Mid-Pleistocene environmental reconstruction based on Xiashu loess deposits in the Yangtze Delta, China

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Available online 30 December 2004

Abstract

A 5.67-m-thick section in loess-like sediments at Xiashu was exposed during archaeological excavation of the Fangniushan Palaeolithic site. ESR dating and grain-size analysis suggested that the sediments are wind-blown in origin and were deposited within a period of about 400 kyr. Environmental proxy indicators, including magnetic susceptibility, frequency-dependent magnetism, Kd, median grain size and clay grade percentage show that five warm and humid climatic periods occurred in the study region in the mid-Pleistocene, namely at 130–90, 192, 195–198, 203–230 and 345–357 ka. These five periods roughly correspond to the S1, S2, S3, S4 and S5 paleosols in the Chinese Loess Plateau stratigraphy and also to the deep-sea oxygen isotope stages 5, 7, 9, 11, and 13–15. The upper four climatic periods are comparable to the four warm climatic periods recorded in the Laohushan Xiashu loess section. Discovery of stone implements from the sixth and the seventh layers during the archaeological excavation indicates human activities at that time, and the environmental proxies suggest that the environment was suitable for human activities.

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1. Introduction

Chinese loess-palaeosol profiles are now regarded as continental sediments of major importance for the study of global changes (Liu and An, 1985; An et al., 1991a). The magnetic susceptibility signal in these sequences has received notable attention because of its similarity to the deep-sea oxygen isotope record (Steven et al., 1989; Yang, 1991; Zhou et al., 1996). The Xiashu loess in the Yangtze Delta region has been studied for about 50 years. It is similar in origin to the loess of southern China (Huang et al., 1988). The source, cause and periods of formation of the Xiashu loess have been studied for some time (Huang et al., 1988; Zhang et al., 2000). However, these studies have concentrated on the natural sediments, to the neglect of the archaeological sections; especially those that date back to the mid-Pleistocene.

In this paper, we report the results of a study of a 5.67-m-thick aeolian sediment section exposed during the archaeological excavation of the Fangniushan palaeolithic site (31°55′N; 119°18′E), 20 m above sea level (a.s.l.) (Fig. 1). Grain-size, magnetic susceptibility, frequency-dependent magnetic susceptibility ($X_{fd}$) and Kd were measured for the purpose of determining the climatic changes in the mid-Pleistocene of this region. Based on these data, further studies will be undertaken to investigate the response of the regional climatic changes to global changes.

The vegetation of the study region is characterized by mixed deciduous and evergreen forest. Mean annual temperature is 15.5°C. In summer, the region is dominated by the Subtropical High and the mean monthly temperature reaches 28.9°C in July. In winter, the region is influenced by the Mongolian High and the
mean temperature is 3.3 °C in January (Jiang, 1991; Yu et al., 2000).

The importance of this section lies mainly in the following characteristics: (1) It is situated in East China and has a subtropical monsoon climate. It is synoptically sensitive because it is located along the transition from subtropical to temperate climatic zones. (2) It contains exceptional information about palaeolithic human activities. Thus, it may help to establish the nature of the relationship between climatic evolution and human activities in the mid-Pleistocene. Such studies will form an extension to earlier studies of the relationship between human activities and climatic evolution in the Neolithic (Yu et al., 2000).

2. Materials and methods

The section was divided into seven layers according to the colour of the sedimentary materials (Fig. 2). Forty-two samples were taken at intervals of either 10 or 20 cm from the bottom to the top of the section. Low-frequency magnetic susceptibility was determined in m³/kg using a Bartington magnetic susceptibility meter (MS2) and probe (MSF). The sensor emitted a 1-Oersted alternating magnetic field and the operating frequency of the probe was 580 Hz (Thompson and Oldfield, 1986). Particles coarser than 45 µm were first separated through a gravity screen box (SFY-A), while others were separated using an optical separator-size analyzer (SKC-2000). ESR dating was performed in the Structure Center of China Science and Technology University on four samples, one from each of the second, fourth, sixth, and seventh layers.

