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ORIGINAL ARTICLE

Vegetation characteristics in the western Loess plateau between 5200 and 4300 cal. B.P. based on fossil charcoal records

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Abstract Understanding terrestrial vegetation dynamics is a crucial tool in global change research. The Loess Plateau, an important area for the study of Asian monsoons and early agriculture, poses a controversial question on the potential vegetation and its pattern. Fossil charcoal as direct evidence of wood provides precision in species identification and hence vegetation reconstruction. Charcoals from the Dadiwan and Xishanping sites suggest a great variety of plants between 5200 and 4300 cal. B.P. in the valley area of the western Loess Plateau. The deciduous broad-leaf wood from *Quercus*, *Ulmus*, *Betula*, *Corylus* and *Acer* is very frequent and makes up almost half the total abundance ratio of the represented taxa. Meanwhile, some typical subtropical taxa such as *Liquidambar formosana*, *Eucommia ulmoides*, *Toxicodendron* and Bambusoideae, are present at the two study sites. The high abundance of *Picea* appearing between 5200 and 4300 cal. B.P. suggests the development of *Picea* forests in the valley of the western Loess Plateau. The assemblages of charcoal indicate that the mixed forest of evergreen deciduous and conifer-deciduous broadleaved trees developed in the valley of the Loess Plateau during the Holocene optimum. Precipitation is the main controlling factor for forest development. The increasing precipitation is the probable reason for the appearance of north-subtropical forests between 5200 and 4300 cal. B.P.

Keywords Charcoal · Vegetation dynamics · Climate change · Precipitation change · Loess Plateau

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Introduction

Understanding terrestrial vegetation dynamics is a crucial tool in global change research. The Loess Plateau is located in the semi-arid and semi-humid climate regions of the warm temperate zone in China. This area is affected by East Asian monsoons and westerly circulation, thus the geomorphological units are complicated and the vegetation types varied (Wu 1980). As one of the cradles of Chinese civilization, the Loess Plateau has been the area of long and intense human activity, and the original vegetation was greatly disturbed by humans (Li et al. 2009; Zhou and Li 2011). Thus, the potential vegetation and its pattern in the Loess Plateau become the controversial question.

Many important achievements have already been attained in the vegetation history research of the Loess Plateau. Shi (1988), through studying historical documents, concluded that the forest vegetation was well developed in the past and that the vegetation characteristics of the present are the result of human activity. Liu et al. (1996) argued this for different vegetation types for different geomorphological units. Evidence from the small number of pollen studies shows that the main vegetation type in the Loess Highlands was grassland (Li et al. 2003; Sun 1989; Sun et al. 1995, 1998; Ke et al. 1993). In addition, soil micromorphological studies (Guo et al. 1994) and the phytolith record (Lu et al. 1999) also indicate that grassy vegetation developed in the Loess Plateau. Evidence from stable carbon isotope records also indicates that no substantial forests have developed in the Loess Highlands (Liu et al. 2005). The lack of forest in the highlands of the Loess Plateau may be due to a combination of lack of moisture and soils unsuitable for forest development (Zhang 2003; Li et al. 2003).

Vegetation types in the valleys of the Loess Plateau are quite different from those in the highlands. Pollen records from the Weihe Valley indicate sparsely wooded grasslands, and that grasslands were the dominant vegetation type, but forests developed extensively in the valley during the Holocene optimum (Shang and Li 2010). Pollen records from the Jingning, Dingxi and Qinan valleys on the western part of the Loess Plateau also show that forests developed during 7.6–5.8 ka B.P. (Tang et al. 2007), while the molecular fossil record in the Dadiwan section found scant evidence of forests and indicated grasslands since the last interglacial period (Xie et al. 2002).

In general, then, there is still little strong evidence confirming vegetation types, plant community attributes and plant species composition on the Loess Plateau. This lack of evidence is due to the limitations of techniques such as pollen analysis, which is limited by the understanding of pollen production rates, dispersal range, preservation and the identification precision.

Fossil charcoal results from incomplete burning, and it retains the anatomic characteristics of the original wood (McGinnes et al. 1974), which raises partly the possibility of greater precision in the level of taxonomic identification, thus overcoming some of the limitations of plant microfossils (Shackleton and Prins 1992; Cui et al. 2002). Charcoal has distinct advantages in providing direct evidence for the reconstruction of terrestrial vegetation, for climate change studies (e.g. Newton 2005) and for the study of early human activity (e.g. Miller 1985; Willcox 1999, 2002; Sun et al. 2010).

Charcoals from Neolithic archaeological sites in the Loess Plateau are sometimes accessible. Tianshui Basin, which is located in the western part of the Loess Plateau, is one example. There are many archaeological sites dispersed throughout this basin, and it contains evidence of the earliest, largest and most comprehensive Neolithic cultures in northwest China (Institute of Archaeology of CASS 1999; Xie 1985). The Dadiwan and Xishanping sites are located on the Huluhe and Xihe River terraces, respectively. The Yangshao, Majiayao and Qijia cultures were well developed at both sites. Large amounts of charcoal exist in the cultural layers, thus providing good material for the Holocene vegetation reconstruction.

