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Taphonomic and paleoenvironmental issues of the Pleistocene loessic Paleolithic sites in the Qinling Mountains, central China

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Abstract Hinterland intermountain basins and northern and southern piedmonts of the Qinling Mountains accumulated a large amount of loess during the Pleistocene. The loess strata not only record local paleogeographic and paleoenvironmental changes, but also contain rich hominin fossils and Paleolithic remains. In the northern piedmont of the Qinling Mountains and the lower valley of the South Luohe River, the loess strata have multi loess-paleosol sequences with aeolian loess continuously accumulating during glacial and interglacial cycles. In contrast to the northern piedmont, loess stratigraphy in the hinterland intermountain basins of the Qinling Mountains is relatively thin and contains finer loess particles. In this “mini” type of loess stratum, the density of Paleolithic remain generally is higher than the Loess Plateau in the north of the Qinling Mountains. Based on stratigraphic, chronological, and lithic artifacts analysis in recent years, it appears that the regional lithic assemblage belongs to the Oldowan (Mode I) lithic industry, and it is dominated by choppers, cores, flakes, and simple retouched flake tools from 1.15 to 0.6 Ma. Paleolithic open-air sites such as Gongwangling and Chenjiawo in the Lantian area, Shangbaichuan and Liuwan in the Luonan Basin, Qiaojiayao in the Lushi Basin, Longgangsi and Yaochangwan in the Hanzhong Basin, Guanmiao in the Ankang Basin, and the Yunxian Man Site in the Yunxian Basin are representative sites in the region; from 400 to 250 ka, the Longyadong cave site in the Luonan Basin inherited the characteristics of the local Mode I lithic industry, the stone assemblage is made up of cores, flakes, and small retouched flake tools, such as scrapers, points, and burins; during the period from 250 to 50 ka, bi-facially retouched Acheulean tools (Model II), such as hand-axes, picks, and cleavers, were commonly found in the Qinling Mountains region. The emergence of a large number of Model II artifacts indicates that local lithic industries went through a major transition process. Zhanghuokou, Guoyuan, and Huaishuping sites in the Luonan Basin, Diaozhai, Ganyu, Laochihe, and Xiehu sites in the Lantian area, Hejialiang site in the Hanzhong Basin are representative sites in this period; to the turn of the Late Pleistocene and Early Holocene, it may also exist a small flake-retouched tools lithic industry in the piedmonts of the northern and southern sides of the Qinling Mountains. The lithic assemblages in different stages of the Qinling Mountains region reflect the hominin behavioral changes and the development of lithic technology during the Pleistocene.

Keywords Qinling Mountains, Pleistocene, Loess stratigraphy, Paleoenvironment, Lithic industry

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1. Introduction

Quaternary loess deposits cover about 12% of the earth's land area, and are discontinuously distributed in the mid latitudes of the northern hemisphere. Aeolian, silt particles represent the main body of the deposit, and have been shown to play an important role in exploring past environmental and climate changes. Meanwhile, as the characterization of sedimentary sequences become more accurate, loess plays an increasingly important role in understanding landscape changes, and the development of Paleolithic industries.

Early hominids first appeared in the late Miocene in Africa. With changes in climate and ecological environments, and after a series of physical evolution, early hominids evolved into *Homo habilis* and *Homo ergaster* from *Australopithecus* in Africa from the late Miocene to Pliocene. During the Tertiary and Quaternary transition, they finally evolved to *Homo erectus*. About 1.8 Ma ago, some *Homo erectus* (perhaps including some *Homo habilis*) began their way of "Out of Africa" under pressures of from the natural environment and population on the African continent, they continuously migrated to Eurasia, and settled down in the northern hemisphere in the lower latitudes.

Early hominin survival is thought to be greatly restricted by natural environments in the case of using rudimentary chipped stone tools. Vast low latitude areas in Eurasia is represented by undulating terrain, with a diversity of climate and ecological environments and, thus, it is suitable for human occupation. Early hominins migrated into Eurasia, and habited new environment highly consistent with the Quaternary loess accumulation process in the northern hemisphere. Studies regarding the loess strata of Paleolithic sites can provide the paleoenvironment background of early hominin life, and its chronological work can accurately reflect the human footprint at different stages of evolution. For these reasons, in the 1980s, Ranov firstly put forward the "loess Paleolithic" to integrate loess-paleosol sequence and its chronology, stratigraphy and environmental background with Paleolithic archaeological research (Ranov, 1989, 1995). Later, Prof. Liu used the term of "Loessic Geoarchaeological Belt" and "Loess Lithic Industry", to advocate the combination of Chinese loess research and Paleolithic archaeology (Liu, 1999). Now more than ten years later, Chinese Paleolithic archaeology has made great progress with a growing number of Paleolithic sites being identified in loess areas (Xia et al., 1999; Wang, 2005, 2007; Wang et al., 2008, 2013, 2014a, 2014b, 2014c; Wang and Huang, 2001; Wang and Liu, 2011; Wang and Lu, 2014; Yang et al., 2005; Yang and Liu, 2008; Lu et al., 2007, 2011a, 2011b, 2012; Du et al., 2008, 2010; Du and Liu, 2014a; Liu and Du, 2010, 2011; Sun et al., 2015). Recent archaeological site surveys, lithic analysis, and loess sedimentary research have now achieved a new level enabling researchers to sketch out the relationship between regional loess strata and Paleolithic remains. This article will briefly summarize the basic information for the loess deposits and Paleolithic remains in the Qinling Mountains areas of central China.

