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Late Pleistocene changes in vegetation and the associated human activity at Beiyao Site, Central China

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ABSTRACT

The hypothesis that climate change paced modern human dispersal is complicated by newly found fossil evidence from East Asia. Here we conduct a palynological analysis to a loessic Paleolithic site in Central China, spanning past 240 ka, to investigate the vegetation history and assess the impact of climate change to human activity intensity. Our results show that steppe was dominant during glacial periods and local forest was recovered during interglacial periods, pretty correlative to the quantity of stone artifacts. This correlation would suggest a coupling between human activity intensity and climate fluctuation in the study area. In addition, few stone artifacts continuously occurred in the later Last Glacial period, being tentatively attributed to improved adaption of local habitants or immigration of modern human.

1. Introduction

Modern humans are broadly thought to expand to all continents except to Antarctica and Americas and to replace or assimilate archaic human species essentially by the Last Glacial Maximum (~20 ka BP). Evidenced by both biogeographic scenarios of *Homo sapiens* and numerical modeling of human dispersal (Eriksson et al., 2012), it is generally accepted that dispersals of modern human were paced by climate changes (e.g. Breeze et al., 2016; Carto et al., 2009). However, latest discoveries from China (Fig. 1a) made the pattern of *H. sapiens* migrations more complex (Liu et al., 2016; Wu and Xu, 2016; Li et al., 2017). For instances, the homonins at the Zhiren Cave in Guangxi and the Fuyan Cave in Hunan, both in southern China, may represent early modern humans into East Asia between 120 and 80 thousand years ago, a warm interglacial period (MIS 5). On the other hand, the human fossils from the Tianyuan Cave and the Upper Cave, Beijing, appeared during the last glacial periods (27–40 ka BP, Chen et al., 1992; Shang et al., 2007). These new discoveries intensified the debate on the relationship between human evolution and environmental change.

As researchers pointed out previously, understanding the response of *H. sapiens* to climate changes has been hampered, at least, by the sparseness of correspondent paleoenvironmental data (e.g. Breeze et al., 2016) and the dating uncertainties of archeological records (e.g. Behrensmeyer, 2006). Although a latest numerical reaction/diffusion model successfully simulated the overall dispersal of *H. sapiens* (Timmermann and Friedrich, 2016), case studies in key regions are also invaluable to understand the impact of climate changes to human beings.

At central China, the Luohe Basin was extensively occupied by early hominins since as early as early Mid-Pleistocene (e.g. Lu et al., 2011; Zhang et al., 2012). The latest discoveries even suggested that the occupants at Longquan Cave (Fig. 1b) were bone toolmakers and had the ability to use their settlement space for specific purposes, showing a vital feature of modern human behavior (Du et al., 2016). From ca. 300 paleolithic localities more than 20,000 artifacts have been collected/excavated in the basin (Wang et al., 2005). Among these localities, the Beiyao site is a well preserved and deliberately excavated loessic Paleolithic site (Du and Liu, 2014; Liu and Du, 2011; Xia et al., 1998). The excavation exposed a continuous loess outcrop on a terrace, called Beiyao section. On the base of absolute dating results from the upper part of the Beiyao section (Du et al., 2011), we here refine the chronology of the complete section and reconstruct its regional vegetation sequence, allowing for further discussion on human occupation history.

2. Background and materials

On the southeastern margin of the Chinese Loess Plateau, the study area zonally belongs to warm temperate deciduous broadleaved forest district (Wu, 1995; Zhang, 2007). On fluvial plains lower than 500 m a.s.l., natural vegetation is completely replaced by cultivated plants due to extensive agricultural activities. On the northern slope of Qinling