Study area

The Tianshui Basin is located in the northern Qinling Mountains, west of the Loess Plateau. The mean annual temperature is 11.6°C, the mean annual precipitation is 491.6 mm and the rainfall is more concentrated in the summer months. Today, the natural vegetation is warm-temperate mixed conifer-broadleaved forest, woodland and grasslands (Wu and Wang 1983). The vegetation has, however, been greatly altered by agriculture. The few remaining natural woodlands are found on bedrock in Longshan, Xiqinling and Guanshan (Wu and Wang 1983). The common natural woody plants are Fagaceae, Betulaceae, Pinaceae, Salicaceae, Ulmaceae, Aceraceae, Rosaceae and Tiliaceae, and the main herbaceous plants are Poaceae, Asteraceae, Fabaceae and Ranunculaceae.

The Xishanping site (34°33′50″N, 105°32′41″E, 1,330 m a.s.l.) is located on a terrace on the southern bank of the Xihe River, approximately 50 m above the river bed (Fig. 1). The site was first surveyed by the Gan-Qing archaeological team in 1956, and was excavated between 1986 and 1990. The site covers an area of 204,800 m^2. There were eight cultural periods between 7800 and 3000 cal. B.P.; however, the stoneware and pottery are representative of the Majiayao and Qijia cultures of the Middle-Lower Neolithic (Institute of Archaeology of CASS 1999; An et al. 2005). Archaeobotanical evidence from Xishanping indicates that eight main crops (fox millet, common millet, rice, wheat, oat, barley, soybean and buckwheat) have been cultivated for the last 4,000 years, with rice present for at least the last 5,000 years (Li et al. 2007a, b).

The Dadiwan site (35°0′29.40″N, 105°54′40.70″E, 1,500 m a.s.l.) is located in Shaodian village, northeast of Qinan, on terraces I and II and the gentle slope zone of the southern bank of the Qingshuihe River (Fig. 1). Extensive excavation work has been done on the Dadiwan site (Gansu Provincial Institute of Archaeology 2006), and the culture of this site is supposed to be the most developed and continuous, including the Pre-Yangshao (8000–7000 year B.P.), the Yangshao (7000–5000 year B.P.), the Majiayao (5000–4100 year B.P.) and the early phase of the Changshan culture (4100–3800 year B.P.).

Materials and methods

A 650 cm continuous and undisturbed cultural sediment section on the northern part of the Xishanping site was selected as the Xishanping section. The modern cultivation layers are above 40 cm. Previous research based on pollen, phytoliths and seeds has been published (Li et al. 2007a, b). Eight accelerator mass spectrometry (AMS) radiocarbon

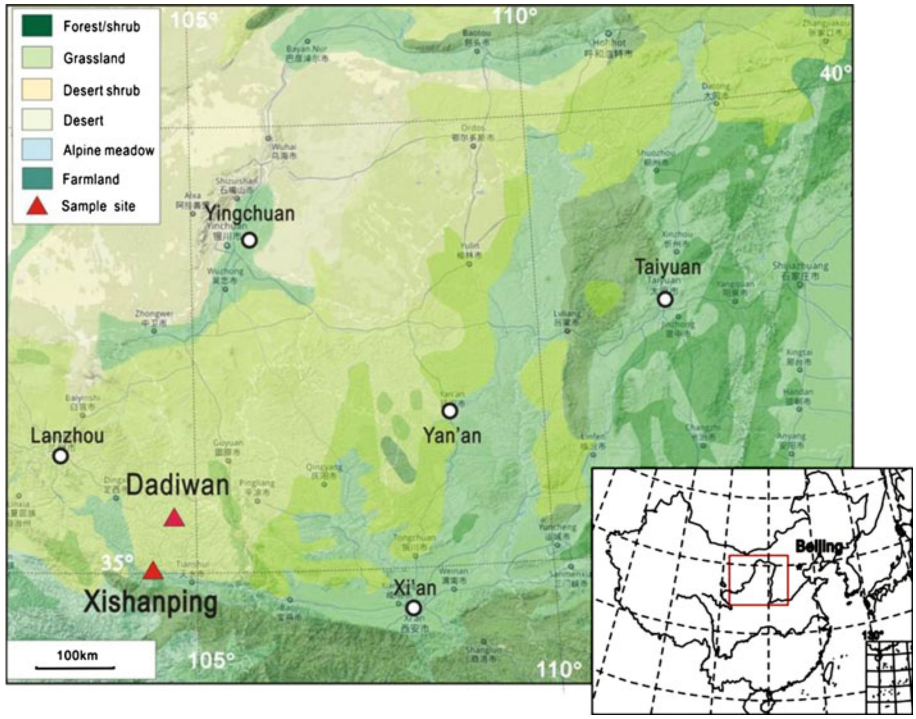


Fig. 1 Map of the study area and the sites

Table 1 Accelerator mass spectrometry (AMS) dates from the Xishanping and Dadiwan sites