2. Loess deposits and early hominin activities in the Qinling Mountains areas

There are typical loess deposits from Lantian to Tongguan area at the northern piedmont of the Qinling Mountains, meanwhile stretch across the Luoning-Luoyang basins in the middle to lower reaches of the South Luohe River. The northern piedmont of the Qinling Mountains under the control of the wind from northwest in winter and spring in the Quaternary period, the thickness of the loess deposits is large. While in Sanmenxia, Lingbao, Luoning-Luoyang basins, because of air outlet to the southeast along the Yellow River in the Tongguan region, those areas also have thicker aeolian loess deposits which was carried out by northwest wind during the Quaternary period.

Traditionally, it is commonly recognized that the southern boundary of the Quaternary loess distribution is mainly the northern Qinling Mountains, but recent studies suggest that Chinese Quaternary loess deposits are also distributed in its hinterland intermountain basins and the southern piedmont areas. This now includes the areas of the Lunan-Lushi basins in the upper reach of the South Luohe River (Wang and Huang, 2001; Wang, 2007; Wang et al., 2008; Lu et al., 2007, 2011a, 2011b, 2012; Zhang et al., 2012), Yaoshi-Shangluo-Danfeng basins in the upper valley of the Danjiang River (Lei, 1999; Wang and Liu, 2011; Wang et al., 2013), from Fengxian County, Shuangshipu to Chaiguanling Mountain in the Liuba County in the western Qinling Mountains (Lei, 1998, 2000) as well as Hanzhong-Ankang-Yunxian basins in the southern piedmont of the Qinling Mountains (Sun et al., 2012, 2015; Wang et al., 2014a) (Figure 1).

Although south of the Qinling Mountains have Quaternary loess deposits, due to the factors of local topography, climate and atmospheric circulation, loess deposits in the region significantly differ from the typical loess deposits in the north of the Qinling Mountains (i.e., the China Loess Plateau). The differences are mainly reflected in the color, thickness, accumulation, continuity, and chemical or physical aspects of the sediments.

2.1 Loess Paleolithic sites in the northern piedmont of the Qinling Mountains

In northern China, aeolian dust accumulation began during the late Miocene, was continuous during the Pliocene-Pleistocene, and continues to this day. Typical loess deposits have obvious stratification. Multi light reddish, brown, or brown-reddish buried paleosols are also often observed in