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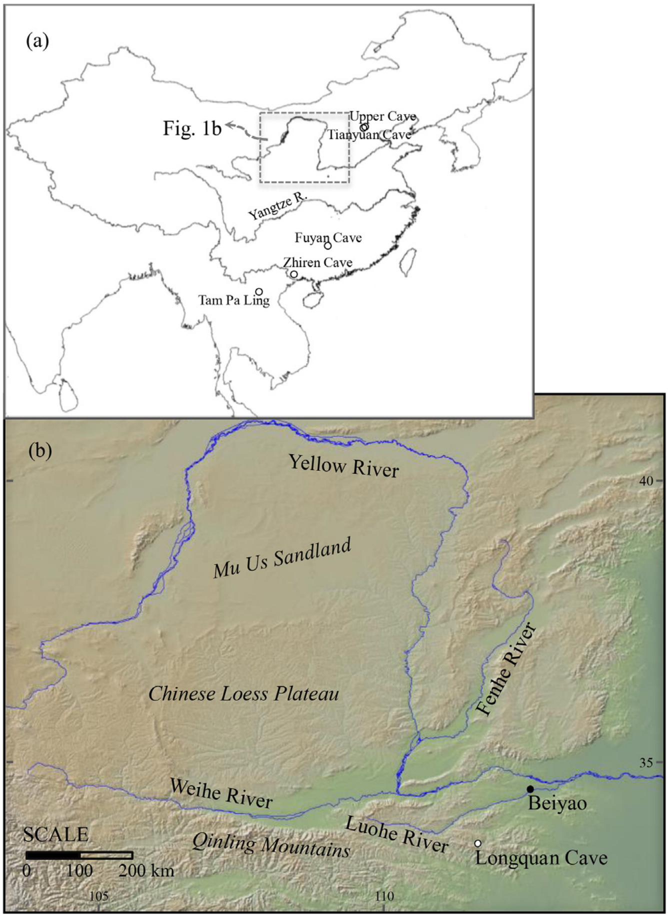

Fig. 1. (a) Sketched East Asia map with some late Paleolithic sites mentioned in the text; (b) locations of the study site. The black dot indicates the Beiyao site, and the circle represents the Longquan Cave site.

Mountains, deciduous *Quercus* forest dominates the elevation from 500 to 2600 m a.s.l. with increasing *Betula* and *Pinus*, montane *Abies*/*Picea* forests up to 3300 m a.s.l., and subalpine meadows the mountain top (Wu, 1995). The common arboreal species include *Quercus variabilis*, *Quercus aliena*, *Pinus tabliformis*, *Populus* spp., *Sophora* spp., and *Ailanthus altissima,* and herbs are dominated by Poaceae, *Artemisia* spp., *Aster* spp., and *Taraxacum* spp.

The Beiyao site is located on a terrace of a tributary of the Luohe River (Fig. 1b). On the northern slope of the Qinling Mountains, the terrace as well as surrounding hills is covered by thick eolian loess. A paleolithic survey in 1998 unearthed 771 stone artifacts and the lowest cultural layer was primarily estimated more than 200 ka BP (Liu and Du, 2011). A systematic excavation was completed during 2007–2008. Four squares were designedly excavated and consequently exposed a 16-meter-thick outcrop. The upper part of the outcrop is a well-preserved loess–paleosol sequence, consisting of three paleosol and two loess units, S0, L1, S1, L2 and S2 from top to bottom. On the base of lithological features and OSL dating results these strata have been correlated to the Marine Isotope Stage (MIS) 1–MIS 7. The loess deposit reaches to ca. 14 m thick. The basal part is reworked by fluvial processes.

During the archeological seasons, a total of 719 paleolithics were collected mainly from S2 and L1, including 49 cores, 180 flakes, 3 tools and 487 pieces of knapping debris. Although the lithics recovered from various layers, the simple core–flake technology sufficed throughout the various cultural layers in the Beiyao site (Du and Liu, 2014). Alongside the archeological squares a loess section was logged and sampled at the interval of 10 cm. These samples were subjected to grain size and palynological analyses.

3. Chronology refined

As mentioned earlier, lithological features demonstrated that the section consisted of the loess (L)–soil (S) sequence S_0, L_1, S_1, L_2, and S_2. The stratigraphy was confirmed by five OSL samples from the upper part of the section (Du et al., 2011) and by correlating magnetic susceptibility to benthic $\delta^{18}O$ record for the lower part (Du and Liu, 2014). Accordingly, the Beiyao section was loosely constrained to the last two glacial–interglacial cycles.

To refine the chronology of the study section, we measured here its grain size and correlated the grain size sequence to the Chinese Loess Millennial-scale Oscillation Stack (CHILOMOS, Yang and Ding, 2014). The CHILOMOS is a stacked grain size record based on 12,330 samples from eight loess sections across the Chinese Loess Plateau, whose chronology was correlated to the precisely dated Chinese stalagmite $\delta^{18}O$ record (Cheng et al., 2009; Wang et al., 2008). It is the very first millennial scale stack for the past glacial cycles in northern China.