Sample	Depth (cm)	Lab. no	Sample type	AMS age (year B.P.)	Calibrated age (cal. year B.P., 2σ)
XXP-1	60	TKal3882	Charcoal	3900 ± 35	4236–4419
XXP-2	130	TKal3883	Charcoal	2785 ± 30	2839–2949
XXP-3	345	TKal3884	Charcoal	4430 ± 35	4870–5069
XXP-4	490	TKal3885	Charcoal	4855 ± 35	5579–5655
XXP-5	560	TKal3886	Charcoal	4360 ± 35	4845–4983
XXP-6	570	TKal3887	Charcoal	4400 ± 35	4859–5051
XXP-7	585	TKal3888	Charred seed	4430 ± 100	4833–5312
XXP-8	620	TKal3889	Charred seed	4490 ± 35	5035–5295
DDW-3	420	OZK647	Charcoal	4470 ± 60	4960–5306
DDW-4	500	OZK648	Charcoal	4485 ± 50	5028–5303
DDW-5	640	OZK649	Charcoal	4370 ± 50	4842–5055
DDW-6	760	OZK650	Charcoal	4445 ± 50	4950–5288
DDW-7	810	OZK651	Charcoal	4555 ± 50	5048–5324

dates, including six charcoal samples and two charred seeds, were determined at the University of Tokyo (Table 1). The calendar ages were estimated using the Radiocarbon Calibration Program (Reimer et al. 2004). A good chronological framework was established by Li et al. (2007a, b) and will also be quoted in this study (Fig. 2).

The Dadiwan section is located on the second terrace of the South Qingshuihe River. The total thickness is 820 cm, and the Neolithic culture layer occurs between 400 and 820 cm. Five charcoal AMS radiocarbon dates were determined at the Australian Nuclear Science and Technology Organisation (ANSTO), and the calendar ages were calculated (Reimer et al. 2004). These confirmed that the depth of 400–820 cm is the sediment from 5300 to 4900 cal. B.P. and belongs to the Late Yangshao and the early Changshan cultures (Table 1; Fig. 2).

Charcoal samples are abundant in the cultural layers. These samples were recovered using the floatation method described in Tsuyuzaki (1994). Sufficient charcoal samples were recovered from the sediment for quantitative analysis. The number of taxa present in a sample rises sharply as the first few charcoal specimens are examined and then settles down as more fragments are identified (Keepax 1988; Smart and Hoffman 1988). Keepax (1988) suggested that a

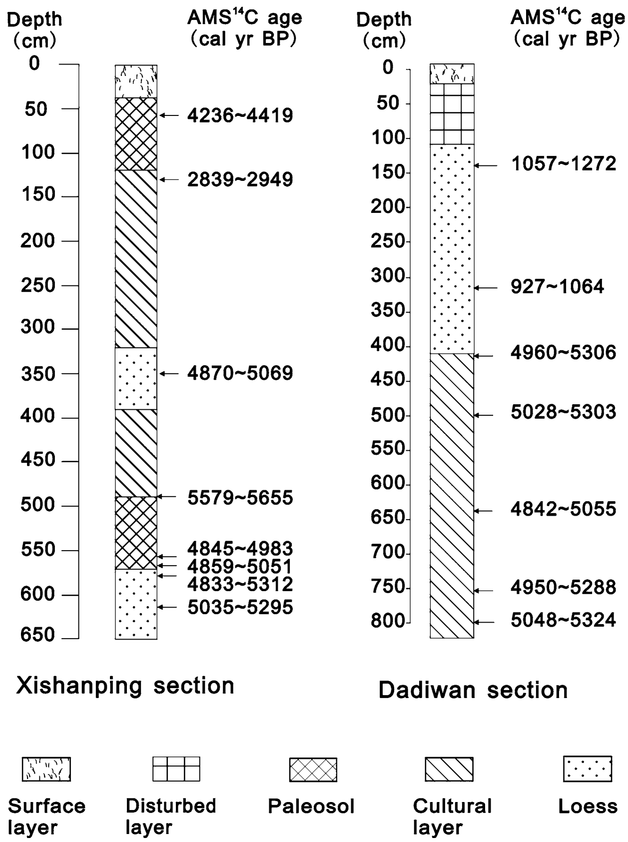


Fig. 2 Stratigraphic sections and radiocarbon data at the Xishanping and Dadiwan sites

minimum of 100 charcoal fragments per sample should be examined in temperate regions, which would normally provide a good representation of most types of charcoal. Here, two indices are used to describe the charcoal assemblages in the two sections. The first is "abundance ratio", that is the ratio of the fragment count of a certain taxon to the total fragment count, and the second is "frequency", that is the number of times a certain taxon presented in different samples out of the total sample number.

