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# The impact of ancient civilization on the northeastern Chinese landscape: palaeoecological evidence from the Western Liaohe River Basin, Inner Mongolia

Y.Y. Li,[1,2]* K.J. Willis,[2] L.P. Zhou[1] and H.T. Cui[1]

*([1]Laboratory for Earth Surface Processes, College of Environmental Sciences, Peking University, Beijing 100871, China; [2]Long-term Ecology Laboratory, Oxford University Centre for the Environment, School of Geography, South Parks Road, Oxford OX1 3QY, UK)*

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**Abstract:** The Western Liaohe River Basin in northeastern China is one of the cradles of ancient Chinese civilization. Archaeological records from this region indicate that human occupation began about 8000 years ago and that agriculture and pastoralism were important activities from an early stage. Very little is known, however, about the effects that these activities had upon the landscape. This paper presents the results of a palaeoecological study from a 3.6 m sedimentary sequence in a relict oxbow lake in the Western Liaohe River Basin of southeast Inner Mongolia. The 5400-yr sequence indicates that human activities had a noticeable impact on an apparently open landscape. Buckwheat cultivation began as early as 5400 cal. yr BP with intensification of agricultural activities from approximately 4700 cal. yr BP. Nitrophilous plants such as *Solanum* and *Cerastium*, and also *Artemisia* were growing in the region at certain times, linked with fluctuations in the $\delta^{15}N$ record and probably indicative of increased pastoralism and unintentional/intentional manuring. Burning was probably used for clearance of the steppe vegetation for agriculture with a close relationship apparent between increased influx of microfossil charcoal and the presence of buckwheat. Superimposed upon this record of human impact is also clear indication of three significant intervals of climate change between 2900 and 2600, 1200 and 600 and 600 and 30 cal. yr BP. The latter two are discussed in relation to the 'Mediaeval Warm Period' and 'Little Ice Age' apparent in sedimentary sequences across the Northern Hemisphere. Discussions are therefore made in terms of the impact that both climate change and ancient Chinese civilizations had upon shaping the present day landscape and vegetation.

**Key words:** Holocene, human impact, environmental archaeology, pollen analysis, microfossil charcoal, nitrogen isotopes, civilization, Inner Mongolia, buckwheat cultivation.

## Introduction

Numerous archaeological studies indicate that Western Liaohe River Basin in northeastern China was one of the cradles of ancient Chinese civilization with a long history detailing remarkably distinctive local traditions (An, 1998; Linduff *et al.*, 2002–2004). Archaeological survey reveals numerous traces of human occupation at Western Liaohe River Basin since 8000 years ago (Chinese Academy of Social Sciences, Institute of Archaeology (CASS), 1983; Chifeng Comprehensive Archaeological survey Team (Chifeng), 2003; Zhao, 2006) with evidence of diversified early human activities including agriculture, pastoralism, gathering, hunting and fishing (Liu and Xu, 1981; CASS, 1983, 1998). Compared with South China, which has well-watered and highly productive farmland for rice, the Western Liaohe River Basin is thought to have remained cooler and drier during the Holocene with archaeological evidence to suggest that this region was the centre for Chinese dry farming as well as the place of origin for pastoral

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*Author for correspondence (e-mail: lyy@urban.pku.edu.cn)

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culture (Harlan, 1971; Yan, 1992; Lu, 1999). Presently, dry farming in northern China is characterized by planting foxtail millets (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*), which is quite different from the rice cultivation agriculture in southern China.

Where and when dry farming emerged in China has been a hot topic of debate (Yan, 1999; Shelach, 2000) and in particular the environmental conditions under which it developed. Previous attempts to reconstruct the palaeoenvironment of the northeastern region of China have been primarily centred around archaeological studies (Kong and Du, 1981; Kong *et al.*, 1991; Shi and Zhang, 1996; Yang and Sou, 2000; Cui *et al.*, 2002). Very few environmental records in the vicinity of archaeological sites have been found, impeding an assessment of the impact of human disturbance on the landscape in this region (Linduff *et al.*, 2002–2004) – an issue that is particularly relevant for China as a whole, given her long history of agriculture and the size of current and future populations and potential climate change.

In this study, we aimed to reconstruct the environmental history of northeastern China by examining a 3.6 m sedimentary record from a relict oxbow lake in the Western Liaohe River Basin (Figures 1 and 2). Presently the region is one of the extensive croplands surrounded by steppe vegetation characterized by *Stipa bungeana*, *Filifolium sibiricum* and *Aneurolepidium chinense*. A multiple-proxy approach involving palynology, microfossil charcoal, stable isotopes ($\delta^{13}$C and $\delta^{15}$N) and sediment geochemistry was taken in order to understand the contribution of natural climate variability and human activity to the vegetation dynamics. Particular attention was paid to the anthropogenic pollen indicators typical to this region including pollen from secondary shrubs (*Corylus*-like *Ostryopsis*), cultivated plants (mainly *Cerealia* and *Fagopyrum*), crop-weeds and ruderals (*Humulus*, *Plantago*, *Solanum*, *Artemisia* and Chenopodiaceae). Our results reveal a long history of impact upon the environment with little evidence of a 'natural' or 'undisturbed' landscape over the past 5400 years.

## Study area

The Western Liaohe River Basin is situated in a mid-latitude ecotone between a semi-humid zone and a semi-arid zone in northern China (41°17′N ~ 45°24′N, 116°20′E ~ 121°E) covering an area of approximately $9 \times 10^4$ km$^2$ (Figure 1). This region is characterized by a continental monsoon climate; a mean annual temperature that varies from 5 to 6.7°C, and annual precipitation from 330 to 500 mm. The northern and western parts of the region are relatively cold and wet while the eastern part is drier, and the southern part is more moist with higher temperature. Two river systems dissect the region, namely the Xilamulun and Laohahe Rivers. Vegetation in the region is composed of meadow steppe in the western plateau; woodland and forest steppe in northern and western mountains; steppe in northern and western low hills and plains; and drifting and semi-drifting sand with sparse elm in the eastern sand fields. Extensive croplands are found in the southeastern loess hill and plains, and transverse all zones of vegetation (Figure 1).