A total of 156 samples were collected at 10 cm intervals, yielding a mean temporal resolution of 200–300 years. The loess units are clearly expressed by peak–trough alternations in the median grain size (Md) curve (Fig. 2), with peaks indicating stadials and troughs indicating interstadials. The great similarity between the Md curve and the CHILOMOS provides age constraints to refine the time scale for the study section. Taking the ages of maximum glacial/interglacial stages as time controls and then using the linear interpolation via the program AnalySeries 2.0 (Paillard et al., 1996), we established a refined time scale for the Beiyao section.

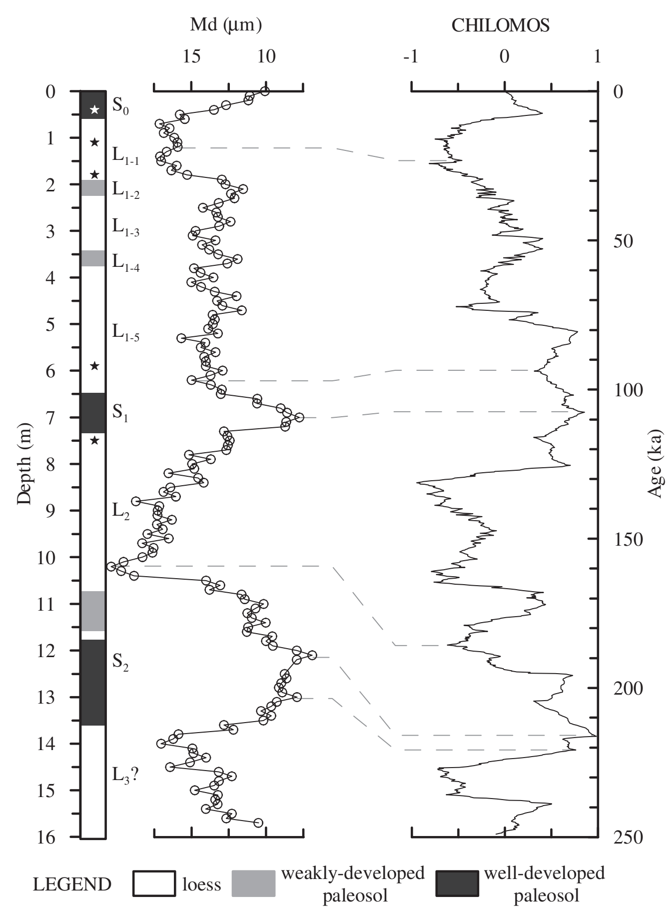

Fig. 2. A refined chronology for the Beiyao section by correlating the median grain size curve to the CHILOMOS (Yang and Ding, 2014). ★ indicates location for OSL dating sample, and the dashed lines indicate tie points, which mainly followed Du & Liu's correlation strategy (2014).

Comparison of the OSL results with their corresponding ages in the refined time scale shows general agreement with slight differences (Table 1). The general agreement indicates the refined time scale reliable, while the slight discrepancy is partly due to deposition process at the local scale or increasing uncertainties of OSL dating method. Within the refined time scale the age of all collected samples was assigned.

4. Palynological results

4.1. Method

We conducted palynological analysis for 132 samples at 10 cm intervals from the uppermost well-preserved loess deposits. The resulting temporal resolution is 1.5–2.5 ka from 241 ka BP upwards. The extraction process followed the standard acid–alkane–acid treatment by Horowitz (1992). After chemical treatment (10% HCl, 10% K_2CO_3, 70% HF), the samples were sieved through 10 μm nylon mesh screens. If necessary the heavy liquid, $ZnCl_2$ solution, was used to further concentrate pollen grains. The samples were mounted in glycerol solution and then microscopically examined using 400× and 1000× magnification. It was routinely counted up to sum of 150 pollen grains for each sample, averaged at 171, with 13 cases fewer than 100 grains because of the poverty of palynomorphs.

The application of multivariate analytical procedures in palynology has become more helpful in the past thirty years (Birks and Gordon, 1985; Hammer and Harper, 2006). In this study the unweighted paired group average linkage cluster (UPGMA) with a Euclidean distance measure has been chosen to identify zones of palynological assemblage. Absolute percentages with respect to pollen sum were used for statistical treatment and the statistical analyses were conducted using PAST version 3.08 (Hammer et al., 2001).