3. Experimental results

3.1. Numerical dating

ESR dating yielded 162±32; 192±38; 203±51 and 345±69 ka for layers 2, 4, 6 and 7, respectively (Fig. 2). Assuming that 0.73 Ma is the boundary between the middle and upper Pleistocene, the section provides a record of environmental evolution during the mid-Pleistocene.

3.2. Grain size

Four grain-size parameters, $M_Z$ (mean grain size), $\sigma_1$ (sorting coefficient), $SK_1$ (skewness), and $KG$ (kurtosis), were determined using conventional methods (Xu et al., 1992). $Y_1$ is a parameter related to the sedimentary environment, determined as $Y_1 = -3.5688M_Z + 3.7016\sigma_1^2 - 2.0766SK_1 + 3.1135KG$ (Xu et al., 1992). The maximum value of $Y_1$ is −4.92 (Table 1), indicating that the sediment is wind-blown in origin. ESR dating, field investigation and earlier research results (Huang et al., 1988; Wang and Cao, 1996) support this interpretation. The mean grain size of the sediments is 2.7–15.4 µm, which is much finer than aeolian sands and similar to paleosols. Standard deviations $\sigma_1$ are between 1.2 and 3.7, a well-sorted to poorly sorted range, reflecting an important feature of aeolian sediment (Sun et al., 2000). The values of $SK_1$ are $-0.57–0.6$, indicating a range from negative to positive skewness. KG values (0.52–1.79) indicate blunt to peaky kurtosis. The variance in these parameters suggests that
the Xiashu loess has been modified by secondary processes, especially pedogenesis. The obvious contrast between the Xiashu loess and the loess of northern China is the evidence for strong pedogenetic modification of the Xiashu loess. The origin and the formation processes also appear to have been more complex than those of the loess of northern China.

In order to quantify the effects of these differences, grain size data for aeolian sediments from several typical loess sections from north to south across China were collected (Table 2, Fig. 3). These results show that the percentage in the coarse sand grade decreases from north to south, and the percentage of fine sand and clay-size material increases from north to south, as shown by Liu and An (1985). These data indicate that the vigor of the winter monsoon decreased southward across China.

At the same time, the effect of climatic zonality with conditions southward warmer and more humid is reflected in the amount of secondary clay minerals. This is in line with the grain-size analyses performed on Xiangyang section of Xuancheng in Anhui province by Li et al. (1997).

### 3.3. Magnetic susceptibility

The concentration of magnetic minerals in sediments may be reflected by low-field magnetic susceptibility values (Nawrocki et al., 1996). In some sedimentary rocks, the distribution of magnetic susceptibility (MS) carriers depends on the climatic conditions in which they are deposited. MS has been used as a palaeoclimatic indicator particularly in loess-palaeosol sequences (e.g.
The magnetic susceptibility of the Xiashu loess has also been used as an environmental indicator (Li, 1993; Lu et al., 2000; Zhang et al., 2000). The MS record at the Fangniushan site shows three peaks and three troughs (Fig. 4). The most obvious MS values are two peaks and one trough. Small fluctuations also occur within both of these sets of peaks, indicating climatic instability. In recent studies of the loess-palaeosol sequences of northern China, particle size, and particularly the median grain size, has been widely used as a proxy measure of the vigor of the northwest winter monsoon (An et al., 1991b; Derbyshire et al., 1995; Porter and An, 1995). At Xiashu, however, this indicator must be applied with some caution because of the evidence of grain size changes induced by strong pedogenesis and secondary physical and chemical weathering processes. In the conditions at this site, grain size is not only a product of wind transport, but also pedogenesis and chemical weathering following sedimentation. These processes allow enhancement of the percentage of finer particles (Derbyshire et al., 1995). Fig. 4 suggests that, despite the effects of pedogenesis and post-depositional chemical weathering on the Xiashu loess, the trend of the median grain size curve is in part negatively correlated with MS, although this relationship is not as clear at Xiashu as it is in the loess-palaeosol sequence in north China.