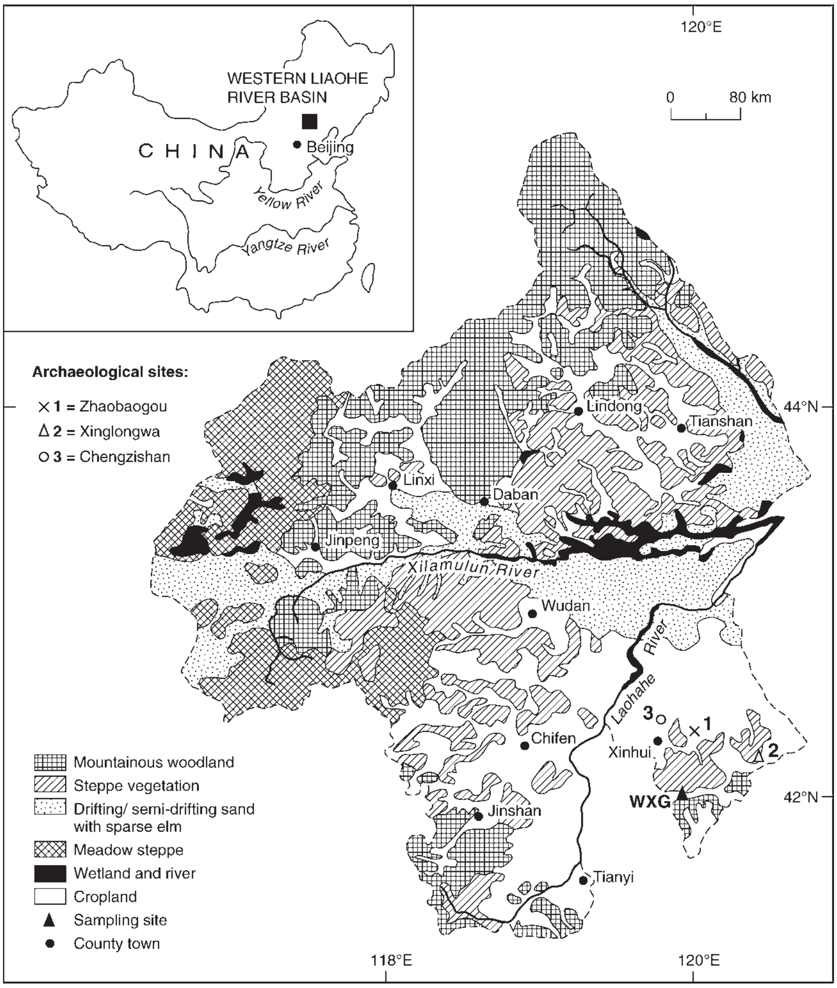

**Figure 1** Map of study area (Western Liaohe River Basin) indicating the distribution of regional vegetation

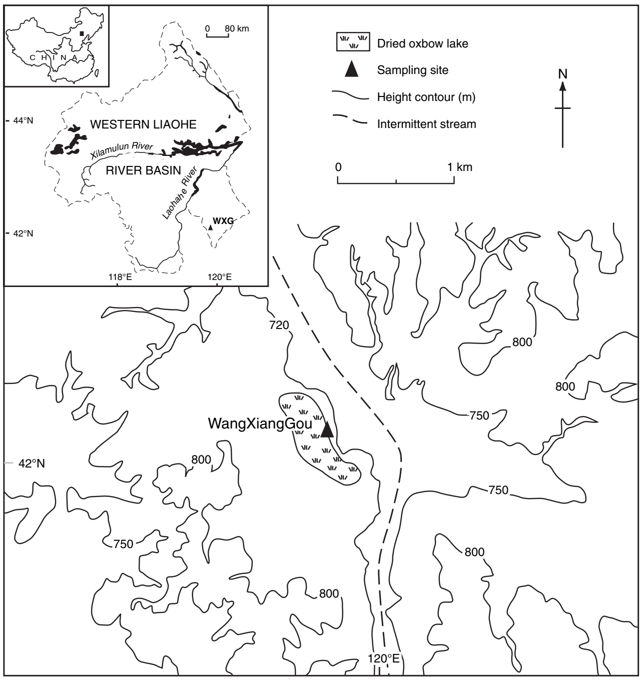

**Figure 2** The locality of the WangXiangGou (WXG) site

The sedimentary sequence was collected from a buried relict oxbow lake (Figure 2). Recent erosion along a tributary of Laohahe River has exposed the organic sediments at an outcrop named WangXiangGou (WXG) located at the foot of southern loess hill (119°55′E, 42°04′N, 751 m a.s.l.) (Figure 2). The profile is 360 cm thick, consisting of mainly organic silts and clay. Arable land is found around the site presently but it is probable that the undisturbed vegetation should be forest-steppe. Only scattered steppe and planted *Populus* forest can be seen locally but on the mountains slopes, at higher elevation, there are forests consisting of *Populus davidiana*, *Betula platyphylla*, *Pinus tabulaeformis*, *Corylus heterophylla*, *Ostryopsis davidiana* and *Prunus ansu*.

## Regional archaeology and culture

In the vicinity of the sampling site, numerous archaeological sites have been found, indicating continuous human occupation since about 8000 years ago. A major shift from sedentary agriculture to pastoral culture occurred during the Upper Xiajiadian period around 3200 cal. yr BP (Table 1). Since then, it is thought that pastoralism has been prevalent. Based on the regional archaeological survey data of Inner Mongolia, Hu and Cui (2002) showed the changes in the number of occupation sites for a given surveyed area in the vicinity of three key archaeological sites within the study region, i.e, Zhaobaogou, Chengzishan and Xinglongwa (Figures 1 and 3). Examination of the number of occupation sites during the different cultural periods indicates that the distribution of sites is dense during the Hongshan culture (6660–4900 cal. yr BP), Lower Xiajiadian (4100–3300 cal. yr BP) and Liao-Jin (1000–716 cal. yr BP). There is a marked decline in the number of occupation sites in the intervening interval. There is, however, an increase in the spatial extension of the sites during Upper Xiajiadian (3200–2200 cal. yr BP), which is thought to reflect the weakening of land potential capacity of the time (Deng, 2005). However, this feature is different from the patterns revealed by an analysis of data collected by a systematic archaeological survey of a much larger area conducted to the northwest of our study area (Figure 4.1 of Drennan *et al*., 2003). Instead of a dramatic decline, Drennan *et al*. (2003) found only a modest decrease in the number of occupation sites from Lower Xiajiadian to Upper Xiajiadian; the two periods represent a substantial peak in the archaeological indications of population density.

## Methods

### Field and laboratory techniques

The 3.6 m profile was sampled at the exposed face, cutting out contiguous sections 2 cm thick using a cleaned knife. The samples were stored in plastic bags and returned to the laboratory for analysis. In the laboratory, samples were analysed at 4 cm intervals throughout the sequence for pollen, microfossil charcoal and stable isotopes ($\delta^{13}C$ and $\delta^{15}N$).

Subsamples of approximately 30 g of air-dried sediment were collected for pollen analysis. These were prepared following standard laboratory procedures including hydrochloric acid, sodium hydroxide, hydrofluoric acid and floatation with heavy liquid (specific gravity of 2.0) (Berglund and Ralska-Jasiewiczowa, 1986). One tablet containing a known number of *Lycopodium* spores was added to each subsample at the beginning of sample preparation in order to calculate the pollen concentration and influx. Pollen identification was performed by comparison with the modern pollen reference collection in the Quaternary Bio-remains Laboratory of Peking University and previous publications (Xi and Ning, 1994; Wang *et al*., 1995). In order to ensure a statistically significant sample size a minimum of 300 grains of terrestrial pollen and spores were counted for each subsample. Scanning electronic microscopy was used in the detailed identification of pollen types of special interest, such as buckwheat.

Samples for microfossil charcoal analyses were prepared as part of the routine pollen analysis (Whitlock and Larsen, 2001) and the microfossil charcoal concentration in each sample was determined using the point count method (Clark, 1982). This provides an estimate of the area of microfossil charcoal covering each slide counted assessing this measurement against

**Table 1** The series for ancient civilization in the Western Liaohe River Basin

| Period | Cal. yr BP | Main human activities |
|---|---|---|
| Qing Dynasty | 39 ~ 306 | pastoralism and agriculture |
| Ming Dynasty | 406 ~ 582 | agriculture and pastoralism |
| Yuan Dynasty | 582 ~ 779 | pastoralism prevails accompanied by agriculture |
| Jin Dynasty | 716 ~ 835 | agriculture and pastoralism |
| Liao Dynasty | 825 ~ 1034 | agriculture and pastoralism |
| Late Tang Dynasty – Eastern Wei | 1043 ~ 1369 | agriculture and pastoralism |
| Sixteen nations – Warring States | 1361 ~ 2445 | pastoralism prevails with agriculture |
| Upper Xiajiadian | 2200 ~ 3200 | pastoralism prevails |
| Lower Xiajiadian | 3300 ~ 4100 | sedentary agriculture with hunting-gathering |
| Xiaoheyan | 4100 ~ 4800 | agriculture depression, mainly hunting-gathering |
| Fuhe | *c.* 5300 | mainly hunting-gathering with agriculture |
| Hongshan | 4900 ~ 6660 | sedentary agriculture with gathering |
| Zhaobaogou | 6150 ~ 7150 | sedentary agriculture with hunting-gathering and fishing |
| Xinglongwa | 7350 ~ 8150 | hunting-gathering, fishing with primitive agriculture |
| Xiaohexi | 8150 onwards | hunting-gathering and fishing |

the exotic pollen count and taking into account the sediment accumulation rate. Using this method, a measure of charcoal influx ($cm^2$ $cm^{-2}$ per yr) per sample was obtained.

Because of the low organic carbon content of the sediment samples submitted for dating, a relatively large quantity of bulk materials was required for radiocarbon dating and the conventional radiocarbon method was employed. Seven samples were divided into two groups and dated at the $^{14}$C dating laboratory of Peking University and State Seismological Bureau of China, respectively (Table 2).

Extraction and measurement of $\delta^{13}C$, $\delta^{15}N$, TOC and TN (total organic carbon and total nitrogen expressed as%) in the sedimentary sequence were carried out using the method outlined in Talbot (2001). Subsamples of approximately 1 $cm^3$ were taken throughout the profile at the same sampling interval as for the pollen and microfossil charcoal samples. They were dried at $<40°C$ and then ground with a mortar and pestle into fine powder and transferred to clean disposable pots for storage. A treatment with dilute HCl was applied to approximately half of the samples in order to remove calcium carbonate. Samples of between 2 and 10 mg (depending on the estimated organic content) were accurately weighed directly into cleaned tin capsules ready for analysis. The total nitrogen (TN) and $^{14}N/^{15}N$ isotope ratio were determined using a COSTECH elemental analyser coupled to a Thermo Finnigan MAT253 mass spectrometer via a Conflo III interface at the Godwin Laboratory, University of Cambridge. The total organic carbon (TOC) and $^{12}C/^{13}C$ isotope ratio were measured with a Delta plus XP mass spectrometer coupled with an elemental analyser in a continuous flow mode at the Department of Plant Nutrition, China Agricultural University. The weight percentages of TOC and TN were used for the calculation of C/N mass ratio. A series of isotopic standards and calibration samples were run at intervals between the samples and the precision of the isotopic analyses is between 0.10 and 0.20‰.

## Data handling

The conversion from radiocarbon dates to calibrated years was made using the programme CALIB 4.1.2 (Stuiver and Reimer, 1993). The relationship between age and depth was modelled using *Psimpoll* 4.10 programme (Bennett, 2002), which resulted in an age model for the entire sequence.