4.2. Pollen spectra

We identified 22,738 pollen grains belonging to 57 taxa in 132 samples from the Beiyao section. The assemblage generally shows two cycles with the dominances of arboreal and grass taxa, respectively. The arboreal taxa is dominated by *Pinus* with frequent occurrences of *Abies*, *Tsuga*, *Betula*, *Quercus*, and *Ulmus*, while the dominant herb taxa are *Artemisia*, Chenopodiaceae, and high frequencies of Poaceae, Compositae and Ranunculaceae. The listed most common taxa contributed 84% of the identified grains and were plotted (Fig. 3).

Considering its general association with the occurrences of *Typha* and Cyperaceae and its low pollen productivity and bad representation of vegetation in eastern China (Xu et al., 2009; Zheng et al., 2014), Poaceae were most likely derived from local swamp rather than from regional steppe. Excluding the pollen grains of Poaceae and local swamp plants, we established four pollen zones based on the UPGMA cluster results (Fig. 3). The zones were broadly agreed to the lithological changes and, from the bottom upward, were described as follows.

Zone 1 (13.2–10.7 m; 291–193 ka BP) is dominated by *Pinus* (63.2% on average), *Artemisia* (20.6% on average), and high frequency of Chenopodiaceae. The AP/NAP values (ratio of arboreal pollen to non-arboreal pollen) reach to 2 at the middle zone and gradually decreased upwards. This zone corresponds to S2 in lithology.

Zone 2 (10.6–7.7 m; 192–124 ka BP) shows high herbal taxa (60.7–92.0%, 77.8% on average) and the corresponding AP/NAP values remain low (0.26 on average), correspondent to L2 in lithology. At the depth of 9.4 m, this zone was subdivided into Zones 2a and 2b, differed from dominant herbal taxa. The lower Zone 2a is dominated by *Artemisia* (48.2% on average) with Chenopodiaceae less than 30%. In the overlying Zone 2b, the percentage of Chenopodiaceae pollen exceeds that of *Artemisia*, and arboreal pollen percentages increase upward, as the AP/NAP value does.

Zone 3 (7.6–6.3 m; 122–96 ka BP) yields abundant *Pinus* (43.6% on average), accompanied by frequent *Artemisia* (16.8% on average) and Chenopodiaceae (11.6% on average) and common *Tsuga* and *Quercus*. Correspondingly the AP/NAP values increase to the maximum of the section (1.37 on average). This zone broadly correlates to S1 in lithology.

Zone 4 (6.2–0 m; 96–0 ka BP), corresponding to L1 and S0 in lithology, shows AP values less than 40% and the resulting AP/NAP values is less than 0.6 with an average of 0.36. *Pinus* dominates the arboreal taxa while *Artemisia* and Chenopodiaceae dominate the herbs. The top of the study section, S0 in lithology, is marked by a slightly increase in AP/NAP values, mainly resulting from increase of *Pinus*.

Table 1
Comparing the OSL-SAR dating results (Du et al., 2011) with the refined chronology using CHILOMOS (Yang and Ding, 2014) for the upper part of study section.

Sample	Depth (m)	Age (ka)	
		OSL dating (±1σ)	Refined age (correlating to CHILOMOS)
10G-06	0.4	9.5 ± 0.4	9.16
10G-07	1.1	22.8 ± 1.4	21.62
10G-08	1.8	26.6 ± 1.5	31.83
10G-09	5.9	75.9 ± 4.0	89.62
10G-10	7.5	112.8 ± 5.1	119.80

5. Discussion

5.1. Regional vegetation history

The pollen assemblage is featured by the dominance of *Pinus*, *Artemisia* and Chenopodiaceae, all of which contributes 65% identified pollen grains. According to investigations on surface soil pollen assemblage on various spatial scales (Xu et al., 2009, 2016; Zhang et al., 2014; Zheng et al., 2008), the three dominant taxa are over-representative, and thus the observed pollen assemblage from the study section, to the first order, reflects regional vegetable changes. Both *Artemisia* and Chenopodiaceae are important steppe components in the northern temperate semi-arid zone, and overwhelmingly dominated the pollen spectra from the Chinese Loess Plateau across glacial–interglacial periods (e.g., Jiang et al., 2014; Zhou et al., 2014). Increasing herbal pollen thus could be an indicator of a southward invasion of semi-arid steppe vegetation. To a specific site, 25% of *Artemisia* pollen in sediments has been proposed to indicate a local occurrence of steppe vegetation for reconstructing the steppe coverage during the LGM (Liu et al., 2013).