In the Xishanping section, the sediment above 40 cm has been disturbed by modern agriculture. Charcoals below 450 cm are rare, and, in any case, because of their small size, they are difficult to identify reliably. Therefore seven samples from the sediment of 40–450 cm (4800–4300 cal. B.P.) with abundant charcoal were collected. In the Dadiwan section, the Neolithic culture sediment section was selected, and a total of 17 samples from a depth of 400–820 cm (5200–4900 cal. B.P.) were collected. At least 100 pieces for each sample were examined and identified following standard procedures. First, pressure fractured charcoals were prepared with a razor blade to produce fresh, clean surfaces to show transverse, radial and tangential sections (Leney and Casteel 1975). These sections were examined under a stereo microscope, categorized, and one or two samples from each type were photographed under a scanning electron microscope (SEM). Identification of the taxa was performed using reference wood anatomy atlases (Cheng et al. 1985; Yao 1988; Schweingruber 1990; Yao et al. 2002).

Results

Xishanping section

A total of 808 pieces of charcoal were identified from the samples and 20 different taxa were identified (Table 2). The most abundant taxa were *Picea*, *Castanea*, *Betula*, *Ulmus*, *Quercus*, *Carpinus*, *Toxicodendron*, *Acer*, *Liquidambar formosana* and Bambusoideae, which were present in all samples. *Padus*, *Castanopsis*, *Pseudotsuga sinensis*, *Cerasus* and *Eucommia ulmoides* appeared in four samples, and *Corylus*, *Picrasma* and *Diospyros* were only present in two samples.

The abundance ratio of charcoal types in the whole of the charcoal counts from the Xishanping site (Table 2) show that the *Ulmus*, *Picea*, *Betula*, *Acer*, *Liquidambar*

Table 2 Charcoal taxa and their relative frequency and abundance ratios from the Xishanping site

Taxa	Absol. fragm. count	Abundance ratio (%)	Ubiquity	Frequency (%)
Acer sp.	65	8.04	7	100
Betula sp.	69	8.54	7	100
Carpinus sp.	61	7.55	7	100
Castanea sp.	28	3.47	7	100
Castanopsis sp.	14	1.73	5	71.43
Cerasus sp.	14	1.73	4	57.14
Corylus sp.	5	0.62	2	28.57
Diospyros sp.	15	1.86	2	28.57
Eucommia ulmoides	7	0.87	4	57.14
Indocalamus sp.	12	1.49	5	71.42
Liquidambar formosana	63	7.80	7	100
Padus sp.	20	2.48	6	85.71
Phyllostachys sp.	56	6.93	6	85.71
Phyllostachys glauca	61	7.55	6	85.71
Picea sp.	86	10.64	7	100
Picrasma sp.	3	0.37	2	28.57
Pseudotsuga sinensis	15	1.86	4	57.14
Quercus sp.	61	7.55	7	100
Toxicodendron sp.	48	5.94	7	100
Ulmus sp.	105	13.00	7	100
Total	808	100	7	100

formosana, *Carpinus*, *Quercus* and *Phyllostachys glauca* taxa make up over 70% of the charcoal assemblages. These are presumed to be the main source of firewood used by prehistoric people.

The charcoals are presented as temperate and subtropical taxa and can be divided into two main periods: 4800–4600 cal. B.P. and 4600–4300 cal. B.P. During 4800–4600 cal. B.P. (Fig. 3), the peak abundance ratio of *Picea*, *Quercus* and *Ulmus* are 28, 21 and 23%, respectively, and the total abundance ratio of the three taxa is 72%. The abundance ratio of *Carpinus* (~5%), *Betula* (~7%), *Toxicodendron* (~8%) and *Acer* (~8%) are stable, while the abundance ratio of Bambusoideae is low, with a range of 1–7%. After 4600 cal. B.P., *Picea* values decreased from a peak value of 28% to below 5%. *Ulmus* decreased to approximately 7%, while Bambusoideae increased significantly to a peak value of 23%. During the period 4800–4300 cal. B.P., the abundance ratio and frequency of *Pseudotsuga sinensis*, *Castanopsis*, *Corylus*, *Cerasus*, *Padus*, *Picrasma*, *Diospyros* and *Eucommia ulmoides* are low, and the abundance ratio of *Castanea* rose from 1.5 to 4.5%.

Dadiwan section

A total of 2,307 charcoal fragments were identified from the 17 samples, and 34 different taxa were identified (Table 3). *Betula*, *Corylus*, *Ulmus*, *Quercus mongolica* and *Acer* were present in all 17 samples, while *Picea brachytyla*, *Abies*, *Ostrya*, *Quercus aliena*, *Xylosma racemosum*, *Toxicodendron* and *Liquidambar formosana* were present in 16 samples. *Alnus*, *Sorbus pohuashanensis*, *Juglans*, *Gymnocladus chinensis*, *Eucommia ulmoides*, *Ehretia* and *Fargesia* appeared in more than 10 samples.