The raw pollen data were constructed into a percentage diagram based on the sum of total arboreal pollen (AP) and

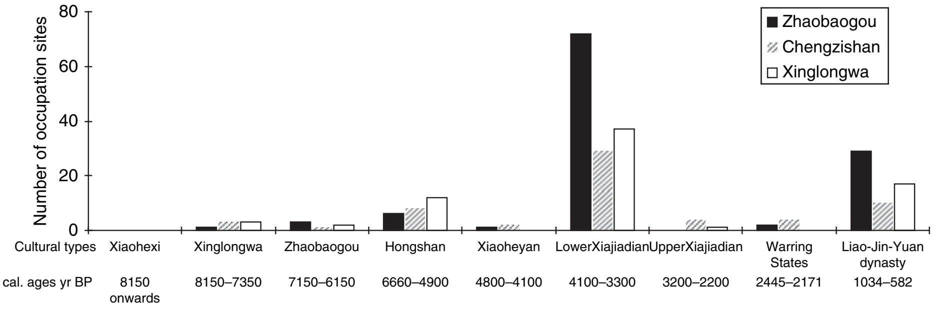

**Figure 3** Number of occupation sites within a given surveyed area for three areas: Zhaobaogou, Chengzishan and Xinglongwa

**Table 2** Radiocarbon dates for WangXiangGou profile

| Laboratory code | Dating material | Depth (cm) | C age (yr BP) | Calibrated age (cal. yr BP) |
|---|---|---|---|---|
| BK200033[a] | Sediments | 28–32 | 985 ± 60 | 930 ± 80 |
| BK96040[a] | Sediments | 40–60 | 1065 ± 75 | 960 ± 65 |
| BK200032[a] | Sediments | 94–98 | 1430 ± 60 | 1310 ± 40 |
| BK96039[a] | Sediments | 200–220 | 2535 ± 80 | 2710 ± 140 |
| CG-4000[b] | Sediments | 244–248 | 3120 ± 140 | 3360 ± 195 |
| BK96038[a] | Sediments | 320–340 | 3985 ± 85 | 4420 ± 130 |
| CG-4001[b] | Sediments | 356–360 | 4660 ± 170 | 5370 ± 250 |

[a] Measured at Peking University.

[b] Measured at State Seismological Bureau of China.

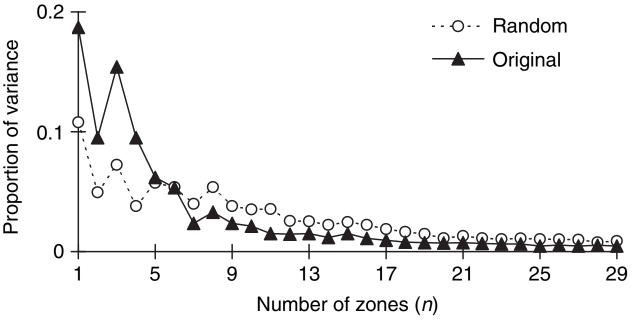

**Figure 4** Variance accounted for the *n*th zone as a proportion of the residual variance after $n-1$ zones, comparing the original data set with the same data set after randomization of the samples. The significance of zones was determined with the broken-stick model

non-arboreal pollen (NAP), excluding spores. The percentage of *Selaginella* spores was calculated on the basis of the sum of pollen and ferns. The pollen data were analysed and plotted against age using the *Psimpoll* 4.10 programme (Bennett, 2002). In order to determine how many zones are most appropriate for the WXG pollen data set, the original data were simulated for zonation and compared with the same data set after randomization of the samples (Figure 4). The division of pollen zones was carried out using optimal splitting and a determination of the number of significant zones was calculated using a broken-stick model (Bennett, 1996, 2002).

In order to quantitatively view any trends in the pollen data set independent of those related to depth and the possible relationship of pollen taxa with microfossil charcoal and nitrogen isotopes, principal components analysis (PCA) of pollen percentage was performed using CANOCO 4.5 (Birks, 1995; ter Braak and Smilauer, 2002).

Rate-of-change analysis was also performed on the data set in order to examine where the greatest amount of change in vegetation over time occurs. The method used here involved measuring the dissimilarity between adjacent samples using chord distance and dividing this measure by the temporal difference between the samples (Bennett and Humphry, 1995); the higher the chord-distance the greater the rate of change.

# Results

## Chronology

Seven $^{14}$C ages on bulk samples were obtained for the sedimentary sequence (Table 2) from two laboratories and these are stratigraphically consistent. From these dates it is apparent that sediment deposition at WangXiangGou began from the middle Holocene at 4660±170 $^{14}$C yr BP (5370±250 cal. yr BP). Results from age–depth modelling indicate that a best-fit of third-order polynomial curve provides the most realistic description for the seven data points (Figure 5). No hiatus is found and the average accumulation rate of the sequence is 66 cm/ka, corresponding to a temporal resolution of 15 yr/cm. As previous studies in the region have been mostly based on fragmentary records, the WXG sequence therefore provides an excellent opportunity for a detailed investigation on vegetation history in relation to regional climate change and human activities.

## Pollen

Sixty-one samples were analysed for pollen and the results presented in a pollen percentage diagram (Figure 6). Results

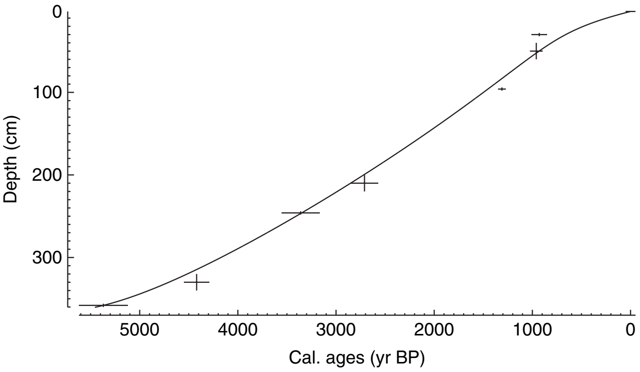

**Figure 5** Age–depth plot for WangXiangGou profile based on calibrated radiocarbon dates

from the zonation of the pollen diagram revealed that five zones of characteristic pollen assemblage can be identified with optimal division using the sums-of-squares statistical method. Zone boundaries occurred at 218, 194, 74 and 14 cm. The main features of each will be described briefly in turn.

### *Zone W-1 (360–218 cm, 5400–2900 cal. yr BP)*

In the lowermost section of the diagram, pollen from open ground vegetation types accounts for between 60 and 80% of the total pollen. These include *Artemisia*, Chenopodiaceae and *Fagopyrum*. Although the tree pollen content is low throughout this zone, the species diversity is high. Tree types indicating a small but persistent presence include warm-temperate broadleaved tree pollen such as *Castanea*, *Celtis*, Anacardiaceae, *Pterocarya* and the temperate broadleaved trees such as *Quercus*, *Betula*, *Pinus*, *Ulmus*, *Juglans*, *Alnus*, *Tilia* and *Salix*. There is also a continuous presence of *Selaginella* spores throughout the zone.

### *Zone W-2 (218–194 cm, 2900–2600 cal. yr BP)*

This is a short yet distinctive zone and is characterized by a sharp decline in tree pollen resulting in the lowest AP/NAP for the entire sequence. Arboreal pollen consists mainly of *Corylus*-type pollen. In the herbaceous pollen record there is clear decline in *Artemisia* and a rise in Chenopodiaceae. There is also a rise in Gramineae (Poaceae) pollen (to approximately 5%).Two peaks occur in the chord distance curve, suggesting a rapid change in vegetation at this time.

### *Zone W-3 (194–74 cm, 2600–1200 cal. yr BP)*

The AP/NAP remains low throughout this zone although higher than in zone W-2 below. Chenopodiaceae pollen shows a sharp decline and is replaced by *Artemisia*. Arboreal pollen remains low with *Corylus*-type pollen accounting for approximately 10% of the total pollen.

### *Zone W-4 (74–14 cm, 1200–350 cal. yr BP)*

There is a dramatic increase in AP/NAP at the beginning of this zone. The increase is primarily related to a rise in *Corylus* pollen, with an average percentage of 32%. *Fagopyrum* pollen also attains percentages as high as 40%. Other tree taxa present include *Betula*, *Quercus*, *Pinus*, *Juglans*, *Carpinus* and *Rhamnus*. There is a fluctuation in *Artemisia* but, towards the end of this zone, herbaceous plants show a rising trend. A distinct peak in the chord distance curve occurs at the beginning of the zone, documenting the highest rate of change in vegetation for the sequence. There is an obvious decrease in the rate of change at 28 cm depth (600 cal. yr).