From modern vegetation survey (e.g., Zhang et al., 2014) and macrofossils from Neolithic cultural sites (Sun and Li, 2012), the valleys at southern Chinese Loess Plateau are covered by coniferous or broadleaved forests. Due to their high pollen productivity and great dispersal ability, including *Pinus*, *Artemisia* and Chenopodiaceae, arboreal pollen is generally under-representative for local vegetation (Zhou et al., 2014) and, however, is informative for understanding the sequence of neighboring forest through time.

The palynological zones are roughly consistent to the lithological changes in the study section: arboreal taxa dominate paleosol layers with high AP/NAP values, while herbal taxa dominate loess layers with low AP/NAP values. It is almost ready to say, during the periods of paleosols, the forest coverage in the neighboring area somewhat recovered. During the periods of loess formation, the recovery of forest was terminated by the increasing of herbal taxa. If we adopt 25% of *Artemisia* pollen as the critical value for local occurrence of steppe, the study area was covered by steppe when the loess deposited, MIS 2–4 and MIS 6. This vegetation pattern of the study area is consistent to the paleovegetation distribution. For example, during the Last Glacial Maximum, the southernmost limit of stepped once reached to the valley of Yangtze River, which is occupied by evergreen broadleaved forests (Liu et al., 2013; Ni et al., 2010; Yu et al., 2000).

Our records also show high proportion of herbal taxa from the S_0 layer, instead of arboreal taxa from the underlying paleosol layers S_1