In the Dadiwan section, the abundance ratio of *Acer* (10.7%), *Ulmus* (8.7%), *Quercus aliena* (8.2%), *Betula* (7.2%), *Quercus mongolica* (6%), *Ostrya* (5.1%) and Bambusoideae (the total abundance ratio of *Phyllostachys*, *Fargesia* and *Indocalamus* is 5.93%) are high, and their frequency of occurrence is above 80%. These taxa are assumed to be the main sources of firewood used by prehistoric people.

The charcoals are presented as temperate and subtropical taxa in Fig. 4. The abundance ratio of *Ostrya* (peak value 11.7%), *Alnus* (peak value 17.3%), *Gymnocladus chinensis* (peak value 13.8%), *Toxicodendron* (peak value 12.1%), *Tilia* (peak value 11.3%) and Bambusoideae (peak value 14.1%) were high between 5200 and 5100 cal. B.P. After 5100 cal. B.P., the abundance ratio of these taxa was generally reduced, while the abundance ratio of *Picea* and *Abies* were relatively low before 5100 cal B.P. and increased after 5100 cal B.P.

Discussion

The Loess Plateau has a varied topography, which creates a mosaic of hydrological and soil microclimatic conditions, thus leading to zonal and non-zonal distributions of vegetation types (Liu 1985; Zhang 2003; Shang and Li 2010).

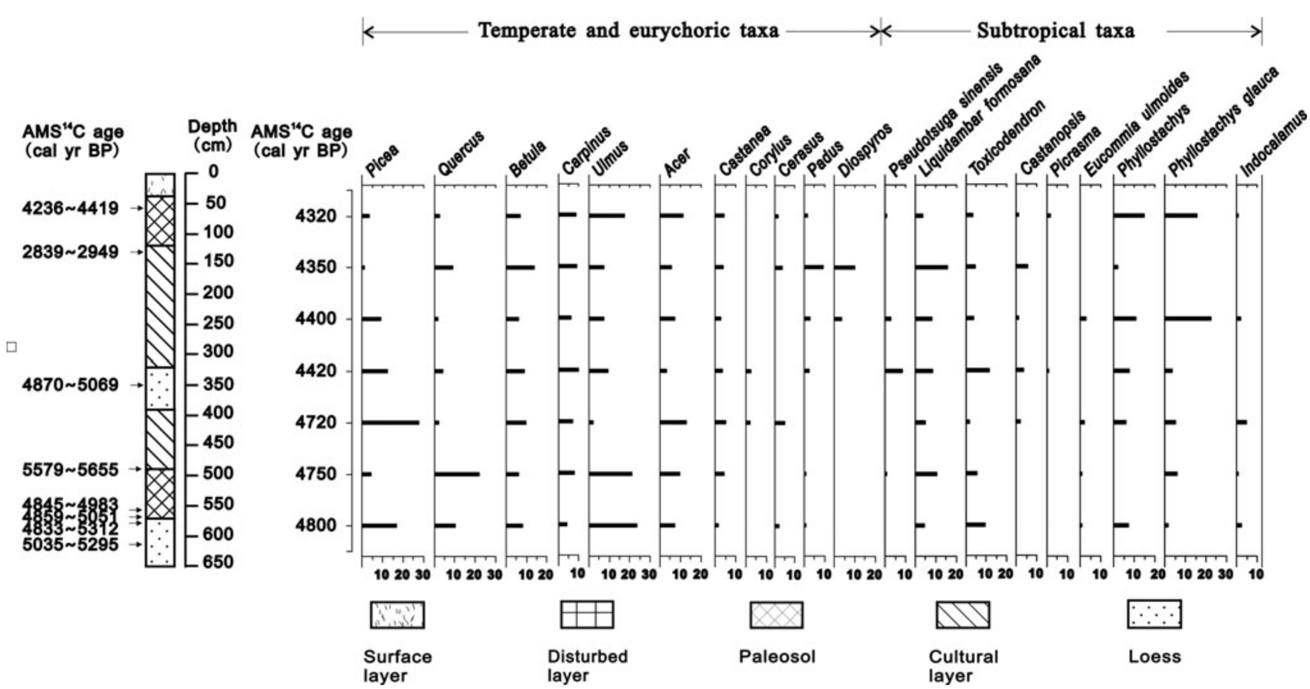


Fig. 3 Charcoal percentages from the Xishanping section

Table 3 Charcoal taxa and their relative frequency and abundance ratio from the Dadiwan site