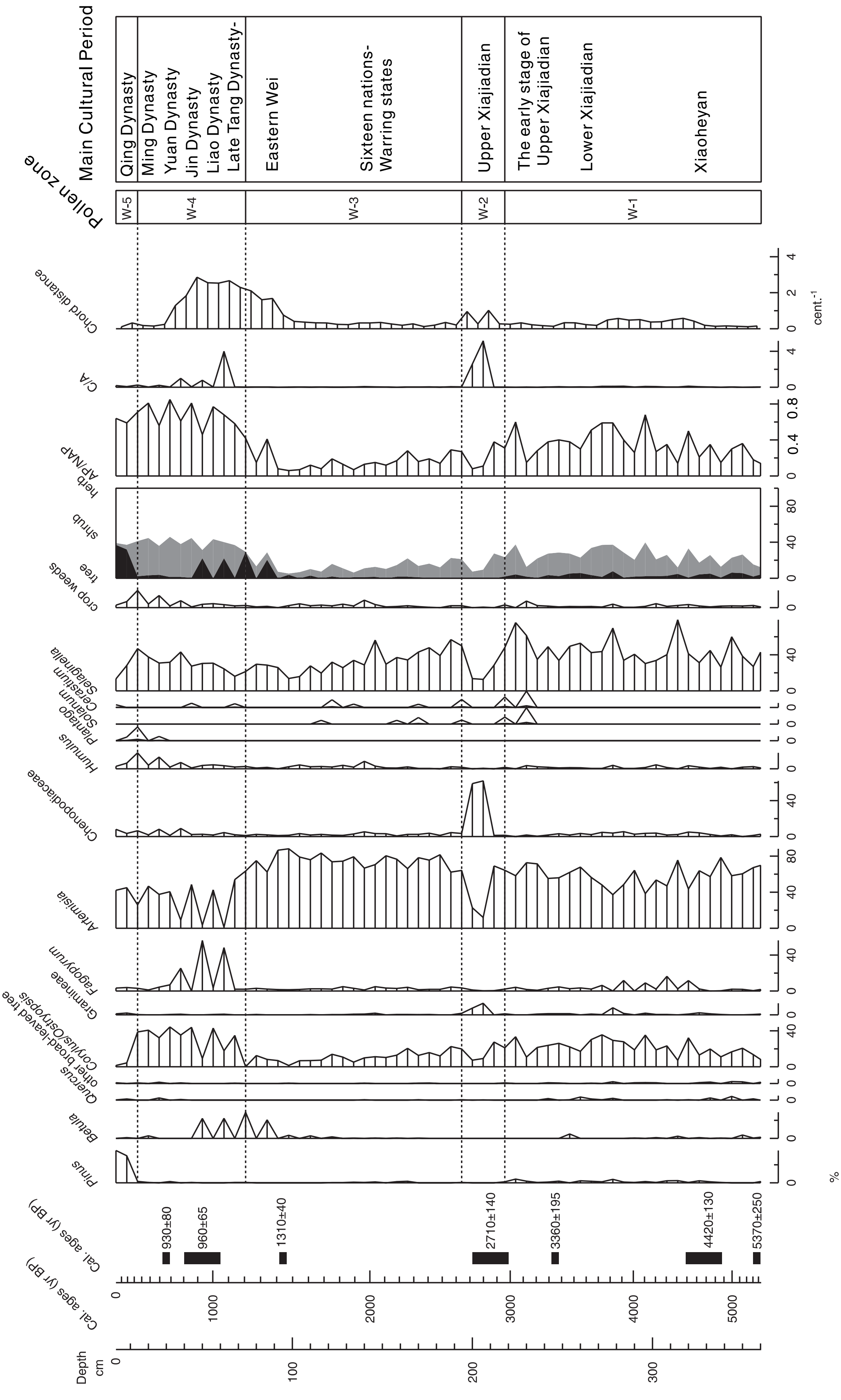

**Figure 6** Percentage diagram of selected pollen and spores from the WangXiangGou profile along with the main cultural periods and the rate of change in pollen as indicated by the chord distance

### *Zone W-5 (14–0 cm, 350 cal. yr BP to present)*

This zone is characterized by a clear rise of *Pinus* pollen, resulting in a high AP/NAP ratio. *Corylus* pollen and *Selaginella* spores decrease sharply, while the average content of *Artemisia* and Chenopodiaceae shows little change. Herbaceous pollen is at its highest content in the beginning of the zone but gradually decreases. *Fagopyrum* remains present in this zone.

## Microfossil charcoal

Results of the microfossil charcoal analysis are presented in Figure 7. Two intervals of higher influx are observed: one is in the lower part of the profile around 4420 cal. yr BP; the other is in the upper part of the profile with an increase around 1400 cal. yr BP and reaching a distinctive peak around 950 cal. yr BP. The peak is within the pollen zone W-4 where high *Fagopyrum* pollen is found. Frequent but minor fluctuations are seen in the rest of the microfossil charcoal record.

## Stable isotopes

Figure 7 plots the results of the nitrogen and carbon analysis. Measurement of the isotopic ratio of $^{14}N/^{15}N$ ($\delta^{15}N$), $^{12}C/^{13}C$ ($\delta^{13}C$) and also total nitrogen (TN), which is dominated by organic nitrogen in lake sedimentary sequences, has been previously demonstrated to be an important proxy for the identification of changes in nitrogen in the soils and vegetation around the basin and also in the lake basin itself (Talbot, 2001). The nitrogen extracted from organic lake sediment reflects both material that has been ‘fixed’ by the algae in the lake (from drainage into the lake from the surrounding soils in the watershed by overland and throughflow) and also nitrogen in any plant material (eg, leaves, seeds, twigs) washed into and preserved in the lake sediment.

Previous studies have indicated a relationship between climate change, vegetation dynamics and nitrogen cycling (eg, Talbot and Johannessen, 1992; Wolfe *et al.*, 1999). An examination of $\delta^{15}N$ in lake sediments to detect past human influence upon the soils, however, has rarely been carried out; yet investigations on modern lakes with sedimentary sequences spanning the last 100–200 years indicate that it can provide important additional information on the impact of agricultural and sewage disposal practices (Talbot, 2001). A study of sediments from Lake Ontario (Canada), and the Greifensee (Switzerland), have revealed, for example, rising trends in $\delta^{15}N$ and total organic nitrogen from the nineteenth through to the twentieth centuries. This is thought to be associated with increased effluent discharge into the lakes (sewage N is relatively enriched in $\delta^{15}N$) (Heaton, 1986) and increased input of soil N into the basin resulting from deforestation and agriculture.

There are a number of mechanisms that can account for changing values of $\delta^{15}N$ and total organic nitrogen in lake sediment and fundamental to their interpretation is a knowledge of the origin of the organic matter from which the values are derived (Wolfe *et al.*, 1999). One of the most important things to determine is whether the values are derived from changes in aquatic productivity (recorded in algae) and thus reflecting changes in the amount and type of dissolved inorganic nitrogen (DIN) entering the basin in response to changes in and around the basin, or a change in the input of macrofossils of terrestrial origin.

A method to determine the source material of the organic matter in the sedimentary sequence is to measure the $\delta^{13}C$ value of the organic material. This is because most terrestrial plants are $C_3$ and have a $\delta^{13}C$ value between $-25‰$ and $-29‰$. In contrast, algae have a $\delta^{13}C$ value between $-12‰$ and $-26‰$ (Talbot and Johannessen, 1992; Meyers, 1994). Using a measure of the $\delta^{13}C$ it should therefore be possible to determine the source material for the $\delta^{15}N$. However, the situation is slightly more complicated than this because $C_4$ plants and aquatic plants have a $\delta^{13}C$ value between $-12‰$ and $-16‰$ and therefore overlap with the algal values. $C_4$ plants are mainly those adapted to hot and seasonally dry conditions but include, significantly for this region, grasses (Poaceae). Therefore a further method to determine whether organic material with a $\delta^{13}C$ value of between $-12‰$ and $-16‰$ is from a $C_4$ or aquatic plant, or algae, is to measure the C/N ratio. This is because algae typically have atomic C/N ratios between 4 and 10, whereas vascular plants, including aquatic macrophytes, have C/N ratios $\geq 20$ (Meyers, 1994).

Results from the nitrogen and carbon measurements are presented in Figure 7. The first thing to note is that the organic matter which is responsible for the $\delta^{15}N$ values is almost certainly algal, since the material has a $\delta^{13}C$ value of around $-22‰$ and a C/N ratio between 8 and 14. It is also probable that this has remained the principal source throughout the sequence; there is very little variation in either of these values throughout. The total nitrogen, which is dominated by organic nitrogen and $\delta^{15}N$ measurements, therefore reflects the type and amount of nitrogen being ‘fixed’ by the algae communities in the lake sediment.

The total nitrogen measurements indicate an increase from approximately 2000 cal. yr BP which is possibly related to soil erosion. The $\delta^{15}N$ measurements are more variable up through the sequence and probably reflect a number of different processes (both physical and chemical) that can affect the isotopic ratio of $^{14}N$ to $^{15}N$ in lake sediments (Talbot, 2001). However, results from the PCA indicate there is a probable linkage between some of the peaks in $\delta^{15}N$ and the presence of the nitrophilous plants *Solanum* and *Cerastium* (Figure 8); possibly reflecting an increase in dissolved inorganic nitrogen in the soils and subsequently their run-off into the basin and the uptake of N by the algae. These two species are most likely *Solanum nigrum* and *Cerastium arvense*, which are growing in the region presently and are found in fields used for pastoralism. This could result, for example, from anthropogenic factors such as intentional and unintentional manuring associated with pasturing (Koerner *et al.*, 1997). Previous research has demonstrated that an increase in the amount of dissolved inorganic nitrogen in a lake basin results in preferential incorporation of $^{14}N$ into algal cell material, inevitably leading to a corresponding $^{15}N$ enrichment in the remaining DIN and subsequently the sedimentary record (Talbot, 2001).