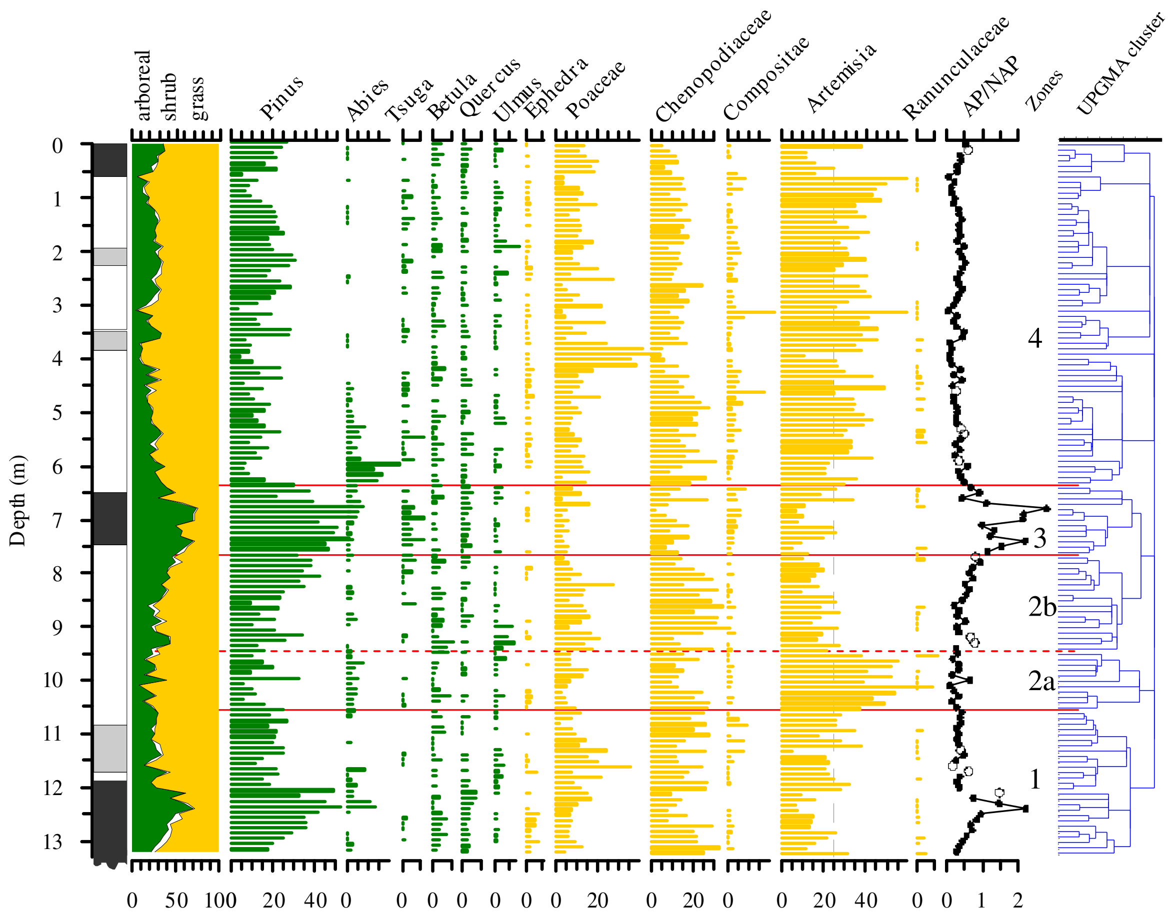

Fig. 3. Results of pollen analysis for the Beiyao section and the dendrograms for stratigraphically constrained UPGMA cluster analysis using a Euclidean distance measure. The open circles in the AP/NAP curve indicate the samples with the counted grains under 100.

and S_2. A possible explanation for this difference is human impacts since the Neolithic period. The Luohe Valley, where the study site located, is one of the agriculture origin centers in East Asia, and extensively utilized at least during the past 8000 years. It is estimated quantitatively that, during the middle Holocene, agricultural activities expanded from gentle slopes along the river to hinterlands in middle and lower parts of the valley, occupying 2–9% land area (Yu et al., 2012). These processes would impact the regional vegetation components.

5.2. Placing the lithic quantity into climate contexts

To the underlying strata, the excavators have noticed that paleosol and loess greatly differ from the number of their bearing artifacts (Du and Liu, 2014). More than 95% lithics (691/720) are from S_2 and S_1, which corresponds to MIS 7 and MIS 5 (Lisiecki and Raymo, 2005), respectively. By contrast, only nine and four lithics are from L_2 and L_{1-5}, which corresponds to the MIS 6 and MIS 4, and few artifacts are sporadically but continuously presented from L_{1-2} to L_{1-1}, correspondent to the late Last Glacial period, the MIS 3 to MIS 2.

Placing the artifacts quantity into the associated paleoenvironmental context will assist us to understand their interactions (Fig. 4). The paleosol layers bearing abundant artifacts are generally of finer grain size, higher magnetic susceptibility, and greater AP/NAP value than those of loess layers with few artifacts. All these proxies lead to a well-established paleoclimatic scenario in Chinese Loess Plateau. Grain size of eolian loess at a specific location is dominated by the proximity of desert (Ding et al., 1999) that is essentially controlled by the strength of East Asian summer monsoon (Yang and Ding, 2008), i.e. during warmer interglacial periods stronger summer monsoon retreats the desert–loess boundary northward, resulting in finer dust deposited on the loess plateau, and vice versa. Magnetic susceptibility is overwhelmingly dominated by the concentration of magnetite. In the loess plateau, it peaks in paleosols for the pedogenic origin of nano-sized magnetite, which is enhanced by stronger summer monsoon (Liu et al., 2007; Maher and Thompson, 1991; Zhou et al., 1990). As discussed earlier, the increasing AP/NAP values would indicate the recovery of local forest that, again, benefits from more summer monsoonal precipitation.

Assumed the frequency of Paleolithic being an indicator of human activity intensity, it appears that humans intended to live around the study area during warm periods instead of cold periods. Considering the climatic contexts of the study area, warm periods host at least two advantages for living during the Paleolithic period. First of all, the local ecosystem in a warmer period has a more diverse ecosystem (Yang et al., 2017; Zhao and Ding, 2014) and greater biomass (Yang et al., 2015), offering ancient humans a stable ecosystem and diverse foods. Moreover, it may be easier to survive winters during interglacial periods than glacial periods.

A plausible mechanism has been tentatively proposed to explain the human activity intensity in the study area: environmental pressures redistribute ancient inhabitants. During an interglacial period, East Asia summer monsoon brought plentiful moisture to the study area, as well as the Loess Plateau, feeding the terrestrial ecosystems and finally allowing human to survive in acceptable circumstances. Conversely, during a glacial period, weakened summer monsoon deteriorated local environments, exerting great pressures over daily life of local habitants. As a result, the human activities constrained and moved southward.