Environmental magnetism properties of the loess indicate that, in contrast with MS, the frequency-dependent susceptibility \( (K_{LF} - K_{HF})/K_{LF} \times 100\% = X_{fd} \) has unambiguous environmental meaning (Liu et al., 1990). Frequency-dependent susceptibility values \( (X_{fd}) \) denote the amount of fine “viscous” ferromagnetic (magnetite or maghaemite) grains around 0.02 mm diameter (Thompson and Oldfield, 1986; Li and

<table>
<thead>
<tr>
<th>Loess</th>
<th>Grain size (%)</th>
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<tbody>
<tr>
<td></td>
<td>&gt;0.05 mm</td>
</tr>
<tr>
<td>Xifeng loess [1] (Mid-Pleistocene)</td>
<td>23.72</td>
</tr>
<tr>
<td>Luochuan loess [2] Upper part of Lishi loess (mid-Pleistocene)</td>
<td>10</td>
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<tr>
<td>Lower part of Lishi loess (mid-Pleistocene)</td>
<td>5.3</td>
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<tr>
<td>Xiashu loess of Dagang, Zhenjiang [3]</td>
<td></td>
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<tr>
<td>1 layer</td>
<td>0.82</td>
</tr>
<tr>
<td>2 layers</td>
<td>0.78</td>
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<tr>
<td>3 layers</td>
<td>0.65</td>
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<tr>
<td>Xiangyang section, Xuancheng, Anhui [4]</td>
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<tr>
<td>6 layers</td>
<td>3.09</td>
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<tr>
<td>9 layers</td>
<td>2.06</td>
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<tr>
<td>Fangniushan section, Jurong, Jiangsu</td>
<td>6.2</td>
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Oldfield, 1993). While MS may be a clearer indicator of strongly changing palaeoclimates, frequency-dependent susceptibility is sensitive to temperate climatic fluctuations, and it can reflect many details not detected by MS (Liu et al., 1990). This property of the frequency-dependent susceptibility is revealed in Fig. 3. The curves show, there are several peaks at depths of around 1.5–2.5 m, indicating warmer and more humid climatic conditions. In comparison, the MS values are low and the curve is rather unambiguous. The $X_{fd}$ changes match those in the clay percentages, a finding consistent with the production of finer “viscous” ferromagnetic minerals during pedogenesis. This result has also been found in the loess-palaeosol sequences of north China (Liu et al., 1990). On the basis of this evidence, it is tentatively concluded that the clay content in the Xiashu loess may be used as an indicator of climatic changes, although further study will be needed to test this supposition.

The Kd value (the ratio of silt content to that of clay, $Kd = (60–8 \mu m \div 5 \mu m)$) is accepted by some workers as an indicator of formative environments within the loess-palaeosol sequences of north China (e.g. Huang et al., 1988; Zhang et al., 2000). High Kd values indicate arid and cold environments, and low Kd represent warmer and more humid conditions (Liu and An, 1985; Zhang et al., 2000). There is a negative correlation between the Kd values and clay content, frequency-dependent MS, and MS. These environmental proxy indicators, together with ESR dating, combine to indicate at least five relatively warmer and more humid climatic periods during the period 400–130 ka. These are 130–90 ka; 192 ka; 195–198 ka; 203–230 ka and 345–357 ka, broadly corresponding to the five palaeosol layers S1, S2, S3, S4 and S5 (Fig. 5). They also roughly match the deep-sea (Hole V28-239) oxygen isotope stages 5, 7, 9, 11 and 13–15, respectively (Huang et al., 1988). The uppermost four warmer and more humid climatic periods roughly correspond to the uppermost four buried palaeosols in the Laohushan Xiaoqin section (Fig. 5). Kd values are notably low while the clay content and frequency-dependent MS have obvious peaks in the second warm–humid climatic period, an interpretation that receives some support from the $\delta^{18}O$ records of the stalagmite in the Tangshan H. Pithecanthropus cave in Nanjing (Wang et al. 1999). In the same period, at ~200 ka BP, the typical fauna in the north-east of China was of the Anping type, with typical species, Macaca robustus, Dicerorhinus Kirchborgensis, and Panthera youngi. This is also indicative of a warm and humid environment (You and Yu, 1989). Taken together, the evidence of climatic change in the study region is in general conformity with the established record of global climatic changes.