## Principal components analysis

Results from the PCA ordination of the WangXiangGou pollen data set (Figure 8) indicate that approximately 50% of the variance in the major pollen taxa is explained by the first two component axes. Anthropogenic pollen taxa including *Humulus*, *Plantago*, Chenopodiaceae, Gramineae, *Fagopyrum* and crop weeds are found to cluster in a group and show greatest variance with *Artemisia* and two nitrogen-preferring pasture plants *Solanum* and *Cerastium*. Microfossil charcoal data show close association with *Fagopyrum*, *Humulus*, Gramineae and Chenopodiaceae. The nitrogen isotope data ($\delta^{15}N$) display a positive correlation with the two clustered nitrophilous plants, *Solanum* and *Cerastium*. The PCA results also show that axes 1 and 2 explain 43% of the variance in the correlations and class means of species with respect to the microfossil charcoal and $\delta^{15}N$ when the two are used as environmental variables.

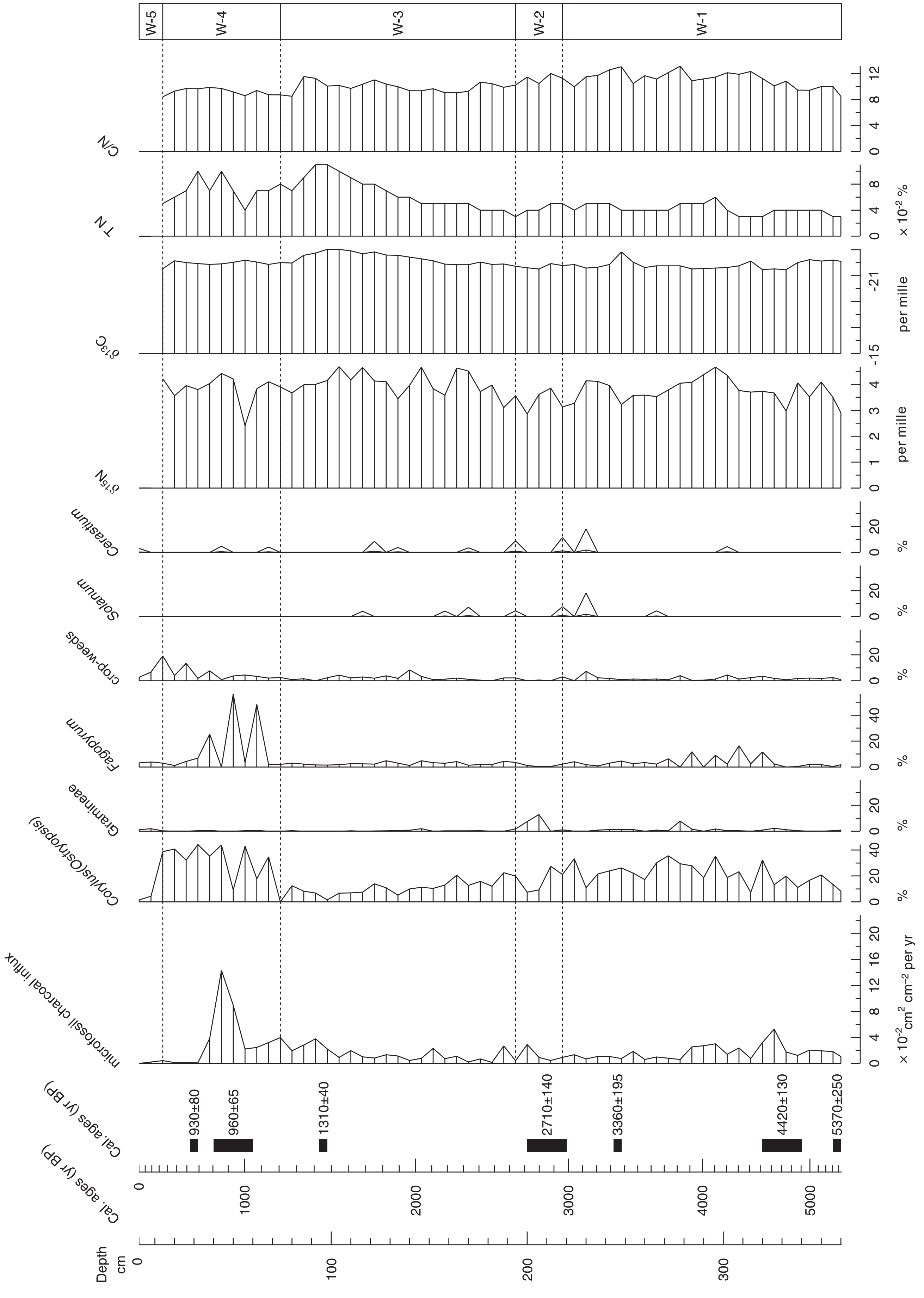

**Figure 7** Microfossil charcoal, open ground vegetation and isotopic data for WangXiangGou profile

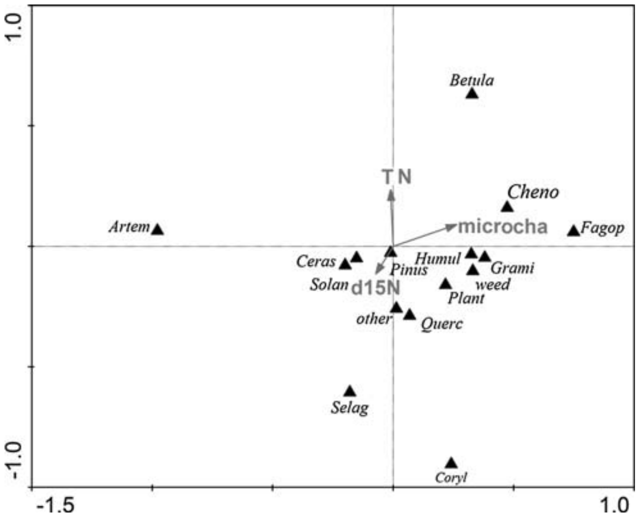

**Figure 8** Principal components analysis (PCA) correlation biplot showing the relationship between main pollen and spore taxa, microfossil charcoal and nitrogen isotope from WangXiangGou profile. Axes 1 and 2 are significant and explain over 50% of the total variance in the species data, and 43% of the variance in the correlations and class means of species with respect to environmental variables (microfossil charcoal and $\delta^{15}$N). *Fagop*, *Fagopyrum*; *Humul*, *Humulus*; *Cheno*, Chenopodiaceae; *Grami*, Gramineae; *Plant*, *Plantago*; *Querc*, *Quercus*; other, other broad-leaved trees; *Selag*, *Selaginella*; *Coryl*, *Corylus and Ostryopsis*; *Ceras*, *Cerastium*; *Solan*, *Solanum*; *Artem*, *Artemisia*; microcha, microfossil charcoal; TN, total nitrogen; d15N, $\delta^{15}$N

# Discussion

## The impact of ancient civilization on the northeastern Chinese landscape

Archaeological evidence from northeastern China indicates that settlement has been occurring on this landscape for at least the past 8000 years (Figure 3). It is also known that during periods of occupation, crops were grown and animal husbandry was undertaken. However, the extent to which activities such as agriculture and pastoralism affected the surrounding landscape remains unknown. It is also unknown how much impact climatic anomalies such as the ‘Little Ice Age’ and ‘Mediaeval Warm Period’, first documented in climate records from Western Europe, had upon the Chinese landscape. Results from this study therefore provide an important benchmark for determining the impact of the ancient Chinese civilizations and late Holocene climate change upon the northeastern Chinese landscape. They also provide an important record of the different types of anthropogenic indicators apparent in palaeoecological sequences from northeastern China.

The WangXiangGou sequence of Western Liaohe River Basin spans the last 5400 years and there are indicators of human activity for the entirety of the sequence. These indicators, however, are apparent upon an already ‘open’ landscape. It is probable that if this landscape was ever wooded, clearance occurred before 5400 years; throughout the pollen diagram, tree and shrub pollen accounts for less than 40% of the total pollen and between 5500 and 1000 cal. yr BP this value rarely exceeds 10%. The predominant herbaceous vegetation is composed of *Artemisia* with very low percentages of grasses (Figure 6). However, recent studies on present-day pollen productivity in the woodland-steppe ecotone in southeastern Inner Mongolia, China (Liu *et al*., 1999; Li *et al*., 2000a,b) have revealed that Gramineae pollen is seriously under-represented in these landscapes.

The only shrub-pollen that indicates a continuous presence throughout the sequence is *Corylus*-type and this can probably be attributed almost entirely to *Ostryopsis davidiana* and *Corylus heterophylla* that grow in the region presently. These are light-preferring species and mainly occur along forest edges (Chinese Academy of Sciences, Inner Mongolia–Ningxia Comprehensive Survey Team (CAS), 1985) or growing as secondary shrubs following forest clearance. The presence of these shrubs, plus spores from *Selaginella*, which is a dry-preferring species and often found growing in the margin of woodland (Zhang and Kong, 1999), could either suggest that these species are relicts of a once wooded landscape or, more likely, are indicative of a forest-steppe landscape similar to that found presently in the region on the higher elevation mountain slopes.