If valid, it is rational to expect more sites of glacial periods from the region to the south. South China and Southeast Asia, however, are

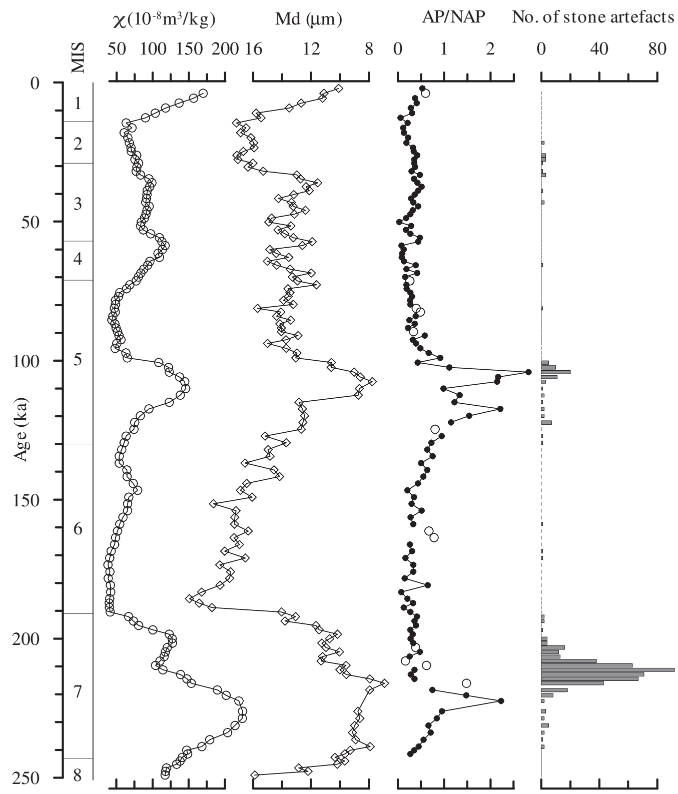

Fig. 4. Paleoclimatic contexts for human activity in the refined chronology. The ages of MIS boundaries follow LR04's proposal (Lisiecki and Raymo, 2005), and the magnetic susceptibility sequence is from Du and Liu (2014).

notable for their scanty of fossil evidence. The most recent fossils also came from relatively warm periods, such as the Daoxian human fossil teeth from the Fuyan cave, Hunan Province, dated to 80–120 ka BP (MIS 5. Liu et al., 2015), and a human cranium from Tam Pa Ling, Laos, by ~46 ka BP (MIS 3. Demeter et al., 2012). Before convincing and concluding evidence comes, the relationship between modern human evolution and environmental changes in East Asia will be open to continuous debate.

One more issue worthy of further consideration is the sparse but continuous occurrence of artifacts during the MIS 3–2 periods. These artifacts are of a simple core–flake technology, just as the artifacts below did. The excavators argued that these indicated increases in human activity intensity in hush glacial conditions, showing some improved adaptations of local habitants (Du and Liu, 2014). Most recently, a contemporary Longquan Cave with radiocarbon dates of 40–30 ka BP was found nearby. The Longquan Cave is featured by a polished bone awl and structured space utilization (Du et al., 2016), both of which are closely associated with modern human behaviors (Mellars, 2005). Although conclusive fossil evidence is still absent, it is highly possible that modern human dispersed to the study area by the last glacial period.

6. Conclusions

The pollen data of the Beiyao section, spanning the past 240 ka, shows that the vegetation sequences were paced by glacial/interglacial cycles. *Artemisia*–Chenopodiaceae steppe dominates the glacial periods, whereas local forests some recovered during the interglacial periods. This pattern might be closely related to zonal vegetation migration in response to summer monsoon.

Paleolithic was mainly presented in warm periods including MIS 7 and MIS 5, and continuously occurred within the last glacial stage, MIS 3–2, without marked technological innovations. Considering nearby contemporary Longquan Cave, which featured by modern human behaviors, it might be associated with modern human immigration to the study area.

The systematical investigation into the loess Paleolithic site at Beiyao provides a valuable case study for assessing the impact of climate cycles on human activity intensity and even new archives for discussing the origin of East Asian modern human.

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