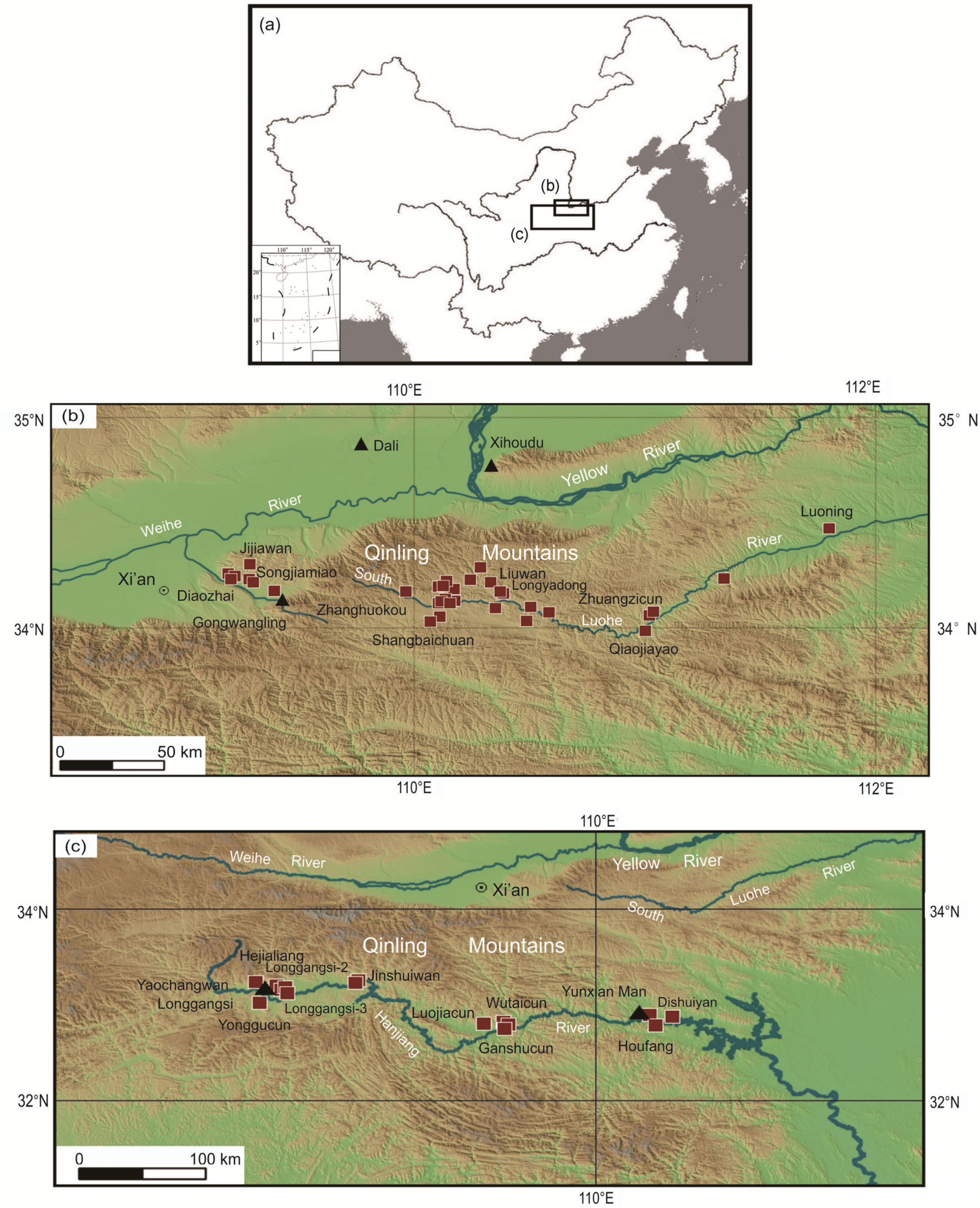

Figure 1 Distribution of Paleolithic sites in the intermountain basins, Qinling Mountains. (a) Image of the study area; (b) Lantian area, and Luonan-Lushi-Luoning basins in the South Luohe River valley; (c) Hanzhong-Ankang-Yunxian basins in the Hanjiang River valley.

the profile. Paleosols are known to form when sedimentary rates are slow during warm and humid interglacial times, and the northwest wind is weak. According to Pleistocene stratigraphic sequences (ca. 2.4 Ma), Prof. Liu divided Chinese Quaternary loess deposits into the Wucheng Loess of the Early Pleistocene, the Lishi Loess of the Middle Pleistocene, and the Malan Loess of the Late Pleistocene (Liu et al., 1985). Paleosols in the Wucheng Loess and Lishi Loess are represented by brown soils that formed in forest-steppe environments. However, paleosols in the Malan Loess are black loams that formed in steppe environments (Liu et al., 1985). Compared with the development of worldwide lithic technologies, the chronology of the Wucheng and Lishi Loess formations substantially correspond with the Lower Paleolithic stage, while the Malan Loess with the Middle-Upper Paleolithic.

According to statistics, more than one hundred Quaternary loess profiles, which contain vertebrate fossils have been identified in China. Mammalian fossils found have mainly been represented by rodents and herbivorous. Carnivorous include: wolves, foxes, badgers, jackals and other small animals (Liu et al., 1985). It has also been observed that loess strata in different periods have different unique animal species, such as *Myospalax omegodon*, *Prosiphneus intermidius*, and *Allocricetus ehiki* Schaub in the Early Pleistocene, *Megaloceros pachyosteus, Cerus grayi*, *Myospalax chaoyatseni*, *Myospalax minor*, *Ochotononoides complicidens* in the Middle Pleistocene, *Myospalax psilurus*, *Myospalax fontaneri*, *Microtus brandtioides* Young and *Struthis anderssoni* in the Upper Pleistocene (Liu et al., 1985). Overall, it appears that Quaternary vertebrates in the Loess Plateau are evolving within arid steppe zones. Paleoenvironments in the Early Pleistocene inherited the warm and humid forest ecological conditions of the Neogene, and gradually evolved into an arid steppe during the Middle and the Late Pleistocene. This aridification trend has been extended to modern times, and it is clearly consistent with the formation of the loess areas in China (Liu et al., 1985).

Since the 1960s, a growing number of hominin fossils and Paleolithic open-air sites were discovered in the Lantian County of the northern piedmont of the Qinling Mountains (Figure 1b). There are well-preserved river terrace sequences along the Bahe River. River terraces are composed of fluvial sediments that are then capped by loess-paleosol sequences. Fluvial sediments range from silt to cobble in particle size, and loess-paleosol sequences have an average thickness of approximately 100 m. The Gongwangling open-air site is located on the highest river terrace on the left bank of the Bahe River. The lower part of the river terrace deposits are composed of gravel beds that lie upon a red sandy clay with a thickness of 30 m. From 1964 to 1966, numerous animal fossils, including a hominin skull and lithic artifacts, were recovered from a silty loess layer, which was attributed to L15. During an extended survey, lithic artifacts were collected in later times (Dai and Ji, 1964; Dai, 1966; Jia et al., 1966; Wei, 1977; Wang et al., 2014a). Paleomagnetic dating suggested that the dates of hominin skull fall into the range of the later Early Pleistocene, about 1.15–1.1 Ma (An and Ho, 1989). Recently, based on Paleomagnetic results some researchers believe that the fossil layer of the Lantian Man may be even older, belonging to S22 or S23, which is about 1.63–1.62 Ma (Zhu et al., 2014).

Also during this time, more than 20 Middle Pleistocene open-air sites were identified, from which more than 200 stone artefacts were collected in the Lantian area. In 1963, a fossil hominin mandible, and more than ten kinds of mammalian fossils were discovered. These fossil remains were buried in the reddish, clayey paleosol S6 on the third terrace of the right bank of the Bahe River. Recently more stone artifacts were discovered in the area of Chenjiawo in the Lishi Loess formation (Wang et al., 2014b, 2014c). Based on paleomagnetic dating, S6 in Chenjiawo site is dated to about 650–500 ka (Cheng et al., 1978; Ma et al., 1978; Liu and Ding, 1984).