4. Discussion and conclusions

The Xiashu loess has undergone strong pedogenesis that produced an abundant fine grain-size component. Pedogenic processes distinguish the Xiashu loess from
the typical loess-palaeosol sediment section of north China.

Grain size analysis suggests that the sediments at Xiashu consist of loess. However, the broader range of variation of the grain size parameters suggests that the Xiashu loess is more complicated in origin. The clay content in the Xiashu loess serves as a proxy indicator of relatively strong pedogenesis and/or chemical weathering. To a certain degree, it is also an indicator of climatic changes, because the clay content increases in known periods of warmer and more humid climate. At the same time, stronger pedogenesis is marked by the greater abundance of finer “viscous” ferromagnetic (magnetite or maghaemite) grains (Zhou et al., 1990; Hus and Han, 1992), which explains the high frequency-dependent susceptibility values. However, further study is needed in order to test the relationship.

ESR dating, MS, frequency-dependent susceptibility, median grain size, Kd values, and clay percentage reveal five warmer and more humid climatic periods at 130–90; 192; 195–198; 203–230 and 345–357 ka, generally corresponding to the palaeosol layers OIS 5, 7, 9, 11 and 13–15. The periods 130–90; 192; 195–198 and 203–230 ka correspond to the uppermost four buried palaeosols at the Laohushan Xiashu loess section. This suggests that the Xiashu loess is a consistent indicator of global changes and that the climatic changes in the study region reflect Asian summer monsoon changes. The Ningzhen region lies in the Yangtze Delta, the transitional zone from subtropical to temperate climate, which is largely controlled by different dominant air masses. Such regions are particularly sensitive to climatic changes. The Xiashu aeolian sediments are widespread in the Yangtze Delta, thus providing important regional data on past climatic changes. They are worthy of study designed to construct a more complete climate-time sequence, and to help to define more precisely the relationship between regional climatic evolution and global changes, which includes broader influences, such as the uplift of the Qingzang Tibet Plateau and variations in the southeast (summer) monsoon.

A number of stone implements, discovered during archaeological excavation in the sixth and seventh layers, indicate human activity (about 340–360 ka according to ESR dating). Proxy indicators such as those used here indicate that conditions were warm and humid at that time and so were suitable for human occupation. Research at the *H. pithecanthropus* cave (Zhu et al., 1998) has suggested that the region in the

![Fig. 5. Comparison between the Fangniushan Paleolithic site section, Xiashu section of Laohushan, Nanjing, and Luochuan loess section (after Huang et al., 1988).](image-url)
mid-Pleistocene (~350 ka) was characterized by deciduous and broad-leaved vegetation, coniferous and ferny mixed forest, and without cold-tolerant plant genera, such as spruce or fir, indicating a relatively warm and humid environment. Thus, research has shown that these two Palaeolithic sites (the Tangshan H. pithecanthropus cave and the Fangniushan Palaeolithic site) were both occupied in periods when the climate was warm and humid.

Acknowledgements

This paper is financially supported by grants from National Natural Science Foundation of China (Grant 40271112), CAS key project (KZCX3-SW-331), National Post-doctoral Foundation of China and the K. C. Wong Education Foundation, Hong Kong. Prof. Derbyshire. E., Prof. Smalley, Prof. Jiri Chlachula, Prof. Norm R. Catto and Prof. Jan A. Piotrowski and other anonymous reviewers critically perused the manuscript and rectified the language. We are also grateful for other valuable comments from anonymous reviewers.

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