Given that this landscape has remained essentially ‘open’ for the past 5400 years, it presents a far more challenging task to identify the impacts of human activity than from a (more usual) palaeoecological study in which human impact can be determined by a change from predominantly tree-pollen to open-ground herbaceous pollen, as documented in Europe (eg, Dimbleby, 1985; Birks *et al*., 1988; Willis *et al*., 1998, 2004; Foster, 2002). In the WangXiangGou sequence there are a number of subtle indicators of human activity and also climate change and each of these will be discussed with reference to the cultural periods within which they appear.

## The cultural periods of Xiaoheyan and Lower Xiajiadian (5400–3300 cal. yr BP)

The lowermost zone (W-1) in this sequence corresponds to the cultural periods of Xiaoheyan, Lower Xiajiadian and the early stage of Upper Xiajiadian. Archaeological evidence (Table 1; Figure 3) suggests that Lower Xiajiadian (4100–3300 cal. yr BP) had intensive agricultural activities. Evidence from the palaeoecological sequence (Figure 6) indicates that buckwheat (*Fagopyrum*) was one of the crops being grown in the region from as early as 5400 cal. yr BP, presumably relating to the Xiaoheyan cultural period. Increase in values of *Fagopyrum* pollen, weeds associated with croplands and burning occurred from approximately 4700 cal. yr BP and is probably associated with an increase in agricultural activities possibly relating to increased population size (Figures 3 and 6). It is noticeable, however, that the values of *Fagopyrum* are significantly lower than for the later period (zone W-4; 1200–350 cal. yr BP) when this crop was also being grown. A possible explanation for this difference might be that during the earlier interval it reflects less extensive planting of the crop because of rather primitive agricultural implements and/or smaller population densities. A similar situation was recorded in the adjacent Northeast China Plain where the earliest occurrence of buckwheat cultivation was dated to AD 902–1125 cal. yr (Makohonienko *et al*., 2004).

In other palaeorecords a cold event has been documented in China around 4000 cal. yr BP which was considered to be responsible for the collapse of the Neolithic cultures (eg, Zhang *et al*., 1997), similar to the sudden collapse of the Akkadian empire in the Near East due to a shift to more arid climate at *c*. 4200 cal. yr BP (Weiss *et al*., 1993). The evidence for such an event in Zone W-1 of the WXG record is not apparent, and needs further investigation.

## The Upper Xiajiadian culture between 3200 and 2200 cal. yr BP

In the archaeological record the Upper Xiajiadian culture represents a key transitional period from a predominantly agriculturally based society to one based on pastoralism. Therefore during much of the period (3200–2200 cal. yr BP), although evidence for settled farming still existed (Drennan *et al.*, 2003), pastoralism gained a much more important position in the economy, and it is suggested that this eventually led to the development of the steppe landscape. The cause of this transition has been the subject of much debate (Qiao, 1992; Tian and Guo, 1997).

Regional archaeological investigations suggest that pastoralism culture started in the Western Liaohe River Basin from 3200 cal. yr BP (Yang, 1994; Wu, 2002). This date ties in closely with evidence from the WangXiangGou sequence for an increase of nitrophilous plants *Solanum* and *Cerastium*, and a slight increase in $\delta^{15}$N. Both are thought to be indicative of a $\delta^{15}$N-enriched nitrogen pool in the soils and, as demonstrated in previous studies, probably resulting from animal excreta (Koerner *et al.*, 1997) through unintentional manuring.

Between 2900 and 2600 cal. yr BP (zone W-3), however, a dramatic change occurred in the vegetation, as evidenced in the rates of change data (chord distance). There was a large increase in Chenopodiaceae, a small increase in grasses and a decline in all other taxa, including those associated with anthropogenic activity. The large increase in Chenopodiaceae relative to *Artemisia* has been shown from other records from dry-land non-forested areas to be a good indicator of aridity (El-Moslimany, 1990; Liu *et al.*, 1999) and is probably the same here. The dramatically increasing C/A ratio seen between 2900 and 2600 cal. yr BP is therefore taken to be indicative of increasing aridity (Figure 6) and this interpretation is supported by evidence from other independent climate proxies; the absolutely dated oxygen isotope record from Dongge Cave stalagmite in southern China, for example, records an interval of increased aridity around 2800 cal. yr BP (Wang *et al.*, 2005).

So was this dry event responsible for the transition from agriculture to pastoralism? Our pollen record at WangXiangGou indicates that the climate began to change towards drier conditions from 2900 cal. yr BP, rather than 3200 cal. yr BP, and that the change to pastoralism occurred before this event (from both archaeological and palynological evidence). The two are therefore not temporally related. However, the short interval of severely dry climate during 2900–2600 cal. yr BP, seemed to have had a long-term effect on the vegetation with dry steppe vegetation, containing very few shrubs remaining on the landscape for approximately 1000 years, and this may have had an influence on the subsequent communities to occupy this region.

## The ancient civilizations between *c.* 2445 and 1361 cal. yr BP

At least six different cultures existed in this region over the following 1000 years (Table 1), the most predominant being the Warring States (Zhan Guo) between 2450 and 2171 cal. yr BP. From the archaeological evidence, however, all of these cultures had one thing in common and that was the prevalence of pastoralism over agriculture in their activities. This is also apparent in the palaeoecological record with only a small presence of pollen from buckwheat and weeds associated with croplands (eg, *Humulus*), the latter starting to show a slight increase from approximately 2000 cal. yr BP. The presence of the nitrophilous plants *Solanum* and *Cerastium* along with fluctuating $\delta^{15}$N values also provides evidence for a pastoralism interpretation (Figure 7).

Throughout this interval the palynological record suggests that the landscape was predominantly open steppe with almost no trees and a very sparse presence of shrubs (Zone W-3). It is debatable whether this absence of shrubs is due to the inferred dry, cold climate (Yang *et al.*, 2002) or grazing pressures in the region at this time. Animals graze the shoots of *Ostryopsis davidiana* and *Corylus heterophylla* in the region presently and, if grazing pressure were heavy, then this may well have been the case during this previous interval in time. It is also plausible, however, that a dry climate prevented the growth of trees and shrubs – both interpretations will be discussed in the context of the changes seen to be occurring in the record from 1400 cal. yr BP.

## The Eastern Wei-late Tang dynasty 1369–1043 cal. yr BP

During the Eastern Wei-late Tang dynasty a distinctive change occurred in the environmental dynamics of this region. There was a significant increase in *Betula* followed by *Corylus/Ostryopsis*, a small decline in *Artemisia* and increases in charcoal influx and total nitrogen (Zone W-3). Archaeological evidence suggests that at this time agriculture became established once again on the landscape, although there is no evidence from the palynological record to suggest that buckwheat cultivation had regained the same level of activity as seen several thousand years previously (see above). The increase in total nitrogen and microfossil charcoal influx, however, both point to the clearance of the landscape using fire and also possibly the addition of fertilizers to the soils, thus increasing the amount of dissolved inorganic nitrogen entering the basin.

There are three possible interpretations for the rise in *Betula* and *Corylus/Ostryopsis* seen to coincide with the Eastern Wei-late Tang dynasty. The first interpretation is that it represents a change in climate, possibly reflecting a move to warmer conditions. All independent climate proxies for this region suggest, however, that this did not occur until approximately 1150 cal. yr BP coinciding with the onset of the ‘Mediaeval Warm Period’ (Yang *et al.*, 2002). The second interpretation is that the increase results from anthropogenically induced changes to the soils. Thus, with better soil quality, these trees and shrubs were able to increase. Again this interpretation seems unlikely given that *Betula* and *Corylus/Ostryopsis* are species that thrive on disturbed and nutrient-poor soils. The third interpretation is that with the introduction of agriculture, grazing pressure was reduced and this allowed these plants to become established once again on the landscape. Without further independent evidence it is impossible to say which of these interpretations is correct but, in a landscape dominated by grazing, it is highly likely that herbivore numbers would have had a significant impact on the shrubby vegetation and this impact may well be detected through the relative presence of these types in the sequence.

## The Liao, Jin and Yuan Dynasties (1034–582 cal. yr BP) and the ‘Mediaeval Warm Period’

Previous investigations have indicated that the impact of the ‘Mediaeval Warm Period’ (MWP) seen in the Europe between AD 900 and 1350 (1050–600 cal. yr BP) was also apparent in China, although its impact was regionally variable (Hong *et al.*, 2000; Yang *et al.*, 2002). Studies have demonstrated that climate change associated with the MWP was more pronounced in eastern China than in the west, and that in northeastern China there was increased summer monsoonal rainfall (Ren, 2000). Studies also indicate that the warm interval was slightly longer than the MWP witnessed in Europe and covered the interval between approximately 1150 and 550 cal. yr BP (Yang *et al.*, 2002). It is interesting to note that this interval of warmer and wetter conditions coincides closely with three of the most successful dynasties in Chinese history.

Clear changes are apparent in the palynological sequence from the Western Liaohe River Basin during this time interval and results from the chord-distance measurements indicate that this was a period of the greatest rate of change in the vegetation (Zone W-4). There was a large increase in buckwheat cultivation, weeds associated with croplands and a corresponding decline in *Artemisia*. Charcoal influx also increased dramatically and, given the decline in *Artemisia,* it is probable that burning was used to clear this plant from the landscape in order to create areas for crop growing.