Taxon	Absol. fragm. count	Abundance ratio (%)	Ubiquity	Frequency (%)
Abies sp.	46	1.99	16	94
Acer sp.	246	10.66	17	100
Alangium sp.	15	0.65	7	41
Alnus sp.	78	3.38	14	82
Betula sp.	166	7.20	17	100
Castanea sp.	22	0.95	9	53
Cercidiphyllum japonicum	55	2.38	15	88
Corylus sp.	65	2.82	17	100
Cyclobalanopsis sp.	90	3.90	15	88
Ehretia sp.	48	2.08	10	59
Eucommia ulmoides	74	3.21	12	71
Fagus sp.	5	0.22	2	12
Fargesia sp.	34	1.47	11	65
Firmiana sp.	4	0.17	4	24
Gymnocladus chinensis	84	3.64	14	82
Indocalamus sp.	6	0.26	5	29
Juglans sp.	53	2.30	12	71
Liquidambar formosana	103	4.46	16	94
Lonicera sp.	10	0.43	4	24
Osmanthus fragrans	12	0.52	6	35
Ostrya sp.	118	5.11	16	94
Phyllostachys sp.	97	4.20	15	88
Picea brachytyla	33	1.43	16	94
Picrasma sp.	7	0.30	5	29
Prunus sp.	2	0.09	1	6
Prunus armeniaca	3	0.13	3	18
Quercus aliena	190	8.24	16	94
Quercus mongolica	138	5.98	17	100
Sorbus pohuashanensis	52	2.25	15	88
Tilia sp.	42	1.82	8	47
Toxicodendron sp.	102	4.42	16	94
Ulmus sp.	200	8.67	17	100
Vaccinium sp.	20	0.87	6	35
Xylosma racemosum	87	3.77	16	94
Total	2,307	100	17	100

At present, the main vegetation types on the western Loess Plateau are steppe and crops, and although some broad-leaved forests appear on the river terrace in the valley, the original forests have disappeared. Charcoal is used as direct evidence of species presence which provides precision in species identification and hence vegetation reconstructions.

Charcoals from archaeological sites are usually the direct result of human activity. Evidence from the site catchment analysis indicates that the activity range of prehistoric farming groups was limited to approximately 5 km, or 1 h walking distance (Renfrew and Bahn 1991; Qin et al. 2010). Assuming the "principle of least effort", the charcoal frequency should track the presence of woody taxa with a direct correspondence in sediments (Shackleton and Prins 1992). Thus, it is here considered that the charcoals at the archaeological site originated from nearby woody plants. Therefore, the charcoal presence should reflect site-related information and reveal information on woodland composition on a local scale (Scheel-Ybert 2000).

The charcoal assemblages in Xishanping and Dadiwan suggested a great variety of plants (Figs. 3, 4). The frequency of deciduous broad-leaf wood such as *Quercus*, *Ulmus*, *Betula*, *Corylus* and *Acer* is high, and the total abundance ratio of these taxa make up almost half of the represented taxa. Meanwhile, some typical subtropical taxa such as *Liquidambar formosana*, *Eucommia ulmoides*, *Toxicodendron* and Bambusoideae, which are now distributed in the Yangtze river valley and areas to the south of it, are present at the two study sites. *Picea* appeared from 5200 to 4300 cal B.P. with high abundance ratio, becoming an important vegetation type (coniferous forest). The vegetation type represented by the charcoal assemblages can be defined as a mixed evergreen deciduous and conifer-deciduous broadleaved forest, and the climate can be described as the north subtropical zone, which is similar to the modern vegetation and climate south of the Qinling Mountains.

Picea is the dominant species of coniferous and mixed forests in north China, and is now distributed in the alpine and sub-alpine areas at altitudes of 4,000–2,000 m (Wu and Wang 1983). Although the abundance ratio of *Picea* pollen from the valley of the Loess Plateau was high during the Holocene optimum, suggesting the appearance of *Picea* forests (Li et al. 2007a; Zhou and Li 2011), some scientists argue that the pollen might have been carried from the mountains hundreds of kilometres away through wind or river transport (Zhu et al. 2001; Xia et al. 1998; Zhong et al. 2007) and therefore does not represent local *Picea* forests.

The frequency of *Picea* at the Xishanping site is 100% and the average abundance ratio reaches above 10% (Table 2). At the Dadiwan site, the frequency is 94% and the abundance ratio is 4.3%. The wood of *Picea* was an important firewood resource for the prehistoric farmer. In addition, the transport of *Picea* wood over hundreds of kilometers was not possible during the Neolithic, thus *Picea* forest was present around the two sites. Considering both that the abundance ratio of *Picea* pollen was 60% in