Located above Lower Paleolithic layers, open-air sites, which are buried in the Late Pleistocene Malan Loess formation, are also found in Lantian area. Sites in the region include: Laochihe, Xiehu, Diaozhai, and Ganyu where thousands of lithic artifacts have been collected (Jia et al., 1966; Gai and You, 1976; Wang et al., 2014b). A number of stone artifacts from the upper part of the Malan Loess deposit were collected in a recent archeological survey. Based on our observation in the field, we estimate that the stone artifacts are buried in the L1SS1 and L1LL1 of the Malan Loess.

To date, more than 40 Paleolithic sites have been discovered over last 40 yr in the Lantian area. Paleolithic artifacts are not only found from the early and middle Pleistocene loess strata on the third terrace, but also unearthed from the Malan Loess on the second terraces. These findings demonstrate that early hominins occupied the Lantian region for a large portion of the Pleistocene (Wang et al., 2014b).

In addition to the Lantian area, lithic artifacts have been collected in the loess strata which are believed belong to the Middle Pleistocene from Sanmenxia and Tongguan in the northern piedmont of the Qinling Mountains (Huang, 1964). In the Luoning-Luoyang basins, the loess strata of the late Middle and Late Pleistocene also contain Paleolithic artifacts (Xia et al., 1999; Wang et al., 2008; Du et al., 2010; Du and Liu, 2014; Liu and Du, 2010, 2011; Lu et al., 2012) (Figure 1b).

Despite the abundance of Paleolithic sites found in typical loess deposits in the northern piedmont of the Qinling Mountains and the middle to lower reaches of the South Luohe River, there are vast areas in the northern Qinling Mountains were archaeological work is still very weak. The Loess Plateau contains complete Quaternary loess-paleosol sequences, and has the advantage in establishing reliable site chronologies, deciphering taphonomic processes, and reconstructing paleoenvironmental backgrounds. The establishment of loess-paleosol type sections also allows Paleolithic archaeologists the ability to stratigraphically correlate sites and chronologically control surveys and excavations. However, in the northern Qinling Mountains, thick loess deposits, the depth of hominin remains, and paucity of surface finds and exposed sections greatly reduce the chance of successfully finding Paleolithic remains. Furthermore, due to the thickness of loess stratigraphy at sites in the region, the systematic excavation will inevitably cost huge human and material resources, and therefore is not conducive to further research. Since the accumulation rates of loess are fast and the relics are quickly buried, these fragmented remains are not conducive for the collection and extraction of site information. As a consequence, the value of large-scale systematic excavations may be limited.

2.2 Loess Paleolithic sites in the intermountain basins of the Qinling Mountains

Intermountain basins of the Qinling Mountains largely contain fine particle sizes as the barrier of the northern alpine terrain, which reaches 2000–3000 m above sea level, inhibit the transport of larger particles. The climate is warmer and more humid during the Quaternary, and surface soils are rich in aluminum in this environment. In addition, loess accumulation is also influenced by the slope wash and dynamic water processes on both sides of the mountains range. Excluding some narrow intermontane basins, loess deposits are often mixed with colluvial debris or alluvial flood deposits. However, deposits in the region still have obvious stratification and display loess-paleosol cycles. Compared with deposits of the northern Qinling Mountains, the thickness of loess strata in intermountain basins is often less than that in the Loess Plateau. Furthermore, paleosols in these intermountain basins are often thick due to strong ground surface weathering, and long term pedogenesis.

Generally, in the intermountain basins south of the main ridge of the Qinling Mountains, the maximum thickness of loess deposits on lower river terraces does not exceed 30 m. Due to local terrain conditions, the thickness of loess is usually only a few meters, and is deposited on the top of hills and higher river terraces. These intermountain loess deposits can be regarded as a “mini” type of loess sedimentary sequence. It has been observed that impacts of local topography, geomorphology and water conditions on these sequences often lead to intercalated deposits that are mixed with alluvial and slope sediments. Furthermore, strata from certain periods have been affected by erosional processes, and therefore are not continuous sequences. However, loess strata in the intermountain basins of the Qinling Mountains are still comparable to the typical profiles of the Loess Plateau. Stratigraphic correlations with Loess Plateau deposits allow researchers to establish both chronological and paleoenvironmental frameworks for sites in the region. During the Quaternary period the environmental conditions of intermountain basins are moderate, and ecological conditions appear to be suitable for human beings. It has been found that due to the limited thickness of the loess deposit, stratigraphic information associated with sites in the region are easily exposed, and represents a great advantage for Paleolithic archaeological survey and excavation. In particular, often times it is easier to reach lower strata in these “mini” loess strata when excavating sites. It has also been observed that Paleolithic remains contained in the Qinling loess units can be richer than sections found in the Loess Plateau. The following examples will be provided from hinterland intermontane basins of the Qinling Mountains.

The main stream and tributaries of the South Luohe River developed a series of faulted Cenozoic basins. There are loess deposits distributed in the upper, middle and lower river valleys, but due to the northern barriers of the Huashan and Xiaoshan mountains, loess accumulation rates are slower, particle sizes are finer, and the thickness of the loess deposit is thinner in the upper reaches in the Shimen-Luonan-Lushi basins of the South Luohe River. The thickness of the loess deposits on the second terrace is generally about 20 m with some strata containing an abundance of stone artifacts. Although there are sporadic loess deposits located on the top of local hills and high terraces, these deposits tend to be only a few meters in thickness. In recent years, numerous Paleolithic artifacts have been found in these loess deposits. Because of the mountain barrier and the existence of wind outlet in the north, the dynamic of aeolian transmission in the middle to lower reaches of the South Luohe River is relatively strong, the rate of loess accumulation is quick, and aeolian particles are coarse. The Luoning Basin has typical loess deposits in 90 m. Since the terrain barrier effect weaken, and a strong wind transmission effects, the thickness of typical loess accumulation even up to 100 m in the lower river valley (Lu et al., 2012; Zhang et al., 2012).

