoined to the Yinchuan basin which subsided continuously in the Cenozoic, and the east margin connected to the Maowusu desert. The topography is plain and wide, and the accumulated Quaternary sediments thin. It should be noted that the profile of Shuidonggou is composed of sediments of various formation types and plentiful sporopollen and vertebrate fossils. Not only does Shuidonggou provide much evidence for reconstructing the living environment of ancient humans, but it also should be considered the type Late Pleistocene section of the arid region of Ningxia-Inner Mongolia. Based on this study, we drew 3 primary conclusions:

(1) The Shuidonggou lower cultural layer is the Late Pleistocene type-section in the southeast margin of the northwest arid region in China. Apart from the ancient human activity traces, plentiful sporopollen and vertebrate fossils are preserved in the section. The sediment types are various and changeable which bears the typical character of the Ningxia-Inner Mongolia arid region. In 1983, the Bureau of Geological and Mineral Resources of Ningxia noted that the Paleolithic layer should be separated out and identified as the “Shuidonggou Formation”[8]. In 2006, Zhou[23] proposed that Shuidonggou could be the standard type-section, Yuan and others[24] began using the “Shuidonggou Formation” in formal publications. The “Shuidonggou Formation” is also suggested by the authors here, with its standard section Locality 1 and ④－⑥ layers of Locality 2, and the geological age about 30－24 ka. Shuidonggou was occupied during the latter part of MIS3, which is younger than the Salawusu Formation, and probably equivalent to the Chengchuan Formation.

(2) The Biangou river began to flow some time during the Paleolithic, but it took time to fully develop. The Maowusu desert also developed during this time[25,26], but the climate was warmer and moister than present.

The vegetation was broadleaf trees and grasses, suitable for arid region animals to survive and hunter-gatherers to hunt. The environmental conditions during the Holocene occupation were similar to the Paleolithic, with plant and animal diversity similar.

(3) Hunter-gatherers initially occupied the region between 29—24 ka (MIS3), with a second major occupation between 9—5 ka. Currently, no evidence has been found of human occupation during the Last Glacial Maximum (MIS2). Human activities were still controlled by climatic changes during MIS2. It is possible that the absence of human activity in this region is not because of their lack of adaptive ability, but rather the plants and animals cold not survive the harsh climates during MIS2. This needs further investigation through continued multi-disciplinary research efforts.

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