Archaeological investigations suggest that population densities and agricultural activities were high during these three dynasties. Evidence from the WangXiangGou sequence, however, also indicates that at certain intervals there was a reduction in agricultural activities, as evidenced by the saw-toothed pattern in the *Fagopyrum* which mirrors rises/declines in *Artemisa* and the tree/shrubs *Betula* and *Corylus*/*Ostryopsis.* This suggests that when there was temporary abandonment of the land, encroachment by woodland-steppe species occurred; an interpretation that is supported by evidence from TN, which suggests a distinct crop at around 1000 cal. yr BP. Although beyond the scope of this paper, it may well be possible to link these intervals of encroachment to the historical writings and records of these three dynasties.

### The Ming and Qing Dynasties (582–39 cal. yr BP) and 'Little Ice Age'

The climatic cooling that resulted in the 'Little Ice Age' (LIA) throughout much of the Northern Hemisphere between AD 1250 and 1920 also had a marked impact on the Chinese climate and was likely controlled by anomalies in the East Asian monsoon circulation (Qian and Zhu, 2002). Evidence from historical documents and stalagmite records suggests that the LIA occurred in China between AD 1400 and 1920 (*c.* 550–30 cal. yr BP) with average temperatures up to 0.5–2°C cooler than present (Qian and Zhu, 2002; Yang *et al*., 2002). The impact of the LIA on the Western Liaohe River Basin landscape is clearly seen in the palynological record (Figure 6, Zone W-4). There is dramatic cessation of buckwheat cultivation from 700 cal. yr BP and *Artemisia* values increase again. There is also a complete reduction in microfossil charcoal input into the basin, suggesting that clearance using burning for buckwheat cultivation stopped. It is probable, however, that other types of agriculture were being carried out on the landscape during this time, since there is noticeable increase in weeds associated with agriculture including *Humulus*, *Plantago* and various other crop weeds. There is also an increase in TN, possibly indicative of fertilizer being added to the soils. *Corylus*/*Ostryopsis* also appears to gain dominance on the landscape, suggesting that this agriculture was carried out within a landscape covered by woodland-steppe.

From 300 cal. yr BP (Zone W-5) there is another dramatic change apparent in the palynological sequence from the West Liaohe River Basin and this is a large increase in *Pinus* with a corresponding decline in *Corylus* (Figure 6). What caused this dramatic change in the dominance of the arboreal species in the woodland-steppe vegetation is unclear but two obvious suggestions are climate change – whereby the cooler LIA climate allowed the *Pinus* to outcompete the *Corylus* – or human impact. It was at this time that the Qing Dynasty became established and it is possible, therefore, that *Pinus* was being selectively grown for its timber. Regional historical records from the Qing Dynasty certainly indicate a large population increase in the Western Liaohe River Basin.

## Conclusions

The development of the present-day landscape in the Western Liaohe River Basin has been a consequence not only of climatic variation but also of prehistoric human activity. The evidence from pollen, microfossil charcoal and stable isotopes indicate that the region underwent substantial and continued human disturbance. This human disturbance occurred on a predominantly open landscape, with evidence from the pollen record to suggest that woodland-steppe vegetation existed within the region from at least 5400 cal. yr BP.

Over the time period covered by the sequence, different cultures developed in the region, some practicing a predominantly agriculturally based economy whereas others were focused around pastoralism. Buckwheat appears to have been an important crop for the agriculturally based communities. The earliest evidence for buckwheat is apparent at approximately 5400 cal. yr BP, with particularly significant periods of cultivation between approximately 4700–3200 cal. yr BP and 1150–550 cal. yr BP. In both of these intervals burning occurred and there was a reduction in the steppe-vegetation, in particular *Artemisia*, suggesting that fire was being used to clear the vegetation for the planting of crops.

During intervals of pastorally based communities there is evidence to suggest that the soils were being affected through the intentional/unintentional enrichment of the nitrogen pool resulting from manuring. This evidence includes the presence of nitrophilous plants and corresponding increases in the $\delta^{15}N$ values. It is also possible that, during period of pastoralism, herbivores were responsible for a reduction in woody vegetation – there are noticeably low values of *Betula*, *Corylus*/*Ostryopsis* and other arboreal trees and shrubs during intervals of pastoralism but increased values for these species when agriculture is predominant.

Given that the Western Liaohe River Basin is obviously a landscape that could support the cultivation of crops from an early stage it is curious that a number of times in this record there is an apparent switch from an agriculturally to pastorally based economy (an observation that is also supported by the archaeological record). A key question therefore is what was driving this change? Climate change appears to have had a profound impact on the civilizations over the past 5400 years and, in a number cases, may well have been the trigger for the shifts between agriculture and pastoralism. A dramatic dry event between 2900 and 2600 cal. yr BP, for example, seems to have coincided with almost total cessation of crop growing and the establishment of a pastoralism-based economy. This remained in place for at least 1000 years. In contrast, with the onset of the 'Mediaeval Warm Period', buckwheat cultivation became established once again, at exactly the time when other climate proxies indicate that the climate became warmer and moister. This also coincides almost exactly with the start of the Liao Dynasty, so it is probable that new technologies brought in by this dynasty were also partially responsible. With the onset of the cool, arid conditions associated with the 'Little Ice Age' (*c.* 600 cal. yr BP) buckwheat and clearance through burning once again disappeared from the palynological record; this coincides almost exactly in date with the start of the Ming Dynasty.

In summary, it is apparent that both human impact and climate change have left a lasting legacy on the present-day landscape of the Western Liaohe River Basin. But, more importantly, this record indicates that throughout the history of this region, climate change and human activities have been intricately linked and that the ability to grow crops on this landscape is particularly vulnerable to intervals of aridity. Such records therefore have the potential to quantify key climatic thresholds for farming communities and this must be a priority for future research in this region.

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## References

**An, Z.** 1998: Prehistoric agriculture in China. In Harris, D.R. and Hillman, G.C., editors, *Foraging and farming: the evolution of plant exploitation*. Unwin Hyman Press, 643–49.

**Bennett, K.D.** 1996: Determination of the number of zones in a biostratigraphical sequence. *New Phytologist* 132, 155–170.

—— 2002: *Psimpoll*, version 4.10. http//www.kv.geo.uu.se (last accessed September 2006).

**Bennett, K.D.** and **Humphry, R.W.** 1995: Analysis of late-glacial and Holocene rates of vegetational change at two sites in the British Isles. *Review of Palaeobotany and Palynology* 85, 263–87.

**Berglund, B.E.** and **Ralska-Jasiewiczowa, M.** 1986: Pollen analysis and pollen diagrams. In Berglund, B.E., editor, *Handbook of Holocene palaeoecology and palaeohydrology*. Wiley, 455–84.

**Birks, H.H., Birks, H.J.B., Kaland, P.E.** and **Moe, D.** 1988: *The cultural landscape – past, present and future*. Cambridge University Press.

**Birks, H.J.B.** 1995: Quantitative palaeoenvironmental reconstructions. In Maddy, D. and Brew, J.S., editors, *Statistical modelling of Quaternary science data*. Cambridge University Press, 161–254.

**Chifeng Comprehensive Archaeological Survey Team** 2003: Regional archaeological surveys in the Chifeng area, Inner Mongolia, in 1999. *Archaeology* 5, 24–34 (in Chinese).

**Chinese Academy of Sciences Inner Mongolia-Ningxia Comprehensive Survey Team (CAS)** 1985: *Vegetation of Inner Mongolia*. Science Press (in Chinese).

**Chinese Academy of Social Sciences Institute of Archaeology (CASS)** 1983: *The radiocarbon date list of China from 1965 to 1981*. The Cultural Relics Publishing House, 24–25 (in Chinese).

**Chinese Academy of Social Sciences Institute of Archaeology, Archaeological Institute of Inner Mongolia, Department of Archaeology of Jilin University (CASS)** 1998: Preliminary report of the 1996 survey in the middle reach of Banzhijian River, Chifeng, Inner Mongolia. *Archaeology* 9, 36–42 (in Chinese).

**Clark, R.L.** 1982: Point counting estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores* 24, 523–35.

**Cui, H.T., Li, Y.Y., Hu, J.M., Yao, X.S.** and **Li, Y.** 2002: Vegetation reconstruction of Bronze Age by using microscopic structure of charcoals. *Chinese Science Bulletin* 47, 2014–17.

**Deng, H.** 2005: *From natural landscape to cultural landscape*. The Commercial Press (in Chinese).

**Dimbleby, G.W.** 1985: *The palynology of archaeological sites.* Academic Press.

**Drennan, R.D., Peterson, C.E., Indrisano, G.G., Teng, M.Y., Shelach, G., Zhu, Y.P., Linduff, K.M.** and **Guo, Z.Z.** 2003: Approaches to regional demographic reconstruction. In The Chifeng International Collaborative Archaeological Research Project, *Regional archaeology in eastern Inner Mongolia: a methodological exploration*. Science Press, 152–65.

**El-Moslimany, A.P.** 1990: Ecological significance of common nonboreal pollen examples from drylands of the Middle East. *Review of Palaeobotany and Palynology* 64, 343–50.