In recent years, loess stratigraphic sections of the Shangbaichuan, Liuwan, Zhanghuokou, Guoyuan and Shizilukou sites have been studied in the Luonan Basin (Figure 1b). These sites are located on the second terrace in the upper valley of the South Luohe River, which is situated between the South Luohe River and its tributary of the Xianhe River. The terrace gravel layer is higher than the modern river by several (if not 10’s) of meters. The age of the overlying loess is approximately 1.1 Ma (Lu et al., 2007). The Liuwan site is located on the second river terrace in between the Shimen River and Maping River, which are both tributaries of the South Luohe River. The site is covered with 13 m of loess deposits, and the age of the lowest loess strata is between 600–500 ka ago. The Qiaojiayao site in the Lushi Basin, which is located on the second terrace of the South Luohe River, is covered with 20 m of typical aeolian loess deposits. Dating results indicate the age of the bottom loess boundary is about 600 ka (Lu et al., 2011a). All these sites contain *in situ* stone artifacts in different layers of the loess stratigraphy. At the Shangbaichuan site, which is located in the upper portion of the South Luohe River valley, the maximum depth of buried lithic artifacts is about 17 m from the surface. Paleomagnetic dating demonstrate that the earliest loess strata containing lithic artifacts corresponds to a date of 700 ka ago, which is in the vicinity of the Brunhes/Matuyama (B/M) boundary. These results indicate that since at least 700 ka ago, early hominins occupied the South Luohe River valley. On the third and the higher terraces of the valley, Optically Stimulated Luminescence (OSL) dating shows that loess deposits accumulated during the Late Pleistocene. In the Luonan Basin, systematic excavations at the open-air sites such as Zhanghuokou, Mengwa, Guoyuan, Huaishuping etc., and the Longyadong cave site, indicates there are several prosperous periods of hominin occupation, which date to 800–600, 400–250, and 250–50 ka ago respectively (Lu et al., 2011b).

As the representative open-air site in the Hanzhong Basin (southern facet of the Qinling Mountains), the Longgangsi site has produced a large number of lithic artifacts during the early 1980s (Wang and Lu, 2014). These finds are in conjuction with at least 10 other Paleolithic sites in the area. In recent years, a series of the archaeological surveys have examined loess deposits on the different river terraces in the Hanzhong and Ankang basins, which are located on both sides of the Hanjiang River (including tributaries) in the southern piedmont of the Qinling Mountains (Figure 1c). Paleolithic sites in the Hanzhong Basin are located from the second to the sixth terraces of the Hanjiang River and its tributaries. These loess deposits are known to have formed in different times throughout the Quaternary, and generally bear rich Paleolithic remains. There is varying thickness of loess sediments occurring on the second to fifth terraces on the right bank of the Hanjiang River. This area is located at the eastern piedmont of the Liangshan Mountain at Nanzheng County, Hanzhong Basin. The thickness of loess strata at the Hejialiang site on the second terrace is about four meters, and consists of a single paleosol. The combination of Thermally Transferred Optically Stimulated Luminescence (TT-OSL) and paleomagnetic dating results show that the Hejialiang paleosol belongs to paleosol S1, which formed approximately 80–70 ka ago. Results also demonstrate that loess strata on the second terrace of the Hanjiang River and its tributaries in the Hanzhong Basin formed during the Late Pleistocene. Located on the third river terrace, the Longgangsi and Yaochangwan sites began to accumulate loess deposit at least since 800–600 ka ago, and has been extent until the first paleosol S1 stage (Sun et al., 2012; Wang et al., 2014a). Since 2013, results from systematic archaeological excavations at the Longgangsi site indicate that loess deposits on the fourth terrace contain four to six paleosols, with the upper strata located near B/M boundary. The age of the lower part of the loess strata may not be later than 1.2 Ma ago. The loess deposit on the fifth river terrace also appears to have been deposited sometime during the Early Pleistocene.

In addition to the Hanzhong Basin, Paleolithic remains have been found in loess deposits on the second and third terraces of the Ankang Basin (Hanjiang River valley), the Yaoshi-Shangluo-Danfeng basins (upper valley of the Danjiang River, the branch of the Hanjiang River) (Wang and Liu, 2011; Wang et al., 2013; Wang and Lu, 2014).

3. The paleoenvironment background of the early hominin subsistence

Results from pollen analysis in the Luonan Basin show that the loess layers L1 and L2 largely consists of herbaceous pollen with relatively few shrub pollen counts. This reflects a meadow landscape where Gramineae and Artemisia are the dominant species. In contrast to loess layers, paleosols S1 and S2, contain higher percentages of tree pollen with the content of *Pinus* pollen steadily increasing. Paleosol S1 may represent a pine forest grassland landscape. Paleosol S2 is dominated by Ulmaceae (forest grassland landscape), with broad-leaved tree pollen accounting for a large proportion of counts, and significantly reduced percentage of herbaceous pollen (Lu et al., 2012).