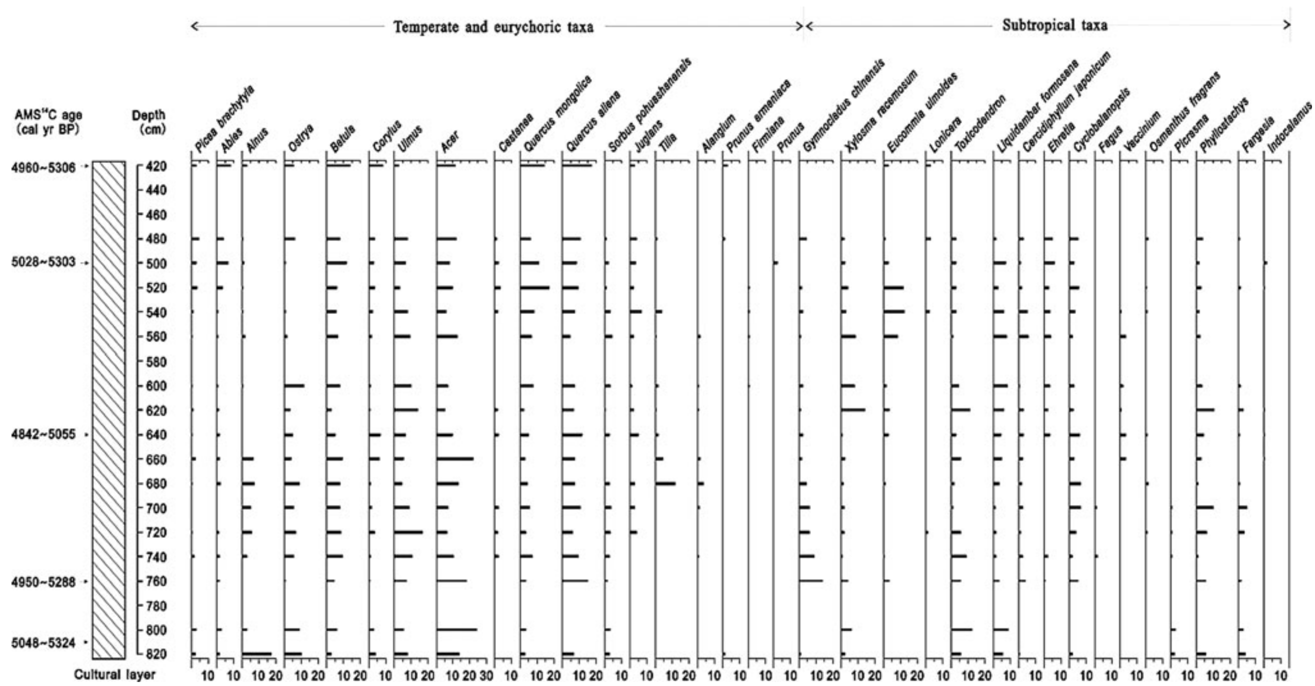


Fig. 4 Charcoal percentages from the Dadiwan section

the Xishanping site during 4800–4300 cal B.P. (Li et al. 2007a) and the evidence of a high abundance ratio of *Picea* pollen records in other regions (Zhou and Li 2011), we can conclude that *Picea* forests developed in the valley of the western Loess Plateau between 5200 and 4300 cal B.P.

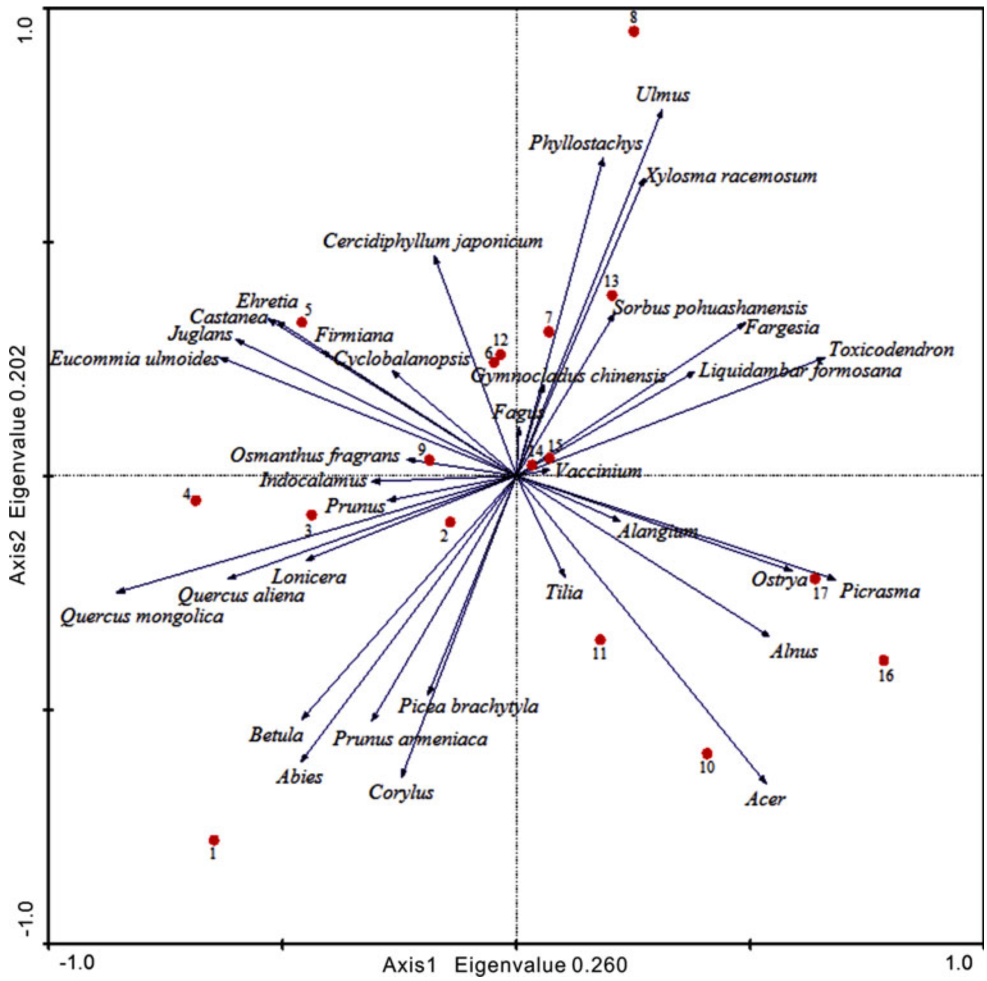
Climate is an essential factor in the distribution of forest vegetation and to species abundance ratio (e.g. Bartlein et al. 1986; Huntley and Birks 1983; Fang et al. 2001). What the main controlling factor is for forests (e.g. *Picea* forest) on the Loess Plateau during the Holocene remains unanswered. Here, we choose the charcoal assemblage at the Dadiwan section, which has numerous plant taxa, to help us identify the main controlling factor of the climate. CANOCO 4.5 software was used for a principal component analysis (PCA), and the eigenvalues of the first four factors, Axis 1–4, were 0.260, 0.202, 0.144 and 0.102 respectively. Figure 5 shows the eigenvalues of the 34 taxa for the first two factors (Axis 1 and Axis 2).