**Foster, D.R.** 2002: Insights from historical geography to ecology and conservation: lessons from the New England landscape. *Journal of Biogeography* 29, 1269–75.

**Harlan, J.R.** 1971: Agricultural origins: centers and noncenters. *Science* 174, 468–74.

**Heaton, T.H.E.** 1986: Isotopic studies of nitrogen pollution in the hydrosphere and atmosphere: a review. *Chemical Geology* 59, 87–102.

**Hong, Y.T., Jiang, H.B., Liu, T.S., Zhou, L.P., Beer, J., Li, H.D., Leng, X.T., Hong, B.** and **Qin, X.G.** 2000: Response of climate to solar forcing recorded in a 6000-year d18O time-series of Chinese peat cellulose. *The Holocene* 10, 1–7.

**Hu, J.M.** and **Cui, H.T.** 2002: Cultural landscape pattern during the early historic period in the Western Liaohe River Basin. *Geographical Research* 21, 723–32 (in Chinese).

**Koerner, W., Dupouey J.L., Dambrine, E.** and **Benoit, M.** 1997: Influence of past land use on the vegetation and soils of present day forest in the Vosges mountains, France. *Journal of Ecology* 85, 351–58.

**Kong, Z.** and **Du, N.** 1981: The climatic implication of the distribution of vegetation pollen in some archaeological sites in the Inner Mongolia Autonomous Region. *Flora and Geoflora* 5, 195–202 (in Chinese).

**Kong, Z., Du, N., Liu, G.** and **Yang, H.** 1991: A preliminary investigation on the environmental archaeology of Chifeng city, Inner Mongolia in 8000–2400 yr BP. In Zhou, K.S. and Gong, Q.M., editors, *Researches of environmental archaeology* (*Volume I*). Science Press, 112–19 (in Chinese).

**Li, Y.Y., Zhang, X.S.** and **Zhou, G.S.** 2000a: Study of quantitative relationships between vegetation and pollen in surface samples in the eastern forest area of northeast China transect. *Acta Botanica Sinica* 42, 81–88.

**Li, Y.Y., Zhang, X.S., Zhou, G.S.** and **Ni, J.** 2000b: The quantitative relationships between vegetation and several common pollen taxa in surface soil from the North of China. *Chinese Science Bulletin* 45, 1519–23.

**Linduff, K., Drennan, R.** and **Shelach, G.** 2002–2004: Early complex societies in NE China: the Chifeng international collaborative archaeological research project. *Journal of Field Archaeology* 29, 45–73.

**Liu, G.** and **Xu, G.** 1981: Two types of Bronze Age culture of the eastern part of Inner Mongolia. *Cultural Relics and Archaeology of Inner Mongolia* 1, 5–14 (in Chinese).

**Liu, H.Y., Cui, H.T., Pott, R.** and **Speier, M.** 1999: The surface pollen of the woodland–steppe ecotone in southeastern Inner Mongolia, China. *Review of Palaeobotany and Palynology* 105, 237–50.

**Lu, T.L.-D.** 1999: *The transition from foraging to farming and the origin of agriculture in China*. BAR international series 774.

**Makohonienko, M., Kitagawa, H, Naruse, T., Nasu, H., Momohara, A., Okuno, M., Fujiki, T., Liu, X., Yasuda, Y.** and **Yin, H.** 2004: Late-Holocene natural and anthropogenic vegetation changes in the Dongbei Pingyuan (Manchurian Plain), northeastern China. *Quaternary International* 123–125, 71–88.

**Meyers, P.A.** 1994: Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemical Geology* 114, 289–302.

**Qian, W.** and **Zhu, Y.** 2002: Little ice age climate near Beijing, China, inferred from historical and stalagmite records. *Quaternary Research* 57, 109–19.

**Qiao, X.Q.** 1992: On the origin of the pastoral culture in northern China. *Cultural Relics and Archaeology of Inner Mongolia* 1–2, 21–25 (in Chinese).

**Ren, G.** 2000: Decline of the mid- to late Holocene forests in China: climatic change or human impact? *Journal of Quaternary Science* 15, 273–81.

**Shelach, G.** 2000: The earliest Neolithic Cultures of Northeast China: recent discoveries and new perspectives on the beginning of agriculture. *Journal of World Prehistory* 14, 363–413.

**Shi, Y.F.** and **Zhang, P.Y.** 1996: *Climatic change in China during historical period*. Shangdong Science and Technology Press (in Chinese).

**Stuiver, M.** and **Reimer, P.J.** 1993: Extended $^{14}C$ data base and revised CALIB 3.0 $^{14}C$ age calibration program. *Radiocarbon* 35, 215–30.

**Talbot, M.R.** 2001: Nitrogen isotopes in palaeolimnology. In Last, W.M. and Smol, J.P., editors, *Tracking environmental change using lake sediments volume 2: physical and geochemical methods.* Kluwer Academic Publishers, 401–39.

**Talbot, M.R.** and **Johannessen, T.** 1992: A high resolution palaeoclimatic record for the last 27,500 years in tropical West Africa from the carbon and nitrogen isotopic composition of lacustrine organic carbon. *Earth and Planetary Science Letters* 110, 23–37.

**ter Braak, C.J.F.** and **Smilauer, P.** 2002: *CANOCO reference manual and CanoDraw for Windows Users' guide: software for canonical community ordination (version 4.5)*. Microcomputer Power, 500 pp.

**Tian, G.J.** and **Guo, S.X.** 1997: Culture of northern China and steppe civilization. *Essays on cultural relics and archaeology of Inner Mongolia*, *Volume 2*. Encyclopedia Press.

**Wang, F.S., Chien, N.F., Zhang, Y.L.** and **Yang, H.Q.** 1995: *Pollen flora of China*. Science Press (in Chinese).

**Wang, Y., Cheng, H., Edwards, R.L., He, Y., Kong, X., An, Z., Wu, J., Kelly, M.J., Dykoski, C.A.** and **Li, X.** 2005: The Holocene Asian monsoon links to solar changes and North Atlantic climate. *Science* 308, 854–57.

**Weiss, H., Courty, M.A.** and **Wetterstrom, W.** 1993: The genesis and collapse of third millennium north Mesopotamian civilization. *Science* 261, 995–1004.

**Whitlock, C.** and **Larsen, C.P.S.** 2001: Charcoal as a fire proxy. In Smol, J.P., Birks, H.J.B. and Last, W.M., editors, *Tracking environmental change using lake sediments volume 3: terrestrial algal and siliceous indicators.* Kluwer Academic Publishers, 75–97.

**Willis, K.J., Sumegi, P., Braun, M., Bennett, K.D.** and **Toth, A.** 1998: Prehistoric land degradation in Hungary: who, how and why? *Antiquity* 72, 101–13.

**Willis, K.J., Gillson, L.** and **Brncic, T.M.** 2004: How 'virgin' is virgin rainforest? *Science* 304, 402–403.

**Wolfe, B.B., Edwards, W.D.** and **Aravena, R.** 1999: Changes in carbon and nitrogen cycling during tree-line retreat recorded in the isotopic content of lacustrine organic matter, western Taimyr Penisular, Russia. *The Holocene* 9, 215–22.

**Wu, E.** 2002: Some ideas on the early nomadic culture in the Eurasian steppe. *Journal of Archaeology* 4, 437–70 (in Chinese).

**Xi, Y.** and **Ning, J.** 1994: Study on pollen morphology of plants from arid and semi-arid areas in China. *Yushania* 11, 119–91 (in Chinese).

**Yan, W.M.** 1992: Origins of agriculture and animal husbandry in China. In Ailens, M.C. and Rhee, S.N., editors, *Pacific Northeast Asia in prehistory.* Washington State University Press, 113–23.

—— 1999: Neolithic settlements in China: latest finds and research. *Journal of East Asian Archaeology* 1, 131–47.

**Yang, B., Braeuning, A., Johnson, K.R.** and **Shi, Y.F.** 2002: General characteristics of temperature variation in China during the last two millennia. *Geophysical Research Letters* 29, 10.1029/2001GL014485.

**Yang, H.** 1994: The archaeological sequence and stages for overlapping Neolithic and Bronze Age cultures in Liaoxi region. *Cultural Relics* 5, 37–52.

**Yang, Z.** and **Sou, X.** 2000: Research on environmental archaeology of the southeastern part of the agriculture-pastoralism interaction zone of north China. In Zhou, K. and Song, Y., editors, *Researches on environmental archaeology* (*Volume II*). Science Press, 81–88.

**Zhang, J.** and **Kong, Z.** 1999: The ecological significance of *Selaginella sinensis* to reconstructing past environment. *Acta Botany Boreal-Occident Sino* 19, 530–37 (in Chinese).

**Zhang, L., Fang, X.** and **Ren, G.** 1997: Environmental changes in the north China farming grazing transitional zone. *Earth Science Frontiers* 4, 127–35 (in Chinese).

**Zhao, Z.J.** 2006: New data for the study of origins of agriculture in China. *Proceedings of the 7th Ethnogenesis of South and Central Asia Harvard-Kyoto Roundtable*. Research Institute for Humanity and Nature, 12 pp.