The magnetic susceptibility, particle size (Lu et al., 2007; Zhao et al., 2008; Zhang et al., 2008), and organic carbon isotope (Zhang et al., 2009) analysis results reveal the paleoclimate and paleoenvironmental changes in time (between glacial-interglacial cycles) and space (the upper, middle, and lower river valleys) in the South Louhe River. Temporally, the South Luohe River valley is largely consistent with the Loess Plateau with incipient aeolian loess deposition beginning in the Early Pleistocene. However, local differences in the initial time of loess accumulation may be related to the local topography, stage of climate change (i.e., interglacial-glacial cycles), and enhancement of the dust accumulation (Lu et al., 2010). Loess-paleosol strata and magnetic susceptibility sequences reveal that the cycles in glacial-interglacial stage are consistent with the typical loess section of the Loess Plateau in Luochuan. Spatially, there are observable differences between the upper reach and lower reach loess deposits in the area. Loess accumulation rates are slow in the upper reaches, and are strongly weathered during interglacial stages. Deposition of loess and weathering in the region are also known to be intimately linked to local topographic and microclimatic effects. Differences in paleoclimate and paleoenvironments in the region demonstrate that hominins lived in a variety of environments in the Qinling Mountains. This suggests that populations in the area had the strong ability to adapt to the local environmental conditions and climate change. Research has shown that loess deposits in the basins of the Qinling Mountains generally experienced a strong weathering process, even during glacial times, suggesting local microclimates were relatively mild and suitable for hominin survival (Zhang et al., 2008; Zhao et al., 2008; Zhang et al., 2012).

The analysis of soil, pollen, magnetic susceptibility and organic carbon isotope shows that the area of the South Luohe River valley is represented by grassland and forest vegetation under the influence of continental, sub-humid climate conditions in the Pleistocene. During interglacial periods, arbor and herbaceous vegetation increase, indicating the establishment of warm and humid environmental conditions. This is seen in a variety of proxies including: increase in tree pollen counts, more positive carbon isotope values, relatively high magnetic susceptibility, the relative increase in the proportion of C4 herbaceous plants, and strong pedogenesis. In contrast, during glacial stages, the number of the arbors decrease, and is reflected in the reduction of arbor pollen, more negative carbon isotope values, the decrease in magnetic susceptibility values, the reduction of C4 herbaceous plants, and pedogenesis weakens.

According to the age of loess deposits, the time span of the second terrace is about between the late Early Pleistocene to the late Middle Pleistocene. Since the second terrace is currently higher than the modern river level about 30–40 m, it indicates that the uplift rate of the Qinling Mountains is not significant during the Pleistocene (especially since the Middle Pleistocene). On both sides of the Qinling Mountains, intermontane basins contain rich Paleolithic sites, which are thought to demonstrate hominins in the region had the ability to occupy a large range of elevations. It is also argued that local landscape patterns have not substantially changed since the first occupation by hominin populations. Although there are some differences in the thickness of the loess deposits in different regions, the initial time of the deposition is not exactly the same, but the loess accumulation rate is relatively stable. The loess-paleosol deposits contains rich information in relation to hominin activities and environmental changes during the Pleistocene.

The intermountain basins of the Qinling Mountains provide the ideal geomorphological conditions for hominin habitats during the Pleistocene. There are well-proportioned low hills and basins in the region. Furthermore, the bottom of these basins is represented by gentle terrain. Since the Middle Pleistocene, the area appears to remains relatively stable, and new tectonic movement is not active. Our work has also demonstrated that Paleolithic sites are located on each terrace of the South Luohe River and its tributaries. The techniques and types of the lithic assemblages found at different heights of the landform are identical or similar. This is direct evidence of the establishment of large-scale hominin activities in the region. In particular, this region represents a transition zone between warm temperate and subtropical climates with temperature and humidity suitable for early hominin survival. This also includes the fact that the barrier of the high mountains in the north block cold air coming from the northwest in winter, and therefore, even in the Pleistocene glacial stages, these basins can provide ideal environments for hominin occupation. There are lush trees, dense vegetation, and various animals in the Qinling Mountains areas. It is a treasure house of wild animals and plants, which provided a wealth of food resources for early human beings. The Paleolithic remains have been found throughout the last glacial and the interglacial period suggests that hominin have stronger ability to adapt the various environments. The high density of hominin activity remains in different stages in the Qinling Mountains is not accidental.

4. Loessic Paleolithic technology and its developmental context

So far, over 400 Paleolithic sites have been identified in the intermountain basins and the northern and southern piedmonts of the Qinling Mountains. From the typo-technological analysis of the lithic artifacts in different areas, we can summarize the development of lithic technology in Qinling Mountain areas.

In terms of the structural geology of the Qinling Mountains, there is a close relationship between the hinterland intermountain basins and the northern and southern piedmonts. Lithic industries in these different regions appear very similar. Quartz, quartzite, siliceous limestone and igneous cobbles/pebbles collected from river terraces by early hominins, were the preferred raw materials for making stone tools. Other raw materials, such as flint, are rare. According to local river gravel composition, raw materials show some regional differences. In the Hanzhong Basin lithic artifacts are dominated by quartz, quartzite, siliceous limestone, and igneous rock. In the Luonan-Lushi and Yaoshi-Shangluo-Danfeng basins, quartz, quartzite, greywacke, and quartzite sandstone cobbles/pebbles are the most prevalent raw materials. In the Lantian area on the northern piedmont of the Qinling Mountains, raw materials are dominated by quartz, quartzite, siliceous rocks and granitic cobbles/pebbles. Direct hard hammer percussion is the principal stone knapping technique. The bi-polar and anvil-chipping methods are also frequently used in the lithic assemblage from this region.