The cool-loving species of *Abies*, *Picea*, *Betula* and *Corylus* are located towards the negative end of Axis 1. Bambusoideae and *Xylosma racemosum*, which prefer warm environments, are located towards the positive end of Axis 1, which suggests that Axis 1 reflects a temperature gradient. *Quercus mongolica* is a dry-tolerant taxon and is located towards the negative end of Axis 2. Hygrophilous taxa, such as *Alnus*, *Toxicodendron* and *Liquidambar formosana*, are located towards the positive end of Axis 2, suggesting that Axis 2 reflects a humidity or wetness gradient. The four quadrants in Fig. 5 thus represent four environments, which are warm-dry, warm-wet, cold-dry, and cold-wet. The first nine samples (between 5100 and 4900 cal B.P.) from the Dadiwan site are almost entirely on the negative side of Axis 2, while the remaining eight samples (between 5200 and 5100 cal B.P.) are mostly distributed towards the positive side of Axis 2. All the samples are distributed in both positive and negative directions on Axis 1. Hence, the distribution of these samples indicates that the atmospheric moisture changed at around 5100 cal B.P., but the temperature was stable. The climate changed from warm-wet to warm-dry, leading to the vegetation changes. Therefore moisture is the main controlling factor in the vegetation change on the Loess Plateau during the Holocene.

Between 5000 and 3000 year B.P., the climate of the Loess Plateau was wetter and warmer than it is today (Shi and Kong 1992; An et al. 2000), with temperatures 2°C higher and January temperatures 3–5°C higher (Zhu 1973). The modern mean temperature in the Tianshui Basin, western Loess Plateau, is 11°C. The climate in the Tianshui Basin between 5200 and 4300 cal B.P. was suitable for *Picea* (for which the optimal temperature is 4–12°C) and for subtropical taxa, such as *Eucommia ulmoides* (opt. 13–20°C), *Pseudotsuga sinensis* (opt. 10–17°C) and *Indocalamus* (opt. 15–20°C).

In the southern Qinling Mountains, subtropical taxa such as *Eucommia ulmoides*, *Pseudotsuga sinensis* and *Indocalamus* grow well under a precipitation of 750–900 mm, which is much higher than modern precipitation (492 mm)

Fig. 5 Principal component analysis (PCA) of the charcoals from the Dadiwan site



in the Tianshui Basin. Meanwhile *Picea* has strict precipitation or moisture requirements, even if the temperatures are suitable. Generally, *Picea* cannot grow well in places where the precipitation is <500 mm (Wu 1985). Therefore, the coexistence of *Picea* and *Abies*, which flourish in cool-wet environments, and *Eucommia ulmoides*, *Pseudotsuga sinensis* and *Indocalamus*, which prefer warm-wet environments, indicates an increasing intensity of monsoon rainfall in the mid-Holocene (An et al. 2000). The increasing precipitation is the probable reason for the co-appearance of subtropical and *Picea* woodlands.

Conclusion

Charcoals from Dadiwan and Xishanping sites suggested a great variety of plants between 5200 and 4300 cal B.P. The deciduous broad-leaf woods of *Quercus*, *Ulmus*, *Betula*, *Corylus* and *Acer* are frequent and make up almost half the total abundance ratio of the represented taxa. Meanwhile, some typical subtropical taxa, such as *Liquidambar formosana*, *Eucommia ulmoides*, *Toxicodendron* and Bambusoideae, are present at the two study sites.

The charcoal assemblages suggest that a mixed evergreen deciduous and conifer-deciduous broadleaved forest developed in the valley of the Loess Plateau during the Holocene optimum. Precipitation is the main controlling factor in the development of the forests and increasing precipitation is the probable reason for the appearance of north-subtropical forests between 5200 and 4300 cal B.P.

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