Stone artifacts were first found on the northern piedmont of the Qinling Mountains, but the stone artifacts of the Gongwangling site are few. Before 1980s, only 26 stone artifacts were collected and unearthed in previous surveys and excavations (Dai and Ji, 1964; Dai and Xu, 1973; Jia et al., 1966; Gai and You, 1976; Wei, 1977, Wang et al., 2014b, 2014c). In addition to cores and flakes, retouched tools include scrapers, spheroids, choppers, and hand-axes/ picks. Loess strata associated with these artifacts may date from the Early to Middle Pleistocene. The composition of lithic artifacts is very simple and only very limited *in situ* artifacts are unearthed from the Early Pleistocene strata at the Gongwangling site. The chronology of the hand-axe/ pick collected from the Pingliang locality in the east of the Gongwangling site is still unclear. The lithic artifacts in the Chenjiawo and Jijiawan sites, which date to the Middle Pleistocene, inherited the characteristics of the Gongwangling site. The composition of lithic assemblages is still very simple, except for cores, flakes, and retouched tools, such as scrapers, points, choppers and spheroids. Heavy-duty tools include choppers and spheroids. Recently a large number of stone artifacts were found from the Malan loess in the Laochihe, Xiehu, Diaozhai, and Ganyu sites on the second terrace of the Bahe River at Lantian area. Based upon the OSL dating results, these sites date between 70 to 30 ka ago. Retouched tools in these assemblages include heavy-duty tools, which were made of cobbles/pebbles, large flakes like choppers, heavy-duty scrappers, hand-axes, picks, cleavers and spheroids, and small tools made of small flakes.

Since the early 1980s, thousands of lithic artifacts have been collected in the eastern part of the Liangshan Mountain in the Hanzhong Basin, along the southern piedmont of the Qinling Mountains. The lithic artifacts assemblages are made up of four groups, including cores, flakes, retouched tools, and chunks/small debris. The retouched tools comprise choppers, picks, hand-axes, heavy-duty scrappers, spheroids, scrappers and points. Among the tools, picks, hand-axes, and spheroids are most representative stone tools in the Hanzhong Basin. The lithic assemblage collected from the Hanzhong Basin has typical features of the cobbles/pebbles lithic industry. This industry represented by China's first Paleolithic open-air sites which were recognized as the cobbles/pebbles lithic industry in the south China. The latest surveys and excavations on the second to third terraces in the Hanjiang River and its tributaries indicate that these lithic artifacts closely resemble the previous lithic industry, but the proportion of flakes and retouched flake tools was significantly underestimated. In addition, a distinctive feature is that spheroids are clearly the predominant tool type in some sites of Chenggu County in the eastern Hanzhong Basin. It is worth noting that since 2013, through three consecutive years of systematic archaeological excavation, the majority *in situ* lithic artifacts on the fourth and fifth terraces in the Longgangsi site have been excavated under the B/M boundary. Small flakes and retouched small flake tools dominate the tens of thousands *in situ* lithic artifacts that have been unearthed in the different terraces at the Longgangsi site in recent years. A large number of the heavy-duty tools, such as choppers, spheroids, picks, and hand-axes, were collected in previous surveys, but they are rarely found during excavations. The Longgangsi lithic artifacts are mainly medium and small in size, and only a small number of large tools, such as choppers and other heavy-duty tools, have been unearthed. These results are significantly different from the results of surveys in 1980s. There are two likely reasons for the differing results. First, larger artifacts are more easily discovered in field surveys, and surface collection was the main means of gathering lithic artifacts during the 1980s. Second, large stone artifacts are put on aside by workers during soil sampling in brick manufacture areas, and the small size of stone artifacts are mixed and lost in the brick clay. This is a common archaeological phenomenon in the Qinling Mountains areas, including the Luonan Basin and the Hanzhoung Basin.

Based upon recent systematic archaeological surveys and excavations in the Luonan Basin in the eastern Qinling Mountains, only simple cores, flakes, and retouched pebble or flake tools such as choppers, scrapers, and points, have been found in the early loess stratigraphy. Large Acheulean tools, such as the hand-axe, cleaver and knife, have not been found in early-stage deposits. The Longyadong cave site is still this case in 400–250 ka. Since 2010, *in situ* Acheulean type (Mode II) tools are commonly unearthed from the upper loess strata on the second terrace in Zhanghuokou, Guoyuan and the other open-air sites in the Luonan Basin. The loess deposits that contain Mode II tools include the loess strata L3, S2, L2, S1, and L1, which range in age from 250–50 ka. Mode II tools are also found in the late Pleistocene loess deposits on higher terraces. The lithic assemblage in the Beiyao site in the lower reach of the South Luohe River consists of cores, flakes, and simple retouched flake tools. Recent continuous archaeological excavations at more than ten Paleolithic sites demonstrate that the loess deposits containing *in situ* hand-axes, picks, and cleavers are not older than the Zhanghuokou and Guoyuan sites. Therefore, the chronology of the Acheulean type tools in the Qinling Mountains areas is likely not older than middle to late Middle Pleistocene. In addition, compared with the sites in the Hanzhong Basin of southern piedmont and the Lantian area of the northern piedmont of the Qinling Mountains, the lithic assemblage in the Luonan Basin lacks well-made round spheroids, and the proportion of spheroids at some of the sites in the Hanzhong Basin is far greater than all other retouched tools.

From the above lithic analysis, it is reasonable to conclude that at least from the late Early Pleistocene until the early Middle Pleistocene, the lithic assemblage in the Qinling Mountains areas still resembles Mode I industry. The stone tools, which are made of local pebbles/cobbles such as quartz, quartzite, greywacke, sandstone and igneous rocks, consist of choppers, scrapers, points, and spheroids, among others *in situ* Mode II tools, such as hand-axes, picks, and cleavers, do not appear in the loess deposits before the Middle Pleistocene. From the middle to late Middle Pleistocene and into the Late Pleistocene, Mode II tools are commonly found in some open-air sites in the Qinling Mountains areas. This technological industry continued to the Late Pleistocene, around 50 ka. According to the latest surveys, a lithic assemblage of small flake and retouched small flake tools made of vein quartz may exist in the northern piedmont of the Qinling Mountains. This assemblage is found on the top of the Malan Loess and may date to the interglacial epoch MIS 3. However, further field surveys and excavations are needed to confirm the prevalence of this assemblage.

5. Conclusion

Based on the latest archaeological survey and excavation data, this paper summarizes the development of lithic industry and the relationship between the regional Paleolithic sites and the environment in the Qinling Mountains, central China. The main points can be concluded as follows.

(1) As a typical Loess Plateau region, the Lantian area on the northern piedmont of the Qinling Mountains is characterized by quick loess accumulation rates, thick stratigraphic sections, and complete loess-paleosol sequences. There is a continuous loess accumulation on glacial-interglacial time-

scales, which offers a great opportunity to study site formation processes and chronology. Existing archaeological information indicates that Paleolithic remains first appeared in this area in the early Late Pleistocene (about 1.15 Ma) and possibly as early as 1.6 Ma. Paleolithic remains are also commonly found in the Lishi Loess of the Middle Pleistocene and the Malan Loess of the Late Pleistocene. There is even a lithic assemblage of a small flake and retouched flake tools found in the Lintong County and the Lantian area thought to date to the later stages of MIS 3. However, the northern Qinling Mountains are not conducive to archaeological survey and excavation because of thick loess deposits and the lower density of the Paleolithic remains. The continuity of hominin activities in this area must be verified with further systematic archaeological work.

(2) There are loess deposits on the terraces of the main rivers and their tributaries south of the main ridge of the Qinling Mountains. The loess in this region is relatively fine, the accumulation rate is lower, and the deposits are reddish-brown in color. Due to the impacts of the Pleistocene climate, surface water flow and topography, the loess deposit is not thick, and some of the strata are missing. Paleolithic sites in the intermountain basins can be reliably dated using OSL and paleomagnetic dating techniques, and comparison of the typical loess strata. The density of the Paleolithic remains in this "mini" atypical loess strata is much higher than that of the loessic Paleolithic sites in the northern Qinling Mountains areas, hence this area is ideal for archaeological survey and excavation. The initial timing of Paleolithic sites in different intermountain basins in the Qinling Mountains may not be consistent. The earliest hominin occupation of the Hanzhong Basin dates to the early Pleistocene, while hominins began to occupy the Luonan Basin in the early Middle Pleistocene. Generally, Paleolithic remains appear through the late Pleistocene in the intermountain basins of the Qingling Mountains. Therefore, hominins might have lived in these areas both during periods of loess accumulation (glacial stages) and periods of paleosol development (interglacial stages).

(3) Regarding lithic technology and its developmental context, stone tools made of cobbles/pebbles and flakes are generally older than the middle Pleistocene. Except cores and flakes, the retouched tools include choppers, scrapers and points. There is no conclusive evidence that the Mode II type tools, such as hand-axes and cleavers, appeared at that time. From the middle to late Middle Pleistocene, hand-axes and cleavers commonly appear at the Qinling Mountains sites. However, the frequency of occurrence of different tool types between the sites is not consistent. The Acheulean type tools are common in deposits that date back about 250–50 ka. A significant chronological gap exists between the West and the same lithic tools in the Qinling Mountains areas. Two lithic assemblages of small flake and retouched flake tools are found in the upper layer of the Malan Loess in the Lantian area on the northern piedmont and in the Ankang Basin on the southern piedmont of the Qinling Mountains. However the developmental direction of the Mode II lithic industry in these areas is still a mystery due to the lack of loess strata associated with this time period in the hinterland intermountain basins.

In summary, the loess deposits in the Qinling Mountains areas contain rich Paleolithic remains, which provide a unique opportunity to explore the evolutionary process of early hominins, the development of lithic technology, and the relationship between human activities and environmental changes. In the past decades, research on the "Loess Paleolithic" has yielded some new insight, but current work is still far from revealing the internal relationships between human activities, technological behavior, and environmental changes. Ultimately, there are still many scientific problems to be explored. Hopefully, ongoing archaeological investigation and excavation, combined with geochronology, semi-quantitative reconstruction of paleoenvironment, geomorphic process analysis, and paleoclimate research, will allow us to better understand relationships between the evolution of hominin behavior, the development of lithic technology, and the environment